ELES-1984

December 1984

EXPANDED LIQUID ENGINE SIMULATION COMPUTER PROGRAM

ADVANCED USERS MANUAL

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RPT:AA0160

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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Bob Schwantes
Adam Siebenhaar
Jim Smith
Charles Taylor
Vic Viteri
Dick Walker

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1.0 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. This manual begins where the New Users Guide leaves off and expands the options available to the user.

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

Both users guides are concerned with proper formulation and input of a problem statement. The new users guide does so in a more basic manner 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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2.0 ADVANCED INPUT WORKSHEETS

Using the liquid stage models in ELES to their fullest potential involves the use of hundreds of inputs. In order to organize the input procedure for those variables, an input worksheet has been developed. The first portion of that worksheet is presented in the ELES New Users Guide, pages 29 through 41. The remainder is presented herein.

The new users worksheet is concerned with a general overview of basic ELES options; that worksheet is the best place to begin. It will be assumed in this manual that the new users worksheet has been completed prior to beginning the advanced users worksheet. That worksheet has been reproduced in Figure 2.1.

There are two major types of input in the advanced users worksheet; 1) recurrent input which must always be considered and 2) contingent input which need only be considered if prior choices dictate.

The recurrent input is shown in Figure 2.2. It includes general inputs, injector related inputs, thrust chamber inputs, and tankage inputs. These should be considered every time ELES is run.

The contingent input worksheet is displayed in Figure 2.3. These inputs relate to tandem tanks, non-conventional tanks, cold gas pressurization, solid gas generator pressurization, turbo-pump assemblies, regen/trans-regen cooling, tankage heat transfer, positive expulsion bladders, user defined propellants, throttling trajectories, and short nozzle designs. Each category need only be considered if it is a part of the design in question.

It is highly recommended that the user photocopy all applicable worksheets and fill them out prior to program execution.

Figure 2.1 sic Worksheet

TITLE -

STAGE #

Field	VARIABLE	NAMELIST	UNITS	DEFAULT
Total Number of Stages	NSTGES	INPGEN	-	3
Vehicle Payload Wt. (lbm)	WPAYLD	INPGEN	lbm	0.0
Miscellaneous Stage Wt. (lbm)	WMISC	INPGEN	lbm	0.0
Expendable Stage Wt. (lbm)	WEXPND	INPGEN	lbm	0.0
Upper Interstage Material Properties				
density (lb/in^3)	RHOINT	INTSTG	lb/in^3	0.101
design stress (psia)	SINST	INTSTG	psia	220000.
modulus of elasticity (psia)	EINSTG	INTSTG	psia	1.8E6
safety factor (-)	SFINST	INTSTG	-	1.5
Kind of Stage (Circle one) 1) solid 2) liquid	KSTAGE	INPGEN	-	1

Tank Geometry

Tandem Tanks

(Draw Sketch Here)

	VARIABLE	NAMELIST	UNITS	DEFAULT
	NCTNK	LFLAG	-	0
monocoque tanks (1) suspended tanks (0)	MNCQA	TNKGEO	-	1
	MNCQF	TNKGEO	-	1
separate domes (0) common domes (1)	KDOME	TNKGEO	-	1
Pressure Tank Geometry 0) spherical in engine bay 1) suspended forward of forward tank 2) monocoque separate dome 3) monocoque common dome 4) cylindrical in forward tank	KPRESS	TNKGEO	-	0
number of tanks	NPRB	TNKGEO	-	1
propellant tank head ellipse ratio	ELDOME	INPGEN	-	1.0
pressurant tank head ellipse ratio	ELRP	LTANK	-	1.0
propellant tank dome orientation (-1 = convex forward) (1 = convex aft	KXATAH	TNKGEO	-	1
	KXATFH	TNKGEO	-	-1
	KXFTAH	TNKGEO	-	-1
	KXFTFH	TNKGEO	-	-1
propellant location (1 = fuel aft, not 1 = fuel not aft	KPRPA	TNKGEO	-	2

Non-Conventional Tanks

(Draw Sketch Here)

Description	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 (cont.)

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) ClF_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

Figure 2 (cont.)

Enginge er Cycle
(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

Field	VARIABLE	NAMELIST	UNITS	DEFAULT
Burned Propellant Wt.	WTLPRP	LIQUID	lb.	13250.0
Ullage Fractions				
Oxidizer	ULLFFL	LTANK	-	0.02
Fuel	ULLFOX	LTANK	-	0.02
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	KACQOX	LFLAG	-	0
	KACQFL	LFLAG	-	0
Propellant Tank Pressurization (Circle One) (KGASOX, KGASFL): 0) non-autogenous (KGAS) 1) solid gas generator 2) cold helium; 1) autogenous	KGASOX	LFLAG	-	0
	KGASFL	LFLAG	-	0
	KGAS	LFLAG	-	2
Cold Helium Storage Pressure	PICG	COLDG	psia	4365.0
Helium Tank Final Pressure Fraction (less than 1.0 indicates blowdown)	FPULCG	COLDG	-	0.8

Figure (cont.)

Mater. 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

Propellant tank heat transfer (Circle One)
- 0) ignore tank heat transfer
- 1) external boundary exposed to conductive source
- 2) worst case solar radiation
- 3) ground hold ice formation

Propellant Tank 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

Figure 2 (cont.)

Combustion Chamber Cooling Method
(Circle One)

1) Ablative

2) Regenerative

3) Trans-Regen

4) Radiation

Nominal Chamber wall material temperature (°R) ☐

Regen/Trans-Regen input

Output a regen summary (0 = no, 1 = yes) ☐

Gas wall minimum gauge (in.) ☐

Gas wall thermal conductivity (BTU/in sec °R) ☐

DIFTBF = $(T_{barrier}\text{-TGWNOM})/(T_{core}\text{-TGWNOM})$ ☐

Nozzle Cooling Method
(Circle One)

1) Ablative

2) Regenerative

3) Trans-Regen

4) Radiation

5) Film

Nominal nozzle material temperature (°R) ☐

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

Figure 2 (cont.)

Pressure Drop Across Injector

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

Fuel [ ]

Oxidizer [ ]

Pressure Drop Acorss 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 weight model (Circle One)
-1) input engine weight
0) simplified ablative engine weight model
1) physical engine weight model

Engine Materials of Construction
14 (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		X

Stage Operating Temperature Range (°F)

Minumum 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 (cont.)

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

Input		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

Tankage

Line printer characters per inch

Horizontal [ ]

Vertical [ ]

Propellant Acquisition device material density (lb/in.^{3})

fuel tank (KACQFL = 6) [ ]

ox tank (KACQOX = 6) [ ]

Cross sectional area of shroud stiffening rings (in.^{2})

forward shroud [ ]

aft shroud [ ]

VARIABLE	NAMELIST	UNITS	DEFAULT
CHRPIX	NCTINP	char/in.	10
CHRPIY	NCTINP	char/in.	6
DACQFL	LTANK	lb/in.^{3}	0.1
DACQOX	LTANK	lb/in.^{3}	0.1
AESSR	LTANK	in^2	0.152
AFSSR	LTANK	in^2	0.25

Injecter

Injecter orifice discharge coefficients (-)

fuel

ox

Injecter element input (IELDEN = 0)

Number of injecter elements (-)

Number of fuel orifices (-)

Number of ox orifices (-)

Barrier liquid film length (in.)

Barrier mixing angle (deg.)

VARIABLE	NAMELIST	UNITS	DEFAULT
CDIFL	INJECT	-	0.77
CDIOX	INJECT	-	0.72
NELEM	INJECT	-	336
NFLORF	INJECT	-	672
NOXORF	INJECT	-	500
XLFL	LQPERF	in.	1.0
ALFMIX	INJECT	deg.	0.15

Figure 2 (cont.)

Thrust Chamber

	Input	VARIABLE	NAMELIST	UNITS	DEFAULT
Engine radiation cooling model (KOOLTC = 4, KOOLNZ = 4)					
TCA material emissivity		EMISTC	LIQENG	-	0.9
vehicle emissivity in engine bay		EMISVE	LIQENG	-	0.5
ambient temperature (°R)		TAMRAD	LIQENG	°R	560
Ablative Chamber/nozzle weight model (KOOLTC = 1, KOOLNZ = 1) (See namelist ABLATE)					
reference chamber pressure for nozzle - (psia)		PNZREF	LIQENG	psia	125
reference chamber pressure for chamber - (psia)		PRFCHM	LIQENG	psia	125
reference throat radius (in.)		RNZREF	LIQENG	in.	3.74
reference chamber radius (in.)		RRFCHM	LIQENG	in.	5.95
reference nozzle thickness (in.)		TNZREF	LIQENG	in.	.019
Chamber structural safety factor (KOOLTC = 1 or 4)		SFCHM	LIQENG	-	1.0
Minimum nozzle extension thickness (in.)		TNZMIN	LIQENG	in.	0.01
Engine size/weight input (KWTMOD = -1)					
nozzle length (in.)		XLNOZ	LIQENG	in.	76.04
engine weight (lb)		WTLTCA	LIQENG	lb	184.4

Figure 2. (cont.)

Thrust Chamber

Engine Performance (Circle One)

0) input engine performance

1) calculate engine performance

Engine Performance (KPERF = 0)

Delivered C* (ft/sec.) [ ]

Overall engine mixture ratio (-) [ ]

Delivered vacuum Isp (sec.) [ ]

Throat Regression (Circle One)

0) no regression

2) input regression coefficients (REGA, REGB, REGC)

$\Delta r_t = C\,(e^{-at} - 1) + bt$

a [ ]

b [ ]

c [ ]

VARIABLE	NAMELIST	UNITS	DEFAULT
KPERF	LFLAG	-	1
CSTARL	LQPERF	ft/sec.	5523
OFMTC	LQPERF	-	1.782
XISP	LQPERF	sec.	314.1
KREG	LFLAG	-	0
REGA	ABLATE	-	.002798
REGB	ABLATE	-	.0005995
REGC	ABLATE	-	.4246

General Input

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

(Circle One)

0) use default temperatures

1) input temperatures

	VARIABLE	NAMELIST	UNITS	DEFAULT
	IPUTMP	LFLAG	-	0
minimum fuel temperature (°R)	TPMINF	LFUEL	°R	varies
nominal fuel temperature (°R)	TPNOMF	LFUEL	°R	varies
maximum fuel temperature (°R)	TPMAXF	LFUEL	°R	varies
minimum ox temperature (°R)	TPMINO	LOXID	°R	varies
nominal ox temperature (°R)	TPNOMO	LOXID	°R	varies
maximum ox temperature (°R)	TPMAXO	LOXID	°R	varies

General Input

Lines full at burnout (Circle One)
(0 = No, 1 = Yes)

Miscellaneous on-board propellant (lbm)
(remains on stage at burnout)

fuel [ ]

ox [ ]

Number of iterations on temperature schedule [ ]
(a value of 1 performs temperature schedule calculations only once)

VARIABLE	NAMELIST	UNITS	DEFAULT
LNFULL	LFLAG	-	1
WMISFL	INPGEN	lbm	0.0
WMISOX	INPGEN	lbm	0.0
NTMPIT	LIQUID	-	1

Figure Contingent Input Worksheet

Tandem Tanks (NCTNK = 0)

Space between suspended tank and structural vehicle wall

aft tank (MNCQA = 0)

forward tank (MNCQF = 0)

pressure tank (KPRESS = 1)

Pressure tank insulation density ☐

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

Propellant feed line flag (Circle One)

0) external feed line

1) internal feed line

Number of pressure bottles in engine bay ☐

(KPRESS = 0)

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

Figure (cont.)

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

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

Figure 2 (cont.)

Non-Conventional Tanks (NCTNK = 1)

Non-conventional tank usable volume ratios

- fuel tanks ____
- ox tanks ____
- pressure tanks ____

Minimum clearance between non-conventional tanks (in.) ____

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

Non-conventional tankage drawing mode (Circle One)

1) draw three views on one page

2) draw three views on separate pages

Non-conventional models engine nesting mode (Circle One)

1) nest each engine independently

2) nest engines to highest common plane

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

Non-conventional tankage thickness option (Circle One)

0) variable wall thickness

1) constant wall thickness

VARIABLE	NAMELIST	UNITS	DEFAULT
RATNK1-4	NCTINP	-	1.0
CLRTNK	NCTINP	in.	2.0
ENGSPC	NCTINP	in.	2.0
IDRAW	NCTINP	-	2
KNEST	NCTINP	-	3
KTHCK1-4	NCTINP	-	1

Non-Conventional Tanks (NCTNK = 1)

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

Figure 2 (cont.)

Cold Gas Pressurization

Pressurant Properties (default is Helium)

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

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

Figure 2 (cont.)

Solid gas generator pressurization

Description	VARIABLE	NAMELIST	UNITS	DEFAULT
Burn rate temperature sensitivity of solid grain (1/°R)	SIGGG	SOLDGG	1/°R	0.0013
Gas generator combustion temperature (°R)	TCMBGG	SOLDGG	°R	2130
Temperature decay time constant	TDCYGG	SOLDGG	sec.	100
Reference temperature for burn rate coefficient (°R)	TREFGG	SOLDGG	°F	80
Molecular weight of combustion products	WTMGG	SOLDGG	lb/lbmole	19.0

Pump

Turbine feed location (circle one) (KCYCLE >1)

0) feed turbine from regen outlet

1) feed turbine from upstream of regen jacket
   (uses regen bypass flow set by BYPREG)

VARIABLE	NAMELIST	UNITS	DEFAULT
LTURFD	LFLAG	-	0

Pump

Item		VARIABLE	NAMELIST	UNITS	DEFAULT
Boost pump fraction of total propellant head rise					
fuel	[ ]	BPFRFL	PUMP	-	.0464
ox	[ ]	BPFROX	PUMP	-	.0464
Gas generator/pre-burner control valve pressure drop multiplier	[ ]	CVMLTF	PUMP	-	0.65
Pressure ratio across gas generator/pre-burner					
fuel side	[ ]	PBPRF	PUMP	-	1.2
ox side	[ ]	PBPRO	PUMP	-	1.2
Turbine outlet pressure (for gas generator bleed cycle) (KCYCLE = 1) (psia)	[ ]	PTURBO	PUMP	psia	20.
Number of turbo pump assemblies (Circle One)					
1) 1 TPA per stage		KPUMP	PUMP	-	2
2) 1 TPA per engine		TULLFL	PUMP	°R	800
Autogenous Pressurant temperature (°R)		TULLOX	PUMP	°R	800
fuel	[ ] (KGASFL = 1)				
ox	[ ] (KGASOX = 1)				

Figure 2. (cont.)

Pump

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

Figure 2 (cont.)

Pump

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

Figure (cont.)

Pump

TPA Material properties

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

Figure 2 (cont.)

<u>Regen/Trans-regen</u>

Item	VARIABLE	NAMELIST	UNITS	DEFAULT
Regen jacket bypass flow fraction (-)	BYPREG	INREGN	-	0.0
Turbine bypass flow fraction (-)	BYPTUR	INREGN	-	0.0
Cooling channel multiplier (-)	CHMULT	INREGN	-	1.0
Absolute surface roughness of regen channels (in.)	EPIPE	INREGN	in.	0.00008
Maximum depth to width ratio in cooling channels (-)	HOWMAX	INREGN	-	5.0
Transpiration cooling criteria (Circle One) 1) use QMAXTR 2) input EPSTRD & EPSTRU	IDTRAN	INREGN	-	2
Regen coolant selection (Circle One) 0) oxidizer 1) fuel	IFREGN	INREGN	-	1

Figure 2 (cont.)

Regen/Trans-regen

Input	VARIABLE	NAMELIST	UNITS	DEFAULT
Number of regen segments in				
Cylindrical chamber section ☐	NCYL	INREGN	-	5
Convergent chamber section ☐	NCON	INREGN	-	5
Expansion nozzle section ☐	NNZL	INREGN	-	5
Maximum heat flux before transpiration cooling ($BTU/in.^2$ sec.) ☐	QMAXTR	INREGN	$BTU/in.^2$sec	1.0
Surface area multiplier on regen cooled engine ☐	SAMULT	INREGN	-	1.0
Transpiration section platelet dimensions (in.)				
etched platelet thickness ☐	TGEOH	INREGN	in.	.08
platelet land thickness ☐	TGEOL	INREGN	in.	.1
separator platelet thickness ☐	TGEOS	INREGN	in.	.04
flow passage widths ☐	TGEOW	INREGN	in.	.14

Figure (cont.)

<u>Regen/Trans-regen</u>

Description		VARIABLE	NAMELIST	UNITS	DEFAULT
Land width of regen cooling channels at throat (in.)		WLTHR	INREGN	in.	.03
Channel width of regen cooling channels at throat (in.)		WTHR	INREGN	in.	.03
Transpiration cooling insert					
material density ($lb/in.^3$)		RHTRIN	LIQMAT	$lb/in.^3$	0.28
thickness (in.)		TRINST	LIQMAT	in.	0.3
thermal conductivity (BTU/in.sec.°R)		TRANKM	INREGN	BTU/insec°R	.0004

Figure 2 (cont.)

<u>Tank Heat Transfer</u>

Propellant tank heat transfer (Circle One)

0) ignore tank heat transfer

1) external boundary exposed to conductive source

2) worst case solar radiation

3) ground hold ice formation

VARIABLE	NAMELIST	UNITS	DEFAULT
KHXOPT	LFLAG	-	0

Tank Heat Transfer

Tank insulation conductivity flag (Circle One)

0) input conductivity of MLI and SOFI

1) calculate conductivity of MLI and SOFI

Effective thermal conductivity of MLI (BTU/in.sec.°R) [ ]

Effective thermal conductivity of SOFI (BTU/in.sec.°R) [ ]

SOFI Thermal conductivity constants (KALCON = 1)

$$K = A + B * T$$

A (BTU/in.sec.°R) [ ]

B (BTU/in.sec.°R^2) [ ]

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

MLI [ ]

SOFI [ ]

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

Average stage acceleration (g's) [ ]

Iteration counter in heat transfer calcs [ ]

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

Tank Heat Transfer

Field	VARIABLE	NAMELIST	UNITS	DEFAULT
Fraction of propellant tank nominal ullage pressure at which venting occurs — fuel [ ]	FVENTF	TANKHX	-	1.1
ox [ ]	FVENTO	TANKHX	-	1.1
Stage action time (sec.) [ ]	FLTTIM	TANKHX	sec.	100
Stage hold time (sec.) [ ]	HLDTIM	TANKHX	sec.	100
MLI environment flag (Circle One): 1) Ground hold with N_2 purge; 2) Ground hold with He purge; 3) Space hold with N_2 purge depleted to PRGMLI psia; 4) Space hold with He purge depleted to PRGMLI psia	MLIENV	TANKHX	-	1
MLI purge gas pressure at space hold conditions (psia) [ ]	PRGMLI	TANKHX	psia	2.0E-7

Figure 2 (cont.)

<u>Tank Heat Transfer</u>

Description	VARIABLE	NAMELIST	UNITS	DEFAULT
External tank boundary temperature (KHXOPT = 1) (°R)	TEXBOU	TANKHX	°R	560
Space hold heat transfer (KHXOPT = 2)				
Earth Infrared heat flux (BTU/sec.in.^{2})	EARIR	TANKHX	BTU/sec.in.^{2}	1.35E-4
Earth reflectance (albedo)	EARREF	TANKHX	-	0.39
Average orbital altitude (miles)	HXALT	TANKHX	miles	125
Angle between earth-sun vector and vehicle orbital plane (deg)	ORBANG	TANKHX	deg	0.0
Stage absorbativity	SABSOR	TANKHX	-	0.2
Solar heat flux (BTU/sec.in.^{2})	SOLCON	TANKHX	BTU/sec.in.^{2}	8.28E-4
Ground Hold Ice formation (KHXOPT = 3)				
Relative humidity	RELHUM	TANKHX	-	50.
Ambient temperature (°R)	TAMICE	TANKHX	°R	560.
Wind velocity (MPH)	WNDMPH	TANKHX	mph	10.

Figure 2 (cont.)

Positive Expulsion Bladders

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

ox tank [ ]

fuel tank [ ]

Bond material density of bonded rolling diaphram

ox tank [ ] ($lb/in.^3$)

fuel tank [ ]

Bladder thickness (for BRD only) (in.)

ox tank [ ]

fuel tank [ ]

Bond thickness (for BRD only) (in.)

ox tank [ ]

fuel tank [ ]

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

User Defined Propellant

Equivalence Ratio method (performance calculation for user defined propellant combination (IPROP = 0)

		VARIABLE	NAMELIST	UNITS	DEFAULT
Product of equivalence ratio and mixture ratio	☐	CONREF	LPROP	-	2.249
Mixture ratio of user propellant for maximum Isp at Pc = 500, ε = 20	☐	OFRMX	LPROP	-	2.03
Cstar of user propellant at Pc = 500 and at mixture ratio (OFRMX)	☐	CSRMX	LPROP	ft./sec.	5689
Maximum Isp for Pc = 500, ε = 20	☐	SPRMX	LPROP	sec.	328.8
Chamber temperature at Pc = 500, MR = OFRMX	☐	TRMX	LPROP	°R	5934
Propellant combination most similar to user defined combination (Circle One)		IPRSIM	LPROP	-	1

1) N_2O_4/MMH

2) MON-25/MHF-3

3) ClF5/MHF-3

4) MON-25/60% MHF-3 + 40% Al

5) LO2/LH2

6) LO2/RP-1

7) LO2/CH4

8) LF2/LH2

9) LF2/N_2H4

Output equivalence ratio ① ① A-50/N_2O_4 ISP
ox/fu atoms ② ②

Figure 2 (cont.)

User Defined Propellant

User defined coolant (should be ox or fuel)

Coolant ideal gas heat capacity constants

$Cp = A + BTr + CTr^2 + DTr^3$

A [ ]

B [ ]

C [ ]

D [ ]

Reference temperature for coolant properties (°R) [ ]

Reference pressure for coolant properties (psia) [ ]

Reference coolant properties

heat capacity (BTU/lb°R) [ ]

thermal conductivity (BTU/in.sec.°R) [ ]

density (lb/in.^{3}) [ ]

viscosity (lb/in sec) [ ]

VARIABLE	NAMELIST	UNITS	DEFAULT
CPCONA	LPROP	-	3.89
CPCONB	LPROP	-	23.2
CPCONC	LPROP	-	-9.818
CPCOND	LPROP	-	1.666
TREF	LPROP	°R	530
PREF	LPROP	psia	14.7
CPREF	LPROP	BTU/lb°R	.725
CREF	LPROP	BTU/in.sec.°R	3.85E-6
DREF	LPROP	lb/in.^{3}	.0327
VREF	LPROP	lb/in sec	5.17E-5

Figure (cont.)

User Defined Propellant

Coolant critical point

temperature (°R) [ ]

pressure (psia) [ ]

Coolant normal boiling point (°R) [ ]

Coolant heat transfer constants

$N_u = K\ R_e^{\alpha}\ P_r^{\beta}$

K [ ]

α [ ]

β [ ]

Coolant ultimate heat flux constants (liquid phase)

$q_{ult} = C_1 + C_2\ V\ (T_{sat} - T)$

C_1 (BTU/in.^{2}sec.) [ ]

C_2 (BTU/in.^{3}sec.°R) [ ]

VARIABLE	NAMELIST	UNITS	DEFAULT
TCRIT	LPROP	°R	1093
PCRIT	LPROP	psia	1731
TBOIL	LPROP	°R	618
DBMLTK	LPROP	-	.005
DBEXPA	LPROP	-	.95
DBEXPB	LPROP	-	.4
QULTC1	LPROP	BTU/in.^{2}sec.	4.55
QULTC2	LPROP	BTU/in.^{3}sec°R	.00686

Figure 2 (cont.)

User Defined Propellant

fuel description (Circle One)

0) storable

1) cryogenic

ox description (Circle One)

0) storable

1) cryogenic

Propellant combination description (Circle One)

0) not hypergolic

1) hypergolic

VARIABLE	NAMELIST	UNITS	DEFAULT
ICRYFL	LFLAG	-	0
ICRYOX	LFLAG	-	0
IHYPER	LFLAG	-	1

Figure 2 (cont.)

User Defined Propellant

Field	Input	VARIABLE	NAMELIST	UNITS	DEFAULT
Fuel ideal gas heat capacity constants $C_p = A + BT_r + CT_r^2 + DT_r^3$					
A	[ ]	CPCNAF	LFUEL	-	3.89
B	[ ]	CPCNBF	LFUEL	-	23.2
C	[ ]	CPCNCF	LFUEL	-	-9.818
D	[ ]	CPCNDF	LFUEL	-	1.666
Reference temperature for fuel properties (°R)	[ ]	TREFFL	LFUEL	°R	530.
Reference pressure for fuel properties (psia)	[ ]	PREFFL	LFUEL	psia	14.7
Reference fuel properties					
heat capacity (BTU/lb°R)	[ ]	CPREFF	LFUEL	BTU/lb°R	.725
thermal conductivity (BTU/in.sec.°R)	[ ]	CREFFL	LFUEL	BTU/in.sec°R	3.854E-6
density (lb/in.^{3})	[ ]	DREFFL	LFUEL	lb/in.^{3}	.0327
surface tension (lb/in.)	[ ]	REFSTF	LFUEL	lb/in.	3.794E-4
viscosity (lb/in sec)	[ ]	VREFFL	LFUEL	lb/in sec.	5.17E-5

Figure 2 (cont.)

User Defined Propellant

Fuel critical point

temperature (°R) [ ]

pressure (psia) [ ]

Fuel normal boiling point (°R) [ ]

Fuel heat of vaporization at normal boiling point (BTU/lb) [ ]

Fuel molecular weight (lb/lbmole) [ ]

Fuel operating temperature range (°R)

minimum [ ]

nominal [ ]

maximum [ ]

VARIABLE	NAMELIST	UNITS	DEFAULT
TCRITF	LFUEL	°R	1093
PCRITF	LFUEL	psia	1731
TBOILF	LFUEL	°R	618
DHVAPF	LFUEL	BTU/lb	346.5
WTMOLF	LFUEL	lb/lbmole	41.802
TPMINF	LFUEL	°R	510
TPNOMF	LFUEL	°R	530
TPMAXF	LFUEL	°R	550

Figure 2 (cont.)

User Defined Propellant

Oxidizer ideal gas heat capacity constants

$$C_p = A + BT_r + CT_r^2 + DT_r^3$$

A [ ]

B [ ]

C [ ]

D [ ]

Reference temperature for oxidizer properties (°R) [ ]

Reference pressure for oxidizer properties (psia) [ ]

Reference oxidizer properties

heat capacity (BTU/lb °R) [ ]

thermal conductivity (BTU/in.sec.°R) [ ]

density (lb/in.^{3}) [ ]

surface tension (lb/in.) [ ]

viscosity (lb/in sec) [ ]

VARIABLE	NAMELIST	UNITS	DEFAULT
CPCNAO	LOXID	-	7.9
CPCNBO	LOXID	-	19.23
CPCNCO	LOXID	-	-5.018
CPCNDO	LOXID	-	0
TREFOX	LOXID	°R	530
PREFOX	LOXID	psia	14.7
CPREFO	LOXID	BTU/lb°R	.378
CREFOX	LOXID	BTU/in.sec°R	1.758E-6
DREFOX	LOXID	lb/in.^{3}	.05177
REFSTO	LOXID	lb/in.	1.433E-4
VREFOX	LOXID	lb/in sec	2.225E-5

Figure (cont.)

User Defined Propellant

Oxidier critical point

temperature (°R) [ ]

pressure (psia) [ ]

Oxidizer normal boiling point (°R) [ ]

Oxidizer heat of vaporization at normal boiling point (BTU/lb) [ ]

Oxidizer molecular weight (lb/lbmole) [ ]

Oxidizer operating temperature range (°R)

minimum [ ]

nominal [ ]

maximum [ ]

VARIABLE	NAMELIST	UNITS	DEFAULT
TCRITO	LOXID	°R	776.5
PCRITO	LOXID	psia	1440
TBOILO	LOXID	°R	529.8
DHVAPO	LOXID	BTU/lb	178.2
WTMOLO	LOXID	lb/lbmole	92.016
TPMINO	LOXID	°R	510
TPNOMO	LOXID	°R	530
TPMAXO	LOXID	°R	550

Figure (cont.)

Throttling trajectory

Table of nozzle efficiencies

Table of chamber efficiencies

Table of chamber pressure fractions

Number of entries in above tables

Throttling profile

chamber pressure fractions

burn duration (sec.)

Propellant use flag

true = burn all propellant

false = burn only through last time interval

* See technical information volume

VARIABLE	NAMELIST	UNITS	DEFAULT
ECFTHR	THROT	-	*
ERETHR	THROT	-	*
THRPC	THROT	-	*
NTHEFF	THROT	-	7
PCTHRT	THROT	-	1.0
TIMTHR	THROT	sec	0.0
LUSEP	THROT	Boolean	TRUE

Short Nozzle

	VARIABLE	NAMELIST	UNITS	DEFAULT
External expansion nozzle thrust multipliers				
base pressure multiplier [ ]	CBMLT	NOZZLE	-	0.7
expansion thrust multiplier [ ]	CTMLT	NOZZLE	-	0.99
Annular nozzle (IPLUG = 2)				
method of calculating annular throat diameter (Circle One) 0) input diameter (DANEX) 1) calculate diameter (DANEX = FANMOT * DMOTOR)	MANDEQ	NOZZLE	-	1
annular throat diameter (in.) [ ]	DANEX	NOZZLE	in.	48
annular throat diamter fraction of DMOTOR [ ]	FANMOT	NOZZLE	-	0.8
Plug cluster base density (lb/in^3) [ ]	RHOPLB	LIQMAT	$lb/in.^3$	0.06
Plug cluster base thickness (in.) [ ]	TPLGBS	LIQUID	in.	0.5

3.0 CENTAUR D1-T SAMPLE CASE

The Centaur D1-T is a high energy upper stage (Figure 3.1) with multiple restart capability. Two thrust chamber assemblies provide a vacuum thrust of 30,000 lb and a vacuum specific impulse of 444 seconds. The propellants are the cryogenic combination, liquid hydrogen and liquid oxygen. Stage diameter is 10 feet and the length is 30 feet. The propellant tanks are loaded with 24,840 lb of liquid oxygen and 4,910 lb of liquid hydrogen.

The tank structure contains the main propellant (liquid hydrogen and liquid oxygen), establishes primary structural integrity for the Centaur vehicle, and provides support for all Centaur stage airborne systems and components. The propellant tanks are of pressure stabilized monocoque construction formed by a series of short stainless steel cylinders welded together. The ends of the tank are formed by stainless steel bulkheads. The fuel and oxidizer tanks are separated by a double-walled, vacuum insulated intermediate bulkhead. The tank structure cylindrical section is made from 301 CRES (extra hard) stainless steel, 0.014 inch thick. The tank skin is stabilized at all times by internal pressure or by the application of mechanical stretch. After erection, structural integrity is assured by minimum standby pressures of 5 psig in the fuel tank and 10.5 psig in the oxidizer tank. The aft and intermediate bulkheads combine to form a 1.38:1 ellipsoidal LO_2 tank. The forward bulkhead of the LH_2 tank is a combination of ellipsoidal and conical sections. All three bulkheads are fabricated from multiple sections of 301 CRES. The aft bulkhead contains mounting provisions for the engine thrust barrel and all other components and hardware located in the aft section which are not attached to the engines.

Primary vehicle thrust is provided by two Pratt and Whitney RL10A-3-3 engines. These are constant thrust, turbopump-fed, regeneratively-cooled, liquid rocket engines. The engines use liquid hydrogen and liquid oxygen as propellant and are capable of making multiple starts after long coast periods in space. The combustion process is initiated through ignition of the initial flow of propellants (gaseous) with a spark igniter which is an integral part of the engine. Each engine is attached to the vehicle by a

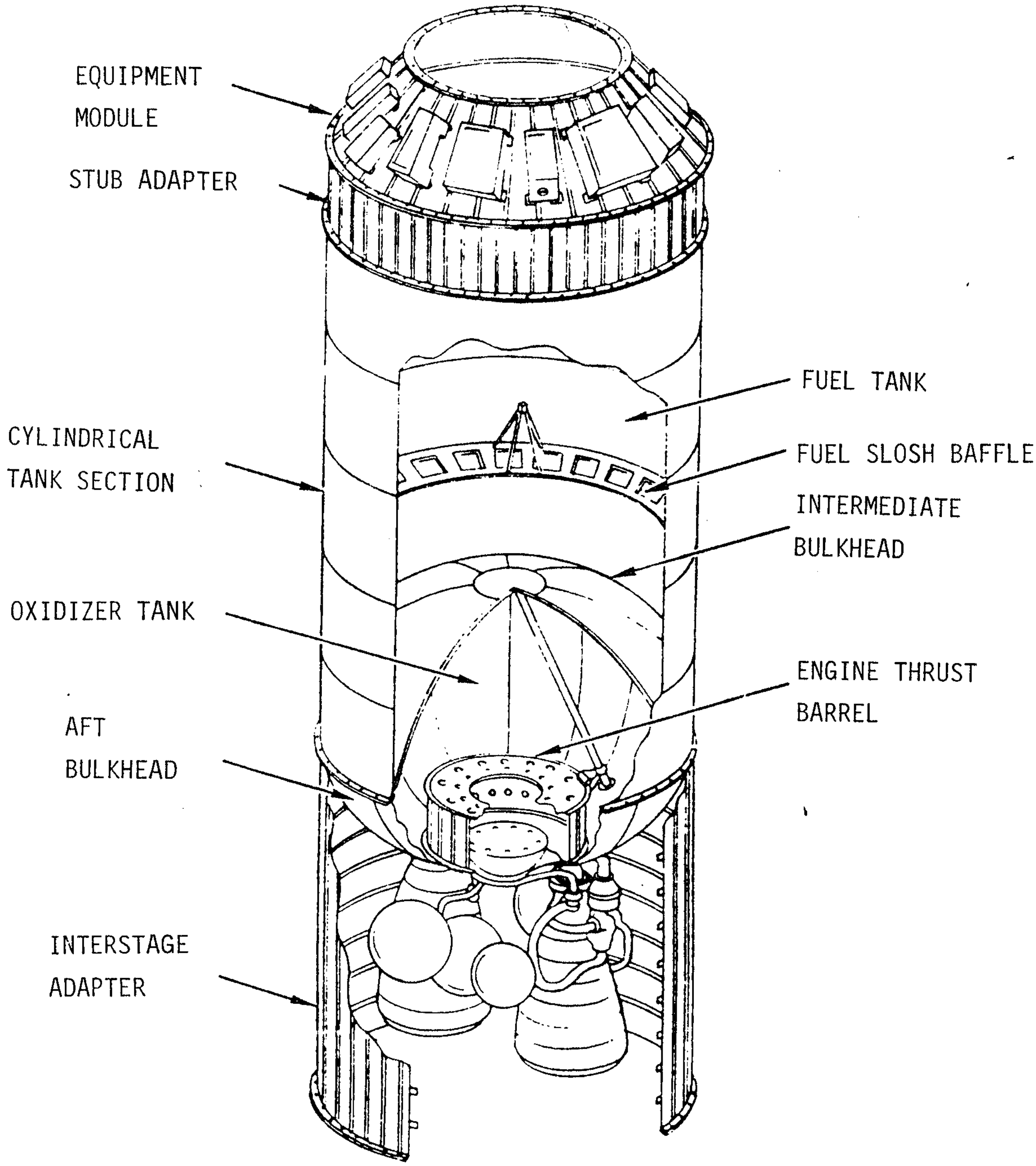


Figure 3.1. Centaur D1-T

gimbal mount assembly. Power to operate the vehicle hydraulic system is supplied through an accessory drive pad on the engine turbopump assembly. The helium required for engine operation is provided from a storage bottle located on the aft bulkhead. Nominal steady state performance and operating parameters at standard pump inlet conditions and at 200,000 feet altitude are:

Chamber Pressure:	400 psia
Thrust/Engine:	15,000 lb
Mixture Ratio:	5.0:1
Flow Rate/Engine:	33.8 lb/sec
Specific Impulse:	444 sec
Rated Continuous Operation Duration:	450 sec

The ELES worksheets which were filled out to model Centaur are shown in Figure 3.2. The ELES inputs derived from those worksheets which model the Centaur D1-T are shown in Figure 3.3. Associated with many of the inputs are explanations as to their origin. The comments in the input listing refer to those explanations which are found in Table 3.1.

The warning page (Figure 3.4) is designed to draw attention to potential design flaws in the stage under consideration. The warnings for Centaur D1-T indicate that the injector inlet propellant temperatures are fairly well defined, that the propellant tanks could hold more internal pressure without requiring additional wall thickness, and that the aft tank volume is larger than required by the program inputs. No significant problems are indicated.

The tankage summary (Figure 3.5) displays the more important tankage parameters such as dimensions, weights, propellant capacity, boiloff, heat flux, etc. It is followed by the tandem tank graphical output page (Figure 3.6) which displays a scaled drawing of the stage.

TITLE - CENTAUR D1-T

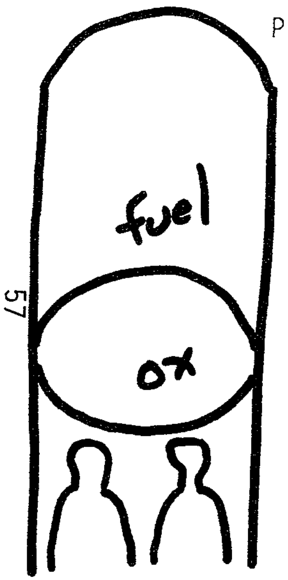
STAGE # 1

Item	Value	VARIABLE	NAMELIST	UNITS	DEFAULT
Total Number of Stages	1	NSTGES	INPGEN	-	3
Vehicle Payload Wt. (lbm)	0	WPAYLD	INPGEN	lbm	0.0
Miscellaneous Stage Wt. (lbm)	1692	WMISC	INPGEN	lbm	0.0
Expendable Stage Wt. (lbm)	0	WEXPND	INPGEN	lbm	0.0
Upper Interstage Material Properties					
density (lb/in^3)		RHOINT	INTSTG	lb/in^3	0.101
design stress (psia)		SINST	INTSTG	psia	220000.
modulus of elasticity (psia)		EINSTG	INTSTG	psia	1.8E6
safety factor (-)		SFINST	INTSTG	-	1.5
Kind of Stage (Circle one): 1) solid; 2) liquid (circled)		KSTAGE	INPGEN	-	1

Tank Geometry

Tandem Tanks

(Draw Sketch Here)



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

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

propellant tank head ellipse ratio 1.38

pressurant tank head ellipse ratio 1.0

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

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

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

Non-Conventional Tanks

(Draw Sketch Here)

Description	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) L_{cyl}/D ; R_{hub}/R_{tube}	KALMOD	NCTINP	-	0
	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) 120	DMOTOR	INPGEN	in	66.0
Forward Skirt Length (in) 2	FFSKTL (0.04)	LIQUID	-	0.3
Aft Skirt Length (in) 121	FASKTL (1.0)	LIQUID	-	0.067

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 (circled)	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: 5.0

Number of Engines: 2

Vacuum Thrust Per Engine (lb_f): 15000

Chamber Pressure (psia): 400

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 (cont.)

Engine Power Cycle
(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	1.46
Specific Heat (BTU/lb °R)	3.25
Molecular Weight	2.0

Tank Outlet Net Positive Suction Pressures

60

Oxidizer (psia)	8
Fuel (psia)	4

Pump Configuration

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

Boost Pumps

1 oxidizer (o = no)

1 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

Item	Entry	VARIABLE	NAMELIST	UNITS	DEFAULT
Burned Propellant Wt.	29750	WTLPRP	LIQUID	lb.	13250.0
Ullage Fractions — Oxidizer	0.02	ULLFFL	LTANK	-	0.02
Ullage Fractions — Fuel	0.02	ULLFOX	LTANK	-	0.02
Propellant Acquisition Device (Circle One)		KACQOX	LFLAG	-	0
		KACQFL	LFLAG	-	0
Propellant Tank Pressurization (Circle One) (KGASOX, KGASFL)		KGASOX	LFLAG	-	0
		KGASFL	LFLAG	-	0
(KGAS)		KGAS	LFLAG	-	2
Cold Helium Storage Pressure		PICG	COLDG	psia	4365.0
Helium Tank Final Pressure Fraction (less than 1.0 indicates blowdown)		FPULCG	COLDG	-	0.8

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 *(circled)*

61 Propellant Tank Pressurization
(Circle One)
(KGASOX, KGASFL)

0) non-autogenous
(KGAS)
1) solid gas generator
2) cold helium
1) autogenous *(circled)*

Figure 3.2. (cont.)

Mate[illegible] of Construction
(fil[illegible] 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	14
Oxidizer Tank	14
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	[illegible]AULT
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

Propellant tank heat transfer (Circle One)
- 0) ignore tank heat transfer
- 1) external boundary exposed to conductive source
- 2) worst case solar radiation
- 3) ground hold ice formation

Propellant Tank Insulation (in.)

		VARIABLE	NAMELIST	UNITS	DEFAULT
Propellant tank heat transfer	1 (circled)	KHXOPT	LFLAG	-	0
Fuel Tank SOFI Thickness	0.5	TSOFIF	TANKHX	in.	0.0
Fuel Tank MLI Thickness	0.018	TMLIF	TANKHX	in.	0.0
Oxidizer Tank SOFI Thickness	0.5	TSOFIO	TANKHX	in.	0.0
Oxidizer Tank MLI Thickness	0.018	TMLIO	TANKHX	in.	0.0
Engine Expansion Area Ratio	57	EPS	INPGEN	-	10.0
Nozzle Extension Attach Area Ratio	6.0	EPSATT	INPGEN	-	1.0
Engine Contraction Ratio	4.0	CR	LIQENG	-	2.54
Combustion Chamber Length (in.)	12.6 (7.6 + 5)	XLC	LIQENG	in.	0.0
		XLN	LIQENG	in.	18.7
		IPLUG	LIQUID	-	0
		KNOZ	LIQENG	-	2
		ALFNOZ	NOZZLE	deg	15.0
	1.1868	RATMLR	LIQENG	-	1.177
		KEXNOZ	LIQENG	-	1

Nozzle Type (Circle One)

	IPLUG	KNOZ
Conical	0	1
Rao/Bell (circled)	0	2
Plug Cluster	1	-
Annular	2	-

Description	Entry	VARIABLE	NAMELIST	UNITS	DEFAULT
Combustion Chamber Cooling Method (Circle One): 1) Ablative; **2) Regenerative** (circled); 3) Trans-Regen; 4) Radiation		KOOLTC	LFLAG	-	1
Nominal Chamber wall material temperature (°R)	2050	TGWNOM	INREGN	°R	2000.0
DIFTBF = $(T_{barrier}-TGWNOM)/(T_{core}-TGWNOM)$	1.0	DIFTBF	INREGN	-	1.0
Regen/Trans-Regen input: Output a regen summary (0 = no, 1 = yes)	1	IRPRNT	INREGN	-	0
Gas wall minimum gauge (in.)	.01275	GWMING	INREGN	in	0.025
Gas wall thermal conductivity (BTU/in sec °R)	.000215	WALLK	INREGN	BTU/in sec °R	0.00039
		EPSTRU	INREGN	-	2.0
		EPSTRD	INREGN	-	1.2
		TDESTR	INREGN	°R	2000.0
Nozzle Cooling Method (Circle One): 1) Ablative; **2) Regenerative** (circled); 3) Trans-Regen; 4) Radiation; 5) Film		KOOLNZ	LFLAG	-	4
Nominal nozzle material temperature (°R)	2000	TNENOM	LIQENG	°R	2000.0

Figure (cont.)

Parameter	Notes		Entry	VARIABLE	NAMELIST	UNITS	DEFAULT
Pressure Drop Across Injector	(15% of Pc is optimistic) (25% of Pc is nominal) (40% of Pc is conservative)	Fuel	0.168	FCHGFL	LIQUID	-	0.15
		Oxidizer	0.114	FCHGOX	LIQUID	-	0.15
Pressure Drop Acorss Valve	(3-30% of Pc)	Fuel	0.437	CPVLVF	LIQUID	-	0.409
		Oxidizer	0.367	CPVLVO	LIQUID	-	0.28
Pressure Drop Across Lines	(3-30% of Pc)	Fuel	0.02	CPLINF	LIQUID	-	0.172
		Oxidizer	0.02	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)		2.61	ELDENS	INJECT	elem/in^2	3.1
			(IELDEN = 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 (circled) 0.5) Vortex, swirl coax 0.33) unlike Triplet, unlike doublet			RMFFL	LQPERF	-	0.33
				RMFOX	LQPERF	-	0.33
			1.0	FLOPEL	INJECT	-	2.0
			1.0	OXOPEL	INJECT	-	1.5

Translating Nozzle
(Circle One)

- **0) None** (circled)
- 1) Spring Actuated
- 2) Gas Deployed Skirt

Translating Nozzle Material Density (lb/in^3) [box struck through]

Gimbal Angle (deg) **16**

Number of Gimbaling Engines **2**

Engine weight model (Circle One)
- -1) input engine weight
- 0) simplified ablative engine weight model
- 1) physical engine weight model

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

	density (lb/in^3)	strength (psi)
CHAMBER	.28	∞
NOZZLE	.28	25K
INJECTOR	.28	25K
VALVE	.28	X

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

Stage Operating Temperature Range (°F)

Minumum temperature	60
Nominal temperature	75
Maximum temperature	90

VARIABLE	NAMELIST	UNITS	DEFAULT
KTRNOZ	LIQENG	-	0
DPTRAT	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 8. (cont.)

Weight Multipliers

use default values

Item	Input	VARIABLE	NAMELIST	UNITS	DEFAULT
All Tanks		CXWTNK	CXWMLT	-	1.7
Fuel Tanks		CXNCT1-4	NCTINP	-	1.0
Oxidizer Tanks		CXWFLT	CXWMLT	-	1.0
Pressure Tanks		CXWOXT	CXWMLT	-	1.0
Structure		CXWPTN	CXWMLT	-	1.0
Propellant Lines		CXWSTR	CXWMLT	-	1.0
		CXWATL	CXWMLT	-	1.0
		CXWFTL	CXWMLT	-	1.0
		CXWPTL	CXWMLT	-	1.0
Total Engine		CXWENG	CXWMLT	-	1.05
Injector		CXINJ	CXWMLT	-	1.0
Valve		CXVALV	CXWMLT	-	1.0
Chamber	1.5	CXWCHM	CXWMLT	-	1.0
Nozzle Extension		CXWNZE	CXWMLT	-	1.1
Hot Gas Ducts		CXWDUC	PUMP	-	2.5
Gimbal System		CXWGIM	CXWMLT	-	1.0
Thrust Mount		CXWTHM	CXWMLT	-	1.0
Gas Generator Injector		CXWIGG	PUMP	-	1.0
Turbo Pump Assembly		CXWTPA	CXWMLT	-	1.0
Engine Bay Lines		CXWLIN	PUMP	-	2.5

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

Tankage

Line printer characters per inch

Horizontal

Vertical

Propellant Acquisition device material density ($lb/in.^3$)

fuel tank (KACQFL = 6)

ox tank (KACQOX = 6)

Cross sectional area of shroud stiffening rings ($in.^2$)

forward shroud

aft shroud

VARIABLE	NAMELIST	UNITS	DEFAULT
CHRPIX	NCTINP	char/in.	10
CHRPIY	NCTINP	char/in.	6
DACQFL	LTANK	$lb/in.^3$	0.1
DACQOX	LTANK	$lb/in.^3$	0.1
AESSR	LTANK	in^2	0.152
AFSSR	LTANK	in^2	0.25

Figure (cont.)

Injecter

Description	VARIABLE	NAMELIST	UNITS	DEFAULT
Injecter orifice discharge coefficients (-)				
fuel	CDIFL	INJECT	-	0.77
ox	CDIOX	INJECT	-	0.72
Injecter element input (IELDEN = 0)				
Number of injecter elements (-)	NELEM	INJECT	-	336
Number of fuel orifices (-)	NFLORF	INJECT	-	672
Number of ox orifices (-)	NOXORF	INJECT	-	500
Barrier liquid film length (in.)	XLFL	LQPERF	in.	1.0
Barrier mixing angle (deg.)	ALFMIX	INJECT	deg.	0.15

Thrust Chamber

Description	VARIABLE	NAMELIST	UNITS	DEFAULT
Engine radiation cooling model (KOOLTC = 4, KOOLNZ = 4)				
TCA material emissivity	EMISTC	LIQENG	-	0.9
vehicle emissivity in engine bay	EMISVE	LIQENG	-	0.5
ambient temperature (°R)	TAMRAD	LIQENG	°R	560
Ablative Chamber/nozzle weight model (KOOLTC = 1, KOOLNZ = 1) (See namelist ABLATE)				
reference chamber pressure for nozzle - (psia)	PNZREF	LIQENG	psia	125
reference chamber pressure for chamber - (psia)	PRFCHM	LIQENG	psia	125
reference throat radius (in.)	RNZREF	LIQENG	in.	3.74
reference chamber radius (in.)	RRFCHM	LIQENG	in.	5.95
reference nozzle thickness (in.)	TNZREF	LIQENG	in.	.019
Chamber structural safety factor (KOOLTC = 1 or 4)	SFCHM	LIQENG	-	1.0
Minimum nozzle extension thickness (in.)	TNZMIN	LIQENG	in.	0.01
Engine size/weight input (KWTMOD = -1)				
nozzle length (in.)	XLNOZ	LIQENG	in.	76.04
engine weight (lb)	WTLTCA	LIQENG	lb	184.4

Thrust Chamber

Engine Performance (Circle One)

0) input engine performance

1) calculate engine performance

Engine Performance (KPERF = 0)

Delivered C* (ft/sec.) [ ]

Overall engine mixture ratio (-) [ ]

Delivered vacuum Isp (sec.) [ ]

Throat Regression (Circle One)

0) no regression

2) input regression coefficients (REGA, REGB, REGC)

$\Delta r_t = C\,(e^{-at} - 1) + bt$

a [ ]

b [ ]

c [ ]

VARIABLE	NAMELIST	UNITS	DEFAULT
KPERF	LFLAG	-	1
CSTARL	LQPERF	ft/sec.	5523
OFMTC	LQPERF	-	1.782
XISP	LQPERF	sec.	314.1
KREG	LFLAG	-	0
REGA	ABLATE	-	.002798
REGB	ABLATE	-	.0005995
REGC	ABLATE	-	.4246

General Input

Propellant temperatures input option for library

propellants (IPROP > 0)

(Circle One)

0) use default temperatures

1) input temperatures

minimum fuel temperature (°R) [ ]

nominal fuel temperature (°R) [ ]

maximum fuel temperature (°R) [ ]

minimum ox temperature (°R) [ ]

nominal ox temperature (°R) [ ]

maximum ox temperature (°R) [ ]

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

General Input

Item	VARIABLE	NAMELIST	UNITS	DEFAULT
Lines full at burnout (Circle One) (0 = No, 1 = Yes)	LNFULL	LFLAG	-	1
Miscellaneous on-board propellant (lbm) (remains on stage at burnout) fuel: 131	WMISFL	INPGEN	lbm	0.0
ox: 0	WMISOX	INPGEN	lbm	0.0
Number of iterations on temperature schedule (a value of 1 performs temperature schedule calculations only once)	NTMPIT	LIQUID	-	1

Figure 3 (cont.)

Form entry	VARIABLE	NAMELIST	UNITS	DEFAULT
<u>Tandem Tanks</u> (NCTNK = 0)				
Space between suspended tank and structural vehicle wall				
aft tank (MNCQA = 0)	TSPCA	LTANK	in.	0.0
forward tank (MNCQF = 0)	TSPCF	LTANK	in.	0.0
pressure tank (KPRESS = 1)	TSPCP	LTANK	in.	0.0
Pressure tank insulation density [ ] (NCTNK = 0)(lb/in.^{3})	RHOINS	MATER	lb/in.^{3}	.0414
Propellant feed line flag (Circle One): 0) external feed line (circled); 1) internal feed line	KLINEA	TNKGEO	-	1
Number of pressure bottles in engine bay [2] (KPRESS = 0)	NPRB	TNKGEO	-	1

Figure (cont.)

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

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

Figure (cont.)

Non-Conventional Tanks (NCTNK = 1)

Input	VARIABLE	NAMELIST	UNITS	DEFAULT
Non-conventional tank usable volume ratios: fuel tanks / ox tanks / pressure tanks	RATNK1-4	NCTINP	-	1.0
Minimum clearance between non-conventional tanks (in.)	CLRTNK	NCTINP	in.	2.0
Minimum clearnace between nozzles in non-conventional model (in.)	ENGSPC	NCTINP	in.	2.0
Non-conventional tankage drawing mode (Circle One): 1) draw three views on one page; 2) draw three views on separate pages	IDRAW	NCTINP	-	2
Non-conventional models engine nesting mode (Circle One): 1) nest each engine independently; 2) nest engines to highest common plane; 3) nest engine exit plane to end of tankage + XMOUNT	KNEST	NCTINP	-	3
Non-conventional tankage thickness option (Circle One): 0) variable wall thickness; 1) constant wall thickness	KTHCK1-4	NCTINP	-	1

Figure (cont.)

Non-Conventional Tanks (NCTNK = 1)

Non-conventional tank feed line hydraulics

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

Figure (cont.)

Cold Gas Pressurization

Pressurant Properties (default is Helium)

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

Figure (cont.)

Solid gas generator pressurization (default is TAL-8)

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

Figure (cont.)

Solid gas generator pressurization

Description	Input	VARIABLE	NAMELIST	UNITS	DEFAULT
Burn rate temperature sensitivity of solid grain (1/°R)		SIGGG	SOLDGG	1/°R	0.0013
Gas generator combustion temperature (°R)		TCMBGG	SOLDGG	°R	2130
Temperature decay time constant		TDCYGG	SOLDGG	sec.	100
Reference temperature for burn rate coefficient (°R)		TREFGG	SOLDGG	°F	80
Molecular weight of combustion products		WTMGG	SOLDGG	lb/lbmole	19.0

Pump

Turbine feed location (circle one) (KCYCLE >1)

0) feed turbine from regen outlet

1) feed turbine from upstream of regen jacket (uses regen bypass flow set by BYPREG)

VARIABLE	NAMELIST	UNITS	DEFAULT
LTURFD	LFLAG	-	0

Pump

Turbine feed location (circle one) (KCYCLE > 1)

0) feed turbine from regen outlet

1) feed turbine from upstream of regen jacket
(uses regen bypass flow set by BYPREG)

VARIABLE	NAMELIST	UNITS	DEFAULT
LTURFD	LFLAG	-	0

<u>Pump</u>

Item	Entry	VARIABLE	NAMELIST	UNITS	DEFAULT
Boost pump fraction of total propellant head rise					
fuel	.008	BPFRFL	PUMP	-	.0464
ox	(struck out)	BPFROX	PUMP	-	.0464
Gas generator/pre-burner control valve pressure drop multiplier	(struck out)	CVMLTF	PUMP	-	0.65
Pressure ratio across gas generator/pre-burner					
fuel side	1.01	PBPRF	PUMP	-	1.2
ox side	1.01	PBPRO	PUMP	-	1.2
Turbine outlet pressure (for gas generator bleed cycle) (KCYCLE = 1) (psia)	(struck out)	PTURBO	PUMP	psia	20.
Number of turbo pump assemblies (Circle One) 1) 1 TPA per stage 2) 1 TPA per engine (circled)		KPUMP	PUMP	-	2
Autogenous Pressurant temperature (°R)					
fuel (KGASFL = 1)	100	TULLFL	PUMP	°R	800
ox (KGASOX = 1)	250	TULLOX	PUMP	°R	800

Figure 19 (cont.)

Pump

Description	Input	VARIABLE	NAMELIST	UNITS	DEFAULT
Suction specific speeds of propellant pumps					
main fuel pump	5800	SSSFL	PUMP	-	20000
main ox pump	5800	SSSOX	PUMP	-	20000
fuel boost pump	15 000	SSSBPF	PUMP	-	30000
ox boost pump	20 000	SSSBPO	PUMP	-	30000
Initial value of turbine pressure ratio (KCYCLE > = 2)	1.4	TURBPR	PUMP	-	2.0
Turbine pitch line velocity divided by isentropic spouting velocity		UOVERC	PUMP	-	0.4
Area ratio of bleed nozzle (KCYCLE = 1)		EPSGGB	PUMP	-	2.0
Gas generator or pre-burner contraction ratio		GGCR	PUMP	-	12.
Gas generator or pre-burner injector material density (lb/m^3)		ROINGG	PUMP	$lb/in.^3$	0.3
Gas generator or pre-burner injector yield strength (psi)		SYINGG	PUMP	psi	30000
Hot gas duct material density ($lb/in.^3$)		ROSTAK	PUMP	$lb/in.^3$	0.3
Hot gas duct material yield strength (psi)		SYDUCT	PUMP	psi	30000

Figure (cont.)

Pump

TPA Start System design (Circle One)

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

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

Figure (cont.)

Pump

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

Figure (cont.)

Regen/Trans-regen

Regen jacket bypass flow fraction (-) [0.313]

Turbine bypass flow fraction (-) [0]

Cooling channel multiplier (-) [ ]

Absolute surface roughness of regen channels (in.) [ ]

Maximum depth to width ratio in cooling channels (-) [4.62]

Transpiration cooling criteria
(Circle One)

1) use QMAXTR

2) input EPSTRD & EPSTRU

Regen coolant selection
(Circle One)

0) oxidizer

1) fuel

VARIABLE	NAMELIST	UNITS	DEFAULT
BYPREG	INREGN	-	0.0
BYPTUR	INREGN	-	0.0
CHMULT	INREGN	-	1.0
EPIPE	INREGN	in.	0.00008
HOWMAX	INREGN	-	5.0
IDTRAN	INREGN	-	2
IFREGN	INREGN	-	1

Figur. .2. (cont.)

Regen/Trans-regen

Number of regen segments in
- Cylindrical chamber section
- Convergent chamber section
- Expansion nozzle section

Maximum heat flux before transpiration cooling ($BTU/in.^2$ sec.)

Surface area multiplier on regen cooled engine 1.641

88

Transpiration section platelet dimensions (in.)
- etched platelet thickness
- platelet land thickness
- separator platelet thickness
- flow passage widths

VARIABLE	NAMELIST	UNITS	DEFAULT
NCYL	INREGN	-	5.
NCON	INREGN	-	5
NNZL	INREGN	-	5
QMAXTR	INREGN	$BTU/in.^2$sec	1.0
SAMULT	INREGN	-	1.0
TGEOH	INREGN	in.	.08
TGEOL	INREGN	in.	.1
TGEOS	INREGN	in.	.04
TGEOW	INREGN	in.	.14

Figure . (cont.)

<u>Regen/Trans-regen</u>

Land width of regen cooling channels at throat (in.)	.025	WLTHR	INREGN	in.	.03
Channel width of regen cooling channels at throat (in.)	.065	WTHR	INREGN	in.	.03
Transpiration cooling insert					
material density (lb/in.^{3})		RHTRIN	LIQMAT	lb/in.^{3}	0.28
thickness (in.)		TRINST	LIQMAT	in.	0.3
thermal conductivity (BTU/in.sec.°R)		TRANKM	INREGN	BTU/insec°R	.0004

Figure (cont.)

Tank Heat Transfer

Propellant tank heat transfer (Circle One)

0) ignore tank heat transfer

1) external boundary exposed to conductive source

2) worst case solar radiation

3) ground hold ice formation

VARIABLE	NAMELIST	UNITS	DEFAULT
KHXOPT	LFLAG	-	0

Tank Heat Transfer

Tank insulation conductivity flag (Circle One)

0) input conductivity of MLI and SOFI

1) calculate conductivity of MLI and SOFI

Effective thermal conductivity of MLI (BTU/in.sec.°R)

Effective thermal conductivity of SOFI (BTU/in.sec.°R)

SOFI Thermal conductivity constants (KALCON = 1)

K = A + B * T

A (BTU/in.sec.°R)

B (BTU/in.sec.°R^2)

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

MLI

SOFI

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

Average stage acceleration (g's)

Iteration counter in heat transfer calcs

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

Tank Heat Transfer

Fraction of propellant tank nominal ullage pressure at which venting occurs

fuel [ ]

ox [ ]

Stage action time (sec.) [300]

Stage hold time (sec.) [300]

MLI environment flag (Circle One)

1) Ground hold with N_2 purge (circled)
2) Ground hold with He purge
3) Space hold with N_2 purge depleted to PRGMLI psia
4) Space hold with He purge depleted to PRGMLI psia

MLI purge gas pressure at space hold conditions (psia) [ ]

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

Figure (cont.)

Tank Heat Transfer

External tank boundary temperature (KHXOPT = 1) (°R) 550

Space hold heat transfer (KHXOPT = 2)

- Earth Infrared heat flux (BTU/sec.in.^{2})
- Earth reflectance (albedo)
- Average orbital altitude (miles)
- Angle between earth-sun vector and vehicle orbital plane (deg)
- Stage absorbativity
- Solar heat flux (BTU/sec.in.^{2})

Ground Hold Ice formation (KHXOPT = 3)

- Relative humidity
- Ambient temperature (°R)
- Wind velocity (MPH)

VARIABLE	NAMELIST	UNITS	DEFAULT
TEXBOU	TANKHX	°R	560
EARIR	TANKHX	BTU/sec.in.^{2}	1.35E-4
EARREF	TANKHX	-	0.39
HXALT	TANKHX	miles	125
ORBANG	TANKHX	deg	0.0
SABSOR	TANKHX	-	0.2
SOLCON	TANKHX	BTU/sec.in.^{2}	8.28E-4
RELHUM	TANKHX	-	50.
TAMICE	TANKHX	°R	560.
WNDMPH	TANKHX	mph	10.

Figure (cont.)

Positive Expulsion Bladders

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

ox tank

fuel tank

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

ox tank

fuel tank

Bladder thickness (for BRD only) (in.)

ox tank

fuel tank

Bond thickness (for BRD only) (in.)

ox tank

fuel tank

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

User Defined Propellant

Equivalence Ratio method (performance calculation for user defined propellant combination (IPROP = 0)

Description	VARIABLE	NAMELIST	UNITS	DEFAULT
Product of equivalence ratio and mixture ratio	CONREF	LPROP	-	2.249
Mixture ratio of user propellant for maximum Isp at Pc = 500, ε = 20	OFRMX	LPROP	-	2.03
Cstar of user propellant at Pc = 500 and at mixture ratio (OFRMX)	CSRMX	LPROP	ft./sec.	5689
Maximum Isp for Pc = 500, ε = 20	SPRMX	LPROP	sec.	328.8
Chamber temperature at Pc = 500, MR = OFRMX	TRMX	LPROP	°R	5934
Propellant combination most similar to user defined combination (Circle One)	IPRSIM	LPROP	-	1

1) N_2O_4/MMH

2) MON-25/MHF-3

3) ClF5/MHF-3

4) MON-25/60% MHF-3 + 40% Al

5) LO2/LH2

6) LO2/RP-1

7) LO2/CH4

8) LF2/LH2

9) LF2/N_2H4

Figure (cont.)

User Defined Propellant

User defined coolant (should be ox or fuel)

Coolant ideal gas heat capacity constants

$$Cp = A + BTr + CTr^2 + DTr^3$$

A

B

C

D

Reference temperature for coolant properties (°R)

Reference pressure for coolant properties (psia)

Reference coolant properties

heat capacity (BTU/lb°R)

thermal conductivity (BTU/in.sec.°R)

density ($lb/in.^3$)

viscosity (lb/in sec)

VARIABLE	NAMELIST	UNITS	DEFAULT
CPCONA	LPROP	-	3.89
CPCONB	LPROP	-	23.2
CPCONC	LPROP	-	-9.818
CPCOND	LPROP	-	1.666
TREF	LPROP	°R	530
PREF	LPROP	psia	14.7
CPREF	LPROP	BTU/lb°R	.725
CREF	LPROP	BTU/in.sec.°R	3.85E-6
DREF	LPROP	$lb/in.^3$	.0327
VREF	LPROP	lb/in sec	5.17E-5

Figure 9 (cont.)

User Defined Propellant

Coolant critical point

temperature (°R) [ ]

pressure (psia) [ ]

Coolant normal boiling point (°R) [ ]

Coolant heat transfer constants

$N_u = K R_e^{\alpha} P_r^{\beta}$

K [ ]

α [ ]

β [ ]

Coolant ultimate heat flux constants (liquid phase)

$qult = C_1 + C_2 V (Tsat-T)$

C_1 (BTU/in.^{2}sec.) [ ]

C_2 (BTU/in.^{3}sec.°R) [ ]

VARIABLE	NAMELIST	UNITS	DEFAULT
TCRIT	LPROP	°R	1093
PCRIT	LPROP	psia	1731
TBOIL	LPROP	°R	618
DBMLTK	LPROP	-	.005
DBEXPA	LPROP	-	.95
DBEXPB	LPROP	-	.4
QULTC1	LPROP	BTU/in.^{2}sec.	4.55
QULTC2	LPROP	BTU/in.^{3}sec°R	.00686

Figure (cont.)

User Defined Propellant

fuel description (Circle One)

0) storable

1) cryogenic

ox description (Circle One)

0) storable

1) cryogenic

Propellant combination description (Circle One)

0) not hypergolic

1) hypergolic

VARIABLE	NAMELIST	UNITS	DEFAULT
ICRYFL	LFLAG	-	0
ICRYOX	LFLAG	-	0
IHYPER	LFLAG	-	1

Figure (cont.)

User Defined Propellant

Fuel ideal gas heat capacity constants

$$C_p = A + BT_r + CT_r^2 + DT_r^3$$

A [ ]

B [ ]

C [ ]

D [ ]

Reference temperature for fuel properties (°R) [ ]

Reference pressure for fuel properties (psia) [ ]

Reference fuel properties

heat capacity (BTU/lb°R) [ ]

thermal conductivity (BTU/in.sec.°R) [ ]

density (lb/in.^{3}) [ ]

surface tension (lb/in.) [ ]

viscosity (lb/in sec) [ ]

VARIABLE	NAMELIST	UNITS	DEFAULT
CPCNAF	LFUEL	-	3.89
CPCNBF	LFUEL	-	23.2
CPCNCF	LFUEL	-	-9.818
CPCNDF	LFUEL	-	1.666
TREFFL	LFUEL	°R	530.
PREFFL	LFUEL	psia	14.7
CPREFF	LFUEL	BTU/lb°R	.725
CREFFL	LFUEL	BTU/in.sec°R	3.854E-6
DREFFL	LFUEL	lb/in.^{3}	.0327
REFSTF	LFUEL	lb/in.	3.794E-4
VREFFL	LFUEL	lb/in sec.	5.17E-5

Figure (cont.)

User Defined Propellant

Fuel critical point

temperature (°R) [ ]

pressure (psia) [ ]

Fuel normal boiling point (°R) [ ]

Fuel heat of vaporization at normal boiling point (BTU/lb) [ ]

Fuel molecular weight (lb/lbmole) [ ]

Fuel operating temperature range (°R)

minimum [ ]

nominal [ ]

maximum [ ]

VARIABLE	NAMELIST	UNITS	DEFAULT
TCRITF	LFUEL	°R	1093
PCRITF	LFUEL	psia	1731
TBOILF	LFUEL	°R	618
DHVAPF	LFUEL	BTU/lb	346.5
WTMOLF	LFUEL	lb/lbmole	41.802
TPMINF	LFUEL	°R	510
TPNOMF	LFUEL	°R	530
TPMAXF	LFUEL	°R	550

Figure (cont.)

User Defined Propellant

Oxidizer ideal gas heat capacity constants

$$C_p = A + BT_r + CT_r^2 + DT_r^3$$

A [ ]

B [ ]

C [ ]

D [ ]

Reference temperature for oxidizer properties (°R) [ ]

Reference pressure for oxidizer properties (psia) [ ]

Reference oxidizer properties

heat capacity (BTU/lb °R) [ ]

thermal conductivity (BTU/in.sec.°R) [ ]

density (lb/in.^{3}) [ ]

surface tension (lb/in.) [ ]

viscosity (lb/in sec) [ ]

VARIABLE	NAMELIST	UNITS	DEFAULT
CPCNAO	LOXID	-	7.9
CPCNBO	LOXID	-	19.23
CPCNCO	LOXID	-	-5.018
CPCNDO	LOXID	-	0
TREFOX	LOXID	°R	530
PREFOX	LOXID	psia	14.7
CPREFO	LOXID	BTU/lb°R	.378
CREFOX	LOXID	BTU/in.sec°R	1.758E-6
DREFOX	LOXID	lb/in.^{3}	.05177
REFSTO	LOXID	lb/in.	1.433E-4
VREFOX	LOXID	lb/in sec	2.225E-5

Figure (cont.)

User Defined Propellant

Oxidier critical point

temperature (°R) [ ]

pressure (psia) [ ]

Oxidizer normal boiling point (°R) [ ]

Oxidizer heat of vaporization at normal boiling point (BTU/lb) [ ]

Oxidizer molecular weight (lb/lbmole) [ ]

Oxidizer operating temperature range (°R)

minimum [ ]

nominal [ ]

maximum [ ]

VARIABLE	NAMELIST	UNITS	DEFAULT
TCRITO	LOXID	°R	776.5
PCRITO	LOXID	psia	1440
TBOILO	LOXID	°R	529.8
DHVAPO	LOXID	BTU/lb	178.2
WTMOLO	LOXID	lb/lbmole	92.016
TPMINO	LOXID	°R	510
TPNOMO	LOXID	°R	530
TPMAXO	LOXID	°R	550

Figure (cont.)

Throttling trajectory

Description	VARIABLE	NAMELIST	UNITS	DEFAULT
Table of nozzle efficiencies	ECFTHR	THROT	-	*
Table of chamber efficiencies	ERETHR	THROT	-	*
Table of chamber pressure fractions	THRPC	THROT	-	*
Number of entries in above tables	NTHEFF	THROT	-	7
Throttling profile				
chamber pressure fractions	PCTHRT	THROT	-	1.0
burn duration (sec.)	TIMTHR	THROT	sec	0.0
Propellant use flag true = burn all propellant false = burn only through last time interval	LUSEP	THROT	Boolean	TRUE

* See technical information volume

Figure (cont.)

Short Nozzle

	VARIABLE	NAMELIST	UNITS	DEFAULT
External expansion nozzle thrust multipliers				
base pressure multiplier	CBMLT	NOZZLE	-	0.7
expansion thrust multiplier	CTMLT	NOZZLE	-	0.99
Annular nozzle (IPLUG = 2)				
method of calculating annular throat diameter (Circle One) 0) input diameter (DANEX) 1) calculate diameter (DANEX = FANMOT * DMOTOR)	MANDEQ	NOZZLE	-	1
annular throat diameter (in.)	DANEX	NOZZLE	in.	48
annular throat diamter fraction of DMOTOR	FANMOT	NOZZLE	-	0.8
Plug cluster base density (lb/in^3)	RHOPLB	LIQMAT	$lb/in.^3$	0.06
Plug cluster base thickness (in.)	TPLGBS	LIQUID	in.	0.5

```
   CENTAUR D  VERIFICATION   2/14/84
 $INFOPT
    INDES=1,
    IOPF=0,
    DELMIN=.07,
    DEL=5.,
   ITLIM=500, TLIMIT=900.,
  IPLOT=0,
    IPRINT=0,2,2,2,1,
C
C
C
   IOPT=92,42,
    IERRMD=0,
    IOBJF=13,
    OBJSCL=1.,
$END
$NLP
$END
$INFGEN
   NSTGES=1,
   KSTAGE=2,2,2,
C  >>>>>>> SEE NOTE 1
   WMISC=1692.,
   F=400.,
   DMOTCP=4*120.,
   ELDOME=1.38,
C  >>>>>>> SEE NOTE 2
   EPS=57.,
   EPSATT=6.,
   WMISFL=131.,
   WMISOX=0.,
$END
$INTSTG
$END
$NOZZLE
$END
$MATER
$END
$FILMNT
$END
$PROPEL
$END
$INTRAJ
$END
$GUIDA
$END
$AEROD
$END
$THVST
$END
$ORF
$END
$LIGUID
   FVAC=15000.,
C  >>>>>>> SEE NOTE 3
   WTLPRP=29750.,
C  >>>>>>> SEE NOTE 4
   FASKTL=1.,
   FFSKTL=0.04,
   GMBANG=16.,
   KGPOWR=1,
   NGIMB=2,
C  >>>>>>> SEE NOTE 5
   FCHGFL=.168,
   FCHGOX=.114,
   CPLINF=.02,
   CPLINO=.02,
   CPVLVO=.367,
   CPVLVF=.437,
```

Figure 3.3. ELES Input for Centaur D1-T Verification (Sheet 1 of 3)

```
$END
$LFLAG
C >>>>>>> SEE NOTE 6
  KHXOPT=1,
  KWTMOD=1,
C >>>>>>> SEE NOTE 7
   KGASOX=1,
   KGASFL=1,
  IPROP=5,
C >>>>>>> SEE NOTE 8
  KCYCLE=3,
  KOOLTC=2,
  KOOLNZ=2,
  KACGFL=6,
  KACGOX=6,
  LNFULL=1,
$END
$LTANK
  ULLFFL=.02,
  ULLFOX=.02,
$END
$TNKGEO
C >>>>>>> SEE NOTE 9
  NPRB=2,
  MNCGF=1,
  MNCGA=1,
   KXFTFH=-1,
   KXFTAH=-1,
   KXATFH=-1,
   KXATAH=1,
   KDOME=1,
   KFRPA=0,
   KLINEA=0,
$END
$BLADER
$END
$COLDGG
C >>>>>>> SEE NOTE 10
  PICG=3500.,
  FPULCG=1.1,
$END
$SOLDGG
$END
$PUMP
  TULLFL=100.,
  TULLOX=250.,
   PBPRF=1.01,
   PBPRO=1.01,
C >>>>>>> SEE NOTE 11
  SSSFL=5800.,
  SSSOX=5800.,
  SSSBPF=15000.,
  SSSBPO=20000.,
C >>>>>>> SEE NOTE 12
  BPFRFL=.008,
C >>>>>>> SEE NOTE 13
  TURBPR=1.4,
C >>>>>>> SEE NOTE 15
  JBPFL=1,
  JBPOX=1,
C >>>>>>> SEE NOTE 14
  FLNPSP=4.,
  OXNPSP=8.,
  ISTART=3,
  KPUMP=2,
C >>>>>>> SEE NOTE 16
  GAMGPB=1.46,
  CPGGPB=3.25,
  WMGGPB=2.0,
  JCONFIG=1,
```

Figure 3.3. ELES Input for Centaur D1-T Verification (Sheet 2 of 3)

```
$END
$INJECT
C >>>>>>> SEE NOTE 17
  ELDENS=2.61,
  OXOPEL=1.,
  FLOFEL=1.,
  IELDEN=1,
$END
$LIGENG
C >>>>>>> SEE NOTE 18
  XLN=5.,
  XLC=7.6,
  CR=4.0,
  KEXNOZ=1,
  RATMLR=1.1868,
   NTC=2,
$END
$INREGN
C >>>>>>> SEE NOTE 19
  BYPREG=0.313,
  GWMING=0.01275,
  TGWNOM=2050.,
  WALLK=.000215,
   HOWMAX=4.62,
  BYPTUR=0.0,
  IFREGN=1,
  IRPRNT=1,
  WTHR=.065,
  WLTHR=.025,
  DIFTBF=1.0,
  SAMULT=1.641,
$END
$ABLATE
$END
$LIGMAT
C >>>>>>> SEE NOTE 20
  MATFT=12,
  SIGCHM=9.0E6,
  SIGCLS=6.0E5,
  RHOINJ=.28,
  RHOVLV=.28,
  MATSTR=11,
  MTNKFL=14,
  MTNKOX=14,
$END
$CXWMLT
C >>>>>>> SEE NOTE 21
  CXWCHM=1.5,
$END
$LPROP
$END
$LQFERF
C >>>>>>> SEE NOTE 22
  RMFFL=1.0,
  RMFOX=1.0,
  OFCORE=5.0,
$END
$THROT
$END
$LFUEL
$END
$LOXID
$END
$NCTINP
$END
$TANKHX
C >>>>>>> SEE NOTE 23
  TMLIF=0.018,
  TMLIO=0.018,
  TSOFIF=.50,
   TSOFIO=.50,
  TEXLOU=550.,
  HLDTIM=300.,
  FLTTIM=300.,
$END
```

Figure 3.3. ELES Input for Centaur D1-T Verification (Sheet 3 of 3)

TABLE 3.1

CENTAUR D1-T VERIFICATION INPUT NOTES

1. Miscellaneous weight (WMISC) based on the table of Centaur weights shown in Table II, the miscellaneous weight input (WMISC) was determined. It includes ACS, electrical, guidance, instrumentation, and separation hardware.

2. Attach area ratio (EPSATT) is set equal to 6 in order to indicate the beginning of the tube construction of the regen cooled nozzle.

3. The burned propellant (WTLPRP) does not include residuals, boiloff, or auxiliary propellant. (Auxiliary propellant is included in WMISFL & WMISOX).

4. Skirt lengths are determined by FASKTL & FFSKTL. FFSKTL of 0.04 indicates a small skirt to which payload can be attached. FASKTL of 1.0 indicates that the aluminum interstage spans the entire engine bay.

5. The injector pressure drops were found in the literature to be 68.6 and 46.7 psi for the fuel and oxidizer circuits respectively. Using the injector face pressure of 408.2 psia from the pressure and temperature schedule calculated by ELES, the values of FCHGFL and FCHGOX are calculated. The values of CPLINO, CPLINF, CPVLVO and CPVLVF were estimated from pump and boost pump pressure schedules.

6. Tank heat transfer was chosen to simulate ground hold conditions at nominal conditions.

7. Tank pressurization is primarily autogenous when operating at steady state however there is a helium system on-board for making up any pressurization deficit. Cold gas pressurization was therefore chosen by setting KGASOX = 1, KGASFL = 1.

TABLE 3.1 (cont.)

CENTAUR D1-T VERIFICATION INPUT NOTES

8. Expander power cycle is chosen by setting KCYCLE = 3. In order to be consistent with that cycle and a fuel regen cooled LOX/LH_2 engine, the following variables must also be set; IPROP = 5, KOOLTC = 2, KOOLNZ = 2, IFREGN = 1.

9. The geometry of the Centaur is specified by the geometry flags in namelist TNKGEO.

10. The storage pressure of the helium bottle is set to 3300 psia by the variable PICG. The blowdown pressure of the bottle is set to 10% higher than the downstream pressure requirement using FPLUCG = 1.1.

11. The suction specific speeds were input in order to limit the RPM of each pump to their actual valves. Using the equation

$$NPSH = (N\ Q^{1/2}/S_s)^{4/3}$$

It can be seen that RPM and suction specific speed are linearly proportionate for a given flowrate and net positive suction head.

12. The boost pump head rise is calculated as a fraction of the total head rise required. The default value for that fraction is 0.0464. In order to fit the actual data of the Centaur, the fuel head rise fraction was set to .008 using the variable BFPRFL. (The oxidizer value of BPFROX was left at the default).

13. Although the turbine pressure ratio (TURBPR) is calculated in ELES, a starting vaue of 1.4 is used to aid in quicker convergence to the final value.

TABLE 3.1 (cont.)

CENTAUR D1-T VERIFICATION INPUT NOTES

14. The net positive suction pressure to the most upstream pumps (in this case the boost pumps) is specified by FLNPSP and OXNPSP.

15. The pump design selection flags used for Centaur are JBPFL and JBPOX which identify boost pump use, ISTART which specifies number of engine restarts, KPUMP which indicates each engine as having its own TPA, and JCNFIG which calls for gearbox driven pumps.

16. The gas properties of the turbine drive fluid must be specified. The inputs GAMGPB, CPGGPB, and WMGGPB indicate the ratio of specific heats, constant pressure heat capacity, and molecular weight respectively.

17. The description of the injector includes the number of injector elements. For the general case it is better to specify an element density which is selected with the flag IELDEN. The default value of the element density (IELDEN) is 3.1 elements/in.^{2}. For Centaur the value is 216 elements/82.9 in.^{2} = 2.61 elements/in.^{2}.

18. The combustion chamber geometry is input in namelist LIQENG. The inputs are all straight-forward except RATMLR which is calculated with the formula

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

$$= 1.1868 \text{ for the RL-10}$$

TABLE 3.1 (cont.)

CENTAUR D1-T VERIFICATION INPUT NOTES

19. Characteristics of the regen cooling jacket are specified in namelist INREGN. The RL-10 chamber is made from Type 347 stainless steel tubes with wall thicknesses of 0.01275 inches. The walls are forced to that thickness by setting GWMING = 0.01275 and the material strength SIGCHM to a very big number.

The wall operating temperature and thermal conductivity are set with the inputs TGWNOM and WALLK. DIFTBF of 1.0 tells ELES to make the combustion gas barrier temperature equal to the core temperature.

All of the fuel coolant does not pass through the regen jacket in order to allow for some control of the TPA. The fraction of total fuel flow which bypasses the regen jacket (BYPREG) is equal to 0.313. Of the flow which does pass through the regen jacket, it all passes through the turbine; BYPTUR is therefore 0.0.

The flags IFREGN and IRPRNT tell ELES to cool using fuel and to output a summary of the cooling jacket.

The geometry of the milled cooling slots are modified to simulate the tube construction of the RL-10. The throat geometry is specified by WTHR and WLTHR. The channel width (WTHR) is set equal to the tube diameter and the land width (WLTHR) is set equal to twice the tube wall thickness. The surface area available for heat transfer is multiplied by 1.641 (SAMULT) in order to simulate tubes. The maximum channel height to width ratio (HOWMAX) is set to 4.62 in order to empirically arrive at the approximate regen pressure drop displayed by the RL-10.

TABLE 3.1 (cont.)

CENTAUR D1-T VERIFICATION INPUT NOTES

20. Materials of construction are identified in namelist $LIQMAT. The engine is made from type 347 stainless steel. The material strengths which are input for the chamber (SIGCHM and SIGCLS) are not the actual values for 347SS, however, because the stress calculations correspond to a milled slot design (not the actual tube design) in which thermal stresses are often controlling. Values for SIGCHM and SIGCLS have been input which result in the known tube thicknesses. The densities of the valve and injector (RHOINJ and RHOVLV) have been input to correspond with stainless steel.

    The propellant tanks are made from 301 CRES having wall thicknesses of 0.014 inches. Because 301 CRES is material number 14 in the materials library and has a minimum gauge of .014, the material MTNKFL and MTNKOX are set to 14. The interstage is made of aluminum and MATSTR is therefore set to 11.

21. Because we have forced the chamber to look like a tube bundle we must multiply it by some factor to tie it together structurally. Based on engineering judgment, a value of 1.5 was chosen.

22. The shear coax elements of the RL-10 have a droplet size correction factor of 1.0 as reflected in the values of RMFFL and RMFOX. The engine operates at a mixture ratio of 5.0 (OFCORE = 5.0).

23. The insulation used on the Centaur propellant tankk is both MLI and combined fiberglass-MLI. That condition is simulated with 0.5 inches of SOFI and 0.018 inches of MLI on both tanks. The heat transfer scenario was selected as a constant boundary temperature (TEXBOU) of 550°R. The times available for heat transfer before and during flight (HLDTIM and FLTTIM) were selected as 300 seconds each.

WARNING

THE FOLLOWING WARNINGS OCCUR FOR STAGE 1

```
TEMPERATURES USED FOR VAPORIZATION WERE          518.0      164.7
MOST RECENT CORRECTED VALUES      521.2      164.7
```

MINIMUM GAUGE DESIGNS AFT TANK WALL THICKNESS

MINIMUM GAUGE DESIGNS FORWARD TANK WALL THICKNESS

AFT TANK ULLAGE INCREASED BY GEOMETRY CONSTRAINT

Figure 3.4. ELES Warning Page

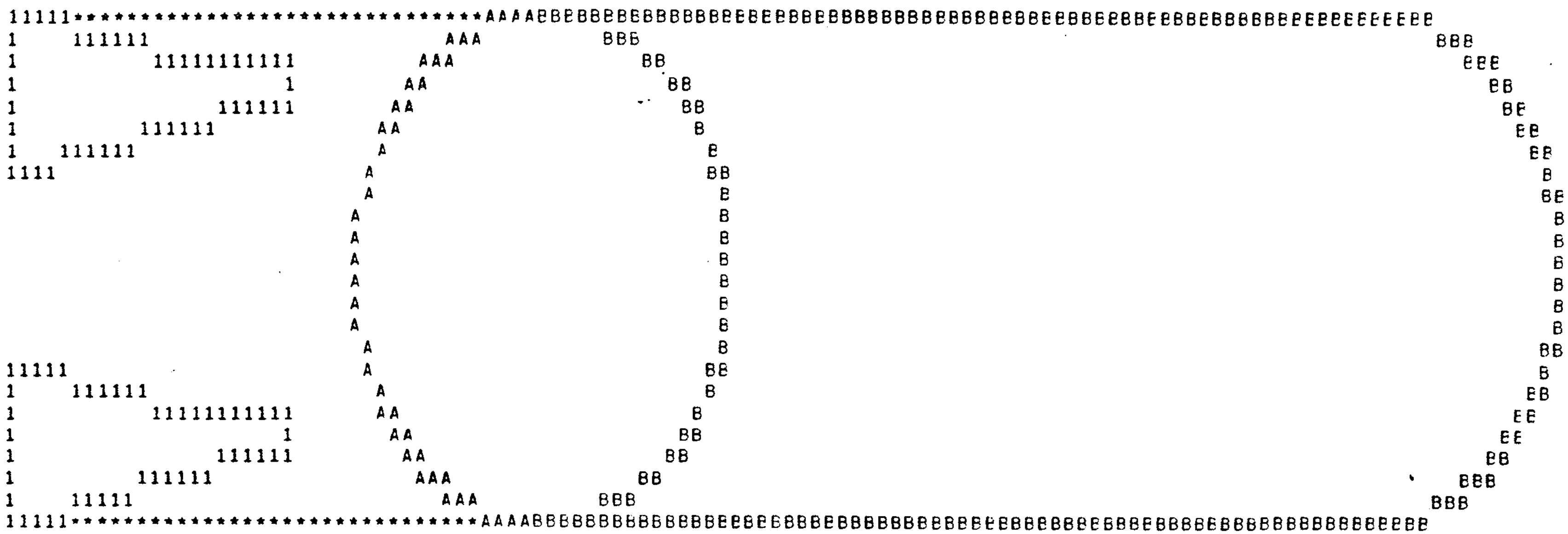


Figure 3.5. ELES Graphical Output

TANKAGE SUMMARY FOR STAGE #1
EXPANDER CYCLE (FUEL SIDE)
AFT TANK CONTAINS OXIDIZER FORWARD TANK CONTAINS FUEL
FUEL TANK IS PRESSURIZED AUTOGENOUSLY
OXIDIZER TANK IS PRESSURIZED AUTOGENOUSLY
TANK MATERIALS (OX - CRES 301) (FUEL - CRES 301)

... DIMENSIONS (INCHES) ...

STAGE DIAMETER	120.0
TOTAL STAGE LENGTH	357.3
TOTAL TANK LENGTH	279.5
NOZZLE LENGTH	48.4
CHAMBER LENGTH	12.6
INJECTOR FACE FORWARD LENGTH	14.8
MOUNT LENGTH	2.0
TANK HEAD ELLIPSE RATIO	1.38
PRESSURE TANK ELLIPSE RATIO	1.00
AFT TANK HEAD HEIGHT	43.3
FORWARD TANK HEAD HEIGHT	43.3
PRESSURE TANK HEAD HEIGHT	0.0
PRESSURE TANK DIAMETER	0.0
AFT TANK CYLINDRICAL LENGTH	0.0
FORWARD TANK CYLINDRICAL LENGTH	190.9
PRESSURE TANK CYLINDRICAL LNGTH	0.0
AFT LINE DIAMETER	1.64
FORWARD LINE DIAMETER	1.66
AFT SKIRT LENGTH	121.06
FORWARD SKIRT LENGTH	1.73
STRUCTURAL WALL THICKNESS	0.057
AFT TANK WALL THICKNESS	0.014
FORWARD TANK WALL THICKNESS	0.014
PRESSURE TANK WALL THICKNESS	0.000
AFT TANK DOME THICKNESS	0.014
FORWARD TANK DOME THICKNESS	0.014
PRESSURE TANK DOME THICKNESS	0.000
FUEL TANK MLI THICKNESS	0.02
FUEL TANK SOFI THICKNESS	0.50
OXIDIZER TANK MLI THICKNESS	0.02
OXIDIZER TANK SOFI THICKNESS	0.50
PRESSURE TANK INSULATION THICK	0.00
FUEL TNK HEAT FLUX(BTU/HR IN**2)	0.75
OX TANK HEAT FLUX(BTU/HR IN**2)	0.64
FUEL BOILOFF RATE (LB/SEC)	0.036
OX BOILOFF RATE (LB/SEC)	0.070

... WEIGHTS (POUNDS) ...

AFT TANK	42.6
FORWARD TANK	554.2
PRESSURE TANK	0.0
TANK CONSTRUCTION WEIGHT	417.8
STRUCTURAL WALL	4.3
AFT SKIRT	139.8
FORWARD SKIRT	12.9
TANK MOUNT	0.0
PRESSURE TANK INSULATION	0.0
FUEL TANK INSULATION	184.0
OXIDIZER TANK INSULATION	87.6
REVERSE HEAD STIFFENER	0.0
FUEL ACQUISITION SYSTEM	10.7
OXIDIZER ACQUISITION SYSTEM	8.6
PRESSURANT CONTROL HARDWARE	8.2
TANK LINES	9.1
BURNED FUEL	4958.3
BURNED OXIDIZER	24791.7
FUEL RESIDUAL	5.0
OXIDIZER RESIDUAL	36.3
FUEL AUTOGENOUS PRESSURANT	69.0
OXIDIZER AUTOGENOUS PRESSURANT	203.2
HOLD TIME FUEL BOILOFF	11.5
HOLD TIME OX BOILOFF	21.0
FLIGHT FUEL BOILOFF	11.5
FLIGHT OXIDIZER BOILOFF	21.0
MISC EXPENDED FUEL	131.0
MISC EXPENDED OXIDIZER	0.0
MISCELLANEOUS WEIGHT	1692.0
INTERSTAGE WEIGHT	0.0

... INPUT MINIMUM SAFETY FACTORS ...

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

Figure 3.6. ELES Tankage Summary

The propellant summary page (Figure 3.7) gives some of the more important propellant properties over the operating range of the stage.

The engine size, weight, and performance summary (Figure 3.8) addresses many of the detailed engine design parameters. Size information includes chamber length and diameter, throat dimensions, and nozzle contour. A detailed engine weight breakdown is included. The engine performance is specified by individual loss mechanisms which are applied to the ideal one dimensional equilibrium as well as overall and stream tube operating points.

The regenerative cooling summary (Figure 3.9) describes the heat transfer characteristics of the combustion chamber. Each station is a location along the regen cooled portion of the chamber and can be identified by the area ratio column. Regen flow is counter-current such that station No. 1 is at the nozzle exit of the regen cooled chamber.

The pressure and temperature schedules (Figure 3.10) shows 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 in this table showing flowrates through the major components of the feed system.

The TPA system (Figure 3.11) gives detailed descriptions of the pumps and turbines involved in the engine design under consideration. Speeds, dimensions, efficiencies, and flowrates are given.

The overall stage weight summary (Figure 3.12) is a list of all items in the stage which contribute to its weight. Inert weights are presented separately from propellant or pressurant weights.

```
PROPELLANT SUMMARY FOR STAGE #1
     PROPELLANT COMBINATION IS LO2/LH2

                         NOMINAL PROPELLANT BULK DENSITY(LB/IN**3)=    0.0397

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

    NOMINAL TANK PRESSURE(PSIA)           20.8              NOMINAL TANK PRESSURE(PSIA)            25.0

    NOMINAL PROPELLANT TEMP(DEGR)        160.0              NOMINAL PROPELLANT TEMP(DEGR)          40.0
    NOMINAL DENSITY(LB/IN**3)              0.0471           NOMINAL DENSITY(LB/IN**3)               0.0025
    NOMINAL VAPOR PRESSURE(PSIA)          12.8              NOMINAL VAPOR PRESSURE(PSIA)           25.0

    MAX PROPELLANT TEMP(DEGR)            160.0              MAX PROPELLANT TEMP(DEGR)              40.0
    MAX TEMP DENSITY(LB/IN**3)             0.0471           MAX TEMP DENSITY(LB/IN**3)              0.0025
    MAX TEMP VAPOR PRESSURE(PSIA)         12.8              MAX TEMP VAPOR PRESSURE(PSIA)          25.0

    MIN PROPELLANT TEMP(DEGR)            160.0              MIN PROPELLANT TEMP(DEGR)              40.0
    MIN TEMP DENSITY(LB/IN**3)             0.0471           MIN TEMP DENSITY(LB/IN**3)              0.0025
    MIN TEMP VAPOR PRESSURE(PSIA)         12.8              MIN TEMP VAPOR PRESSURE(PSIA)          25.0
```

Figure 3.7. ELES Propellant Summary

```
ENGINE SIZE,WEIGHT,& PERFORMANCE SUMMARY FOR STAGE #1
     EXPANDER CYCLE (FUEL SIDE)
     CHAMBER IS REGEN COOLED   (MILLED SLOT CONSTRUCTION)
     NOZZLE IS REGEN COOLED   (TUBE CONSTRUCTION)
     PROPELLANT COMBINATION IS LO2/LH2
```

... ENGINE DIMENSIONS (INCHES) ...		... PERFORMANCE ...	
THROAT DIAMETER	5.04		
CHAMBER DIAMETER	10.09	DELIVERED ISP(VAC),SEC	444.6
NOZZLE EXIT DIAMETER	38.09	IDEAL ISP(ODE),SEC	459.5
NOZZLE EXTENSION ATTACH DIAM	12.36		
CONVERGENT CHAMBER LENGTH	5.00	DELIVERED CSTAR,FT/SEC	7626.
CYLINDRICAL CHAMBER LENGTH	7.60	IDEAL CSTAR,FT/SEC	7758.
CHAMBER STRUCTURAL THICKNESS	0.012		
GAS SIDE WALL THICKNESS	0.013	CHAMBER PRESSURE,PSIA	400.
NOZZLE EXTENSION THICKNESS	0.010	THRUST PER ENGINE(VAC),LBF	15000.
		TOTAL VAC THRUST,LBF	30000.
NOZZLE EXIT AREA RATIO	57.0	BURN TIME,SEC	440.9
CHAMBER CONTRACTION RATIO	4.0		
NOZ EXTENSION ATTCH AREA RATIO	6.0	OVERALL EFFICIENCY	0.968
NOZZLE LENGTH/(MIN RAO LENGTH)	1.187		
NOZZLE LENGTH	48.39	ENERGY RELEASE EFFICIENCY	0.983
CHAMBER LENGTH	12.60	NOZZLE EFFICIENCY	0.985
INJECTOR FACE FORWARD LENGTH	14.78		
MOUNT LENGTH	2.00	KINETIC EFFICIENCY	0.996
		VAPORIZATION EFFICIENCY	0.999
		MIXING EFFICIENCY	0.986
... ENGINE WEIGHTS (POUNDS) ...		MR DISTRIBUTION EFFICIENCY	0.998
NOZZLE EXTENSION	66.5	BOUNDARY LAYER EFFICIENCY	1.000
CHAMBER	16.8	DIVERGENCE EFFICIENCY	0.988
BIPROPELLANT VALVE	8.2	TWO PHASE EFFICIENCY	1.000
INJECTOR	38.3		
TCA SUPPORT HARDWARE	8.9	FOR 2 ENGINES	
TCA CONSTRUCTION	6.5	OXIDIZER FLOWRATE,LB/SEC	56.23
------------------------------		FUEL FLOWRATE,LB/SEC	11.25
SINGLE THRUST CHAMBER ASSY	145.0	TOTAL FLOWRATE,LB/SEC	67.47
THRUST MOUNT	33.4	CORE MIXTURE RATIO	5.00
GIMBAL SYSTEM	31.5	CORE TEMPERATURE,DEG R	5801.
ENGINE BAY LINES	7.9	BARRIER MIXTURE RATIO	5.00
		BARRIER TEMPERATURE,DEG R	5801.
TOTAL NUMBER OF ENGINES	2	ENGINE MIXTURE RATIO	5.00
TOTAL ENGINE	290.0	FUEL FILM COOLING FRACTION	0.00
TOTAL THRUST MOUNT	66.8		
TOTAL GIMBAL SYSTEM	63.0	INJ ELEMENT DENSITY,ELEM/IN**2	2.70
TOTAL ENGINE BAY LINES	15.8	OX ORIFICE DIAMETER (IN)	0.075
		FUEL ORIFICE DIAMETER (IN)	0.143

Figure 3.8. ELES Engine Size/Weight/Performance Summary

THE FOLLOWING IS THE REGENERATIVE COOLING SUMMARY FOR STAGE #1

THE ENGINE IS A FUEL COOLED
CONVENTIONAL CHAMBER AND INTERNAL EXPANSION NOZZLE

STATIONS 1 THROUGH 6 ARE BOUNDS TO THE 5 6.609 INCH LONG NOZZLE SECTIONS
STATIONS 6 THROUGH 11 ARE BOUNDS TO THE 5 1.120 INCH LONG CONVERGENT CHAMBER SECTIONS
STATIONS 11 THROUGH 16 ARE BOUNDS TO THE 5 1.520 INCH LONG CYLINDRICAL CHAMBER SECTIONS

GAS WALL THICKNESS = 0.013
GAS WALL THERMAL CONDUCTIVITY =.00021500 (BTU/IN SEC DEGR)
GAS WALL MAXIMUM OPERATING TEMPERATURE= 2050. (DEG R)

STATION	P	TB	W	H	V	Q	TCW	TGW	HG	HC	E	TGAS
1	.775E+03	.761E+02	.652E+00	.301E+01	.720E+01	.638E-01	.944E+02	.582E+02	.372E-04	.349E-02	.570E+02	.181E+04
2	.775E+03	.822E+02	.534E+00	.247E+01	.123E+02	.108E+00	.100E+03	.107E+03	.562E-04	.591E-02	.389E+02	.203E+04
3	.775E+03	.938E+02	.417E+00	.193E+01	.258E+02	.207E+00	.113E+03	.125E+03	.928E-04	.108E-01	.243E+02	.235E+04
4	.775E+03	.117E+03	.300E+00	.138E+01	.670E+02	.482E+00	.140E+03	.169E+03	.177E-03	.210E-01	.131E+02	.289E+04
5	.775E+03	.173E+03	.182E+00	.842E+00	.282E+03	.168E+01	.202E+03	.302E+03	.443E-03	.562E-01	.534E+01	.410E+04
6	.642E+03	.394E+03	.650E-01	.300E+00	.669E+04	.121E+02	.411E+03	.113E+04	.260E-02	.727E+00	.100E+01	.580E+04
7	.635E+03	.413E+03	.829E-01	.383E+00	.436E+04	.532E+01	.435E+03	.987E+03	.194E-02	.442E+00	.144E+01	.580E+04
8	.632E+03	.431E+03	.101E+00	.466E+00	.308E+04	.725E+01	.455E+03	.885E+03	.147E-02	.300E+00	.196E+01	.580E+04
9	.631E+03	.448E+03	.119E+00	.549E+00	.231E+04	.579E+01	.474E+03	.817E+03	.116E-02	.219E+00	.256E+01	.580E+04
10	.631E+03	.463E+03	.137E+00	.631E+00	.181E+04	.473E+01	.491E+03	.772E+03	.941E-03	.168E+00	.324E+01	.580E+04
11	.630E+03	.477E+03	.155E+00	.714E+00	.146E+04	.394E+01	.507E+03	.740E+03	.779E-03	.133E+00	.400E+01	.580E+04
12	.630E+03	.498E+03	.155E+00	.714E+00	.152E+04	.393E+01	.526E+03	.759E+03	.779E-03	.137E+00	.400E+01	.580E+04
13	.630E+03	.518E+03	.155E+00	.714E+00	.158E+04	.391E+01	.546E+03	.778E+03	.779E-03	.140E+00	.400E+01	.580E+04
14	.629E+03	.538E+03	.155E+00	.714E+00	.164E+04	.390E+01	.566E+03	.797E+03	.779E-03	.143E+00	.400E+01	.580E+04
15	.629E+03	.559E+03	.155E+00	.714E+00	.171E+04	.388E+01	.585E+03	.816E+03	.779E-03	.147E+00	.400E+01	.580E+04
16	.628E+03	.579E+03	.155E+00	.714E+00	.177E+04	.387E+01	.605E+03	.834E+03	.779E-03	.150E+00	.400E+01	.580E+04

DELTA T= 503.1
DELTA P= -147.0

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

Figure 3.9. ELES Regenerative Cooling Summary

PRESSURE AND TEMPERATURE SCHEDULES [illegible]AGE #1
EXPANDER CYCLE (FUEL SIDE)

	PRESSURE (PSIA) FUEL	PRESSURE (PSIA) (COMBINED)	PRESSURE (PSIA) OXIDIZER	TEMPERATURE (DEG R) FUEL	TEMPERATURE (DEG R) (COMBINED)	TEMPERATURE (DEG R) OXIDIZER	
... PRESSURANT ...							
VENT	31.9		22.9	41.8		170.2	(SATURATION TEMP OF PROPELLANT)
ULLAGE	29.0		20.8	100.0		250.0	
... PROPELLANT ...							
TANK PROPELLANT	29.0		20.8	40.0		160.0	
BOOST PUMP OUTLET	44.4		54.5	40.5		160.3	
MAIN PUMP INLET	36.3		46.3	40.5		160.3	
MAIN VALVE INLET	953.6		604.6	63.6		164.7	
MAIN VALVE OUTLET	775.2		454.8	63.6		164.7	
REGEN JACKET OUTLET	628.2		----	566.7		----	
INJECTOR INLET	476.8		454.8	521.2		164.7	
INJECTOR FACE		408.2					
COMBUSTION CHAMBER		400.0			5801.3		
TURBINE INLET		622.0			566.7		
TURBINE OUTLET		476.8			521.2		

... COMPONENT PRESSURE/TEMPERATURE CHANGES ...

	PRESSURE FUEL	PRESSURE (COMBINED)	PRESSURE OXIDIZER	TEMPERATURE FUEL	TEMPERATURE (COMBINED)	TEMPERATURE OXIDIZER
ACQUISITION DEVICE	0.0		0.0			
BOOST PUMP	15.4		33.7	0.5		0.3
FEED LINE	8.2		8.2	0.0		0.0
MAIN PUMP	909.2		550.1	23.1		4.4
MAIN VALVE	178.4		149.8	0.0		0.0
REGEN JACKET	147.0		----	503.1		----
INJECTOR	68.6		46.5	0.0		0.0
TURBINE		145.2			45.5	

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

	FUEL	(COMBINED)	OXIDIZER
TANK OUTFLOW	11.401		56.686
MAIN PUMP	5.701		28.343
MAIN VALVE	5.701		28.113
REGEN JACKET INFLOW	3.941		----
REGEN JACKET BYPASS	1.760		----
REGEN OUTLET TO INJECTOR	0.000		----
TURBINE		3.941	
TURBINE TO INJECTOR	3.863		0.000
AUTOGENOUS PRESSURANT	0.078		0.230
INJECTOR	5.623		28.113

Figure 3.10. ELES Pressure/Temperature/Flowrate Summary

* * * TPA SUMMARY FOR STAGE #1 * * *
EXPANDER CYCLE (FUEL SIDE)
GEARBOX DRIVEN PUMPS

... FUEL PUMP ...

PUMP SPEED (RPM)	25103.
ROOT STRESS SPEED LIMIT(RPM)	74021.
SPECIFIC SPEED	740.
SUCTION SPECIFIC SPEED	5800.
NUMBER OF PUMP STAGES	4.
NET POS SUCTION PRESSURE(PSIA)	11.3
PUMP OUTLET PRESSURE(PSIA)	953.6
VOLUMETRIC FLOWRATE(GPM)	591.13
MASS FLOWRATE(LBM/SEC)	5.70
PUMP HORSEPOWER(HP)	481.53
PUMP EFFICIENCY	0.656
PUMP DIAMETER(IN)	6.1

... FUEL BOOST PUMP ...

PUMP SPEED(RPM)	35816.
SPECIFIC SPEED	13001.
SUCTION SPECIFIC SPEED	15000.
NET POS SUCTION PRESSURE(PSIA)	4.0
OUTLET PRESSURE(PSIA)	44.4
PUMP HORSEPOWER(HP)	5.11
PUMP EFFICIENCY	0.545
PUMP DIAMETER(IN)	1.9

... TURBINE ...

ADMISSION FRACTION	0.790
EFFICIENCY	0.687
PRESSURE RATIO	1.299
MASS FLOWRATE(LB/SEC)	3.94
DIAMETER(IN)	7.0
NUMBER OF TURBINE STAGES	2.
BLADE ROOT STRESS(PSI)	49215.
SPECIFIC SPEED	33.
TURBINE SPEED(RPM)	25103.

... TPA ...

TPA START SYSTEM WT.	6.7
GAS GENERATOR/PREBURNER WT.	0.0
IGNITION SYSTEM WT.	12.4
HOT GAS MANIFOLD WT.	0.0
TPA WT.	80.6

... OXIDIZER PUMP ...

PUMP SPEED (RPM)	10604.
ROOT STRESS SPEED LIMIT(RPM)	74021.
SPECIFIC SPEED	1261.
SUCTION SPECIFIC SPEED	5800.
NUMBER OF PUMP STAGES	2.
NET POS SUCTION PRESSURE(PSIA)	33.5
PUMP OUTLET PRESSURE(PSIA)	604.6
VOLUMETRIC FLOWRATE(GPM)	155.11
MASS FLOWRATE(LBM/SEC)	28.34
PUMP HORSEPOWER(HP)	71.92
PUMP EFFICIENCY	0.702
PUMP DIAMETER(IN)	3.8

... OXIDIZER BOOST PUMP ...

PUMP SPEED(RPM)	11714.
SPECIFIC SPEED	7714.
SUCTION SPECIFIC SPEED	20000.
NET POS SUCTION PRESSURE(PSIA)	8.0
OUTLET PRESSURE(PSIA)	54.5
PUMP HORSEPOWER(HP)	3.92
PUMP EFFICIENCY	0.657
PUMP DIAMETER(IN)	1.9

Figure 3.11. ELES Turbopump Assembly Summary

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

AFT TANK	42.6
FORWARD TANK	554.2
PRESSURE TANK	0.0
TANK CONSTRUCTION WEIGHT	417.8
TANK LINES	9.1
AFT SKIRT	139.8
FORWARD SKIRT	12.9
TANK MOUNT	0.0
STRUCTURAL WALL	4.3
PRESSURE TANK INSULATION	0.0
FUEL TANK INSULATION	184.0
OXIDIZER TANK INSULATION	87.6
FUEL ACQUISITION SYSTEM	10.7
OXIDIZER ACQUISITION SYSTEM	8.6
PRESSURANT CONTROL HARDWARE	8.2
2 THRUST CHAMBER ASSY(S)	290.0
2 THRUST MOUNT(S)	66.8
2 GIMBAL SYSTEM(S)	63.0
2 ENGINE BAY LINE(S)	15.8
2 IGNITION SYSTEM(S)	24.8
2 HOT GAS MANIFOLD(S)	0.0
2 TPA ASSY(S)	161.2
2 TPA START SYSTEM(S)	13.3
2 GAS GENERATOR/PREBURNER(S)	0.0
2 AUTOGENOUS HEAT EXCHANGER(S)	112.8
FLIGHT FUEL BOILOFF	11.5
FLIGHT OXIDIZER BOILOFF	21.0
EXPENDABLE WEIGHT	0.0
MISCELLANEOUS WEIGHT	1692.0
TOTAL INERT WEIGHT	3951.9
INTERSTAGE WEIGHT	0.0
BURNED FUEL	4958.3
BURNED OXIDIZER	24791.7
FUEL RESIDUAL	5.0
OXIDIZER RESIDUAL	36.3
FUEL AUTOGENOUS PRESSURANT	69.0
OXIDIZER AUTOGENOUS PRESSURANT	203.2
MISC ON-BOARD FUEL	131.0
MISC ON-BOARD OXIDIZER	0.0
GROSS IGNITION WEIGHT	34146.3
GROSS BURNOUT WEIGHT	4363.9
HOLD TIME FUEL BOILOFF	11.5
HOLD TIME OX BOILOFF	21.0

Figure 3.12. ELES Overall Stage Weight Summary

The final page of output is the vehicle summary (Figure 3.13) which gives an overview of all vehicle stages. The stage mass, mass fraction, dimensions and performance are overviewed.

Table 3.2 is a weight breakdown of the actual components in Centaur D1-T. Table 3.3 is used to compare ELES output results with actual Centaur data. The agreement between actual and predicted is shown.

CENTAUR D VERIFICATION 2/14/84

**** VEHICLE SUMMARY ****

	STAGE #1
..WEIGHT,LB..	
PAYLOAD	0.0
STAGE WEIGHT	34146.3
USABLE PROPELLANT	29750.0
FIXED INERT	
PROPULSION SYSTEM	3951.9
INTERSTAGE	0.0
EXPENDED INERT	
EXPELLED	32.4
JETTISONED	0.0
GROSS IGNITION WEIGHT	34146.3
GROSS BURNOUT WEIGHT	4363.9
PROPELLANT MASS FRACTION	0.871
..DIMENSIONS,IN..	
STAGE DIAMETER	120.00
NOZZLE EXIT DIAMETER	38.09
NUMBER OF NOZZLES	2
STAGE LENGTH	357.32
..PERFORMANCE..	
PROPELLANT	LO2/LH2
THRUST,VACUUM DELIVERED,LBF	30000.0
PC,PSIA	400.0
USABLE PROPELLANT MR	5.00
NOZZLE AREA RATIO	57.00
BURN TIME,SEC	440.94
ISP,VACUUM DELIVERED,SEC	444.6
ISP EFFICIENCY	0.968
PROPELLANT FLOW RATE,LB/SEC	67.47

Figure 3.13. ELES Vehicle Summary

TABLE 3.2

CENTAUR D1-T WEIGHT SUMMARY

Modeled Subcomponents	WT
Basic Structure	818
Secondary Structure	274
Main Engine System	605
Fuel System	181
Ox System	115
Propellant Load System	17
Hydraulic System	99
Pressurization System	247
Total	2356
WMISC	1692
Centaur Dry Weight	4048
Residual Propellant	169
Gaseous Propellant	254
Auxiliary Propellant	131
Centaur Weight/Residuals	4602

Unmodeled Components	WT
Stub Adaptor	252
Equipment Module	247
ACS	6
Ullage Motors	39
Propellant Utilization	47
Auxiliary Propellant System	147
Guidance System	170
Autopilot System	146
Electrical System	143
Range Safety System	53
Tracking System	11
TLM System	283
Adapter Payload	74
Separation System	54
Helium	8
Ice	12
WMISC	1692

TABLE 3.3

CENTAUR D1-T VERIFICATION SUMMARY

	Actual	Calc	Actual/Calc
Turbine Pressure Ratio	1.337	1.299	1.029
Regen Jacket ΔT	418	503	0.83
Ox Pump Outlet Pressure	597	604	0.99
Fuel Pump Outlet Pressure	990	954	1.04
Engine System	605	634.9	1.05
TPA Weight	76.1	80.6	0.94
Stage Dry Weight	4048	3952	1.02
Stage Burnout Weight	4602	4364	1.05
Stage Length	360	357.3	1.01
Engine Performance	444	444.6	1.00