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GROUND SUPPORT EQUIPMENT TECHNOLOGY
LIGHTWEIGHT LAUNCHERS FOR SHOULDER-FIRED ROCKETS

FY71 ANNUAL REPORT

by

Wayne L. McCowan

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30 July 1971

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9 FY71 ANNUAL REPORT for FY 71,

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10 Wayne L. McCowan

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Directorate for Research, Development, Engineering
and Missile Systems Laboratory
US Army Missile Command
Redstone Arsenal, Alabama 35809

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ABSTRACT

The purpose of this report is to present and describe methods which may be used to define rocket exhaust flow fields, launch tube internal pressure profiles, recoil forces, and effects on missile launch due to launcher-missile interactions.

To this end, computer programs have been written which will calculate relevant data for input into other programs giving plots of the stagnation pressure and temperature profiles in a given rocket exhaust field. A program has been written which will give a plot of internal tube pressure at the rocket nozzle exit plane as a function of missile travel. A method for estimating recoil is explained and a program has been developed which simulates the launcher in the pitch plane for use in determining the launcher and missile motions in this plane and the effects on the missile of thrust misalignment and center of gravity offsets.

FOREWORD

Acknowledgement is made to Mr. Dean Christensen for his major contributions in writing the subject computer programs and to Mr. Billy Campbell for his contributions in the same vein.

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Section I. INTRODUCTION

The object of this task is to provide parameters and information relevant to the reduction in weight of shoulder fired rocket launchers to a minimum value consistent with the maintenance of required system performance.

The scope of this effort encompasses the following: (1) Preparation of computer programs to define the stagnation pressure and temperature profiles in the exhaust field of a rocket, (2) Develop a method for predicting the internal pressure in a launch tube during launch, (3) Discussion of means for estimating recoil forces, and (4) Establish a computer simulation program for predicting launcher effects on aiming and launching of the missile.

Section II. EXHAUST FLOW FIELD DEFINITION

2.1 Introduction

The overall purpose of the rocket exhaust flow field program is to provide, given all necessary data for a rocket, a visual representation of the stagnation pressure and stagnation temperature profiles in the rocket exhaust. Several programs are provided which calculate input data needed by the temperature and pressure programs.

The equations and methods upon which these programs are based are to be found in the references listed in the reference section. Each program will be shown listed on programming forms with input data shown in the appropriate registers and output values blocked in with dashed lines. A description will be given with each program giving its purpose, inputs, outputs and equations.

The machine for which these programs are written is the Hewlett-Packard 9100B with associated Plotter and Extended Memory units.

2.2 Symbol Definitions

a	- Region I Boundary Coefficient
b	- Region I Boundary Coefficient
c	- Region I Boundary Coefficient
D _e	- Nozzle Exit Diameter (inches)
D _t	- Nozzle Throat Diameter (inches)
I _r	- Intercept of Linear Spreading Characteristic Curve.
I _t	- Intercept of Axial Temperature Decay Curve
K	- Ratio of specific heats of exhaust products
l _s	- Length of Supersonic Cone in Exhaust Flow (inches)
M _b	- Maximum Mach Number at End of Region I
M _e	- Exit Mach Number
m _p	- Slope of Axial Pressure Decay Curve
m _t	- Slope of Axial Temperature Decay Curve
P _c	- Nominal Design Chamber Pressure (PSIA)
q	- Value of Isobar to be Plotted
q _e	- Gage Stagnation Pressure at Nozzle Exit (PSIG)
q _{ms}	- Gage stagnation pressure on axis at end of supersonic cone (PSIG)
q _{ms max}	- Maximum value of pressure parameter for plot (PSIG)
r ₁	- Exhaust Plume Radius at End of Region I
SF _x	- Plot Scale Factor for X-Axis
SF _y	- Plot Scale Factor for Y - Axis
T	- Value of isotherm to be plotted (°F)
T _a	- Ambient Temperature (°F)
T _c	- Flame Temperature of Propellant (°F)

- $T_{\max}$ - Maximum value of temperature parameter for plot ($^{\circ}\text{F}$)
- $X_{\max}$ - Maximum value of distance parameter for plot
- ΔX - Plot increment distance
- θ_e - Nozzle expansion half angle (radians)

2.3 Exit Mach Number and Intercept of the Linear Spreading Characteristic Curve

2.3.1 Purpose

To calculate the Mach Number of the Exhaust Flow at the nozzle exit plane, and to determine the value of the linear spreading characteristic curve intercept. This last parameter is necessary in the generation of the Exhaust Pressure Plume Plot.

2.3.2 Inputs

D_e , D_t , K

2.3.3 Outputs

M_e , I_r

2.3.4 Equations

$$\frac{A_t}{A_e} = \frac{D_t^2}{D_e^2} = M_e \left[\frac{K+1}{2 + (K-1) M_e^2} \right]^{\frac{K+1}{2(K-1)}}$$

This equation is solved iteratively for M_e .

$$I_r = 0.15489201 M_e^3 - 2.2941041 M_e^2 + 10.612059 M_e - 4.0070141 \quad (\text{Ref 3})$$

2.3.5 Description

After program is entered the values of K , D_t , D_e are entered in the Z, Y, X registers respectively. Press Continue and the value for M_e will be displayed in the X, Y, Z registers. Press Continue twice and the value for I_r will be displayed in the X, Y, Z registers.

23.6 CALCULATION OF M_e AND I_r

PAGE 1 OF 2

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
00	CLEAR	20				30	CONT	47				60	e	12			
1	1	01				1	e	12				1	↑	27			
2	STOP	41	D _e	D _e	K	2	↑	27				2	↑	27			
3	ROLL ↑	22				3	.	21				3	STOP	41	M _e	M _e	M _e
4	x → ()	23				4	0	00				4	GO TO	44			
5	d	17				5	0	00				5	-	34			
6	2	02				6	5	05				6	0	00			
7	4	04				7	-	34				7	0	00			
8	÷	35				8	y → ()	40				8	e	12			
9	ROLL ↑	22				9	e	12				9	↑	27			
a	x ↔ y	30				a	GO TO	44				a	.	21			
b	÷	35				b	SUB	77				b	1	01			
c	↓	25				c	7	07				c	+	33			
d	ROLL ↓	31				d	8	10				d	y → ()	40			
10	X	36				40	CONT	47				70	e	12			
1	π	56				1	0	00				1	GO TO	44			
2	x	36				2	CONT	47				2	SUB	77			
3	↓	25				3	IF x < y	52				3	7	07			
4	ROLL ↓	31				4	3	03				4	8	10			
5	x	36				5	0	00				5	GO TO	44			
6	π	56				6	CONT	47				6	2	02			
7	x	36				7	e	12				7	9	11			
8	↓	25				8	↑	27				8	e	12			
9	x ↔ y	30				9	.	21				9	↑	27			
a	÷	35				a	0	00				a	x	36			
b	y → ()	40				b	0	00				b	d	17			
c	C	16				c	1	01				c	↑	27			
d	CONT	47				d	+	33				d	1	01			
20	3	03				50	CONT	47				Storage					
1	x → ()	23				1	y → ()	40				f					
2	e	12				2	e	12				e	M _e				
3	CONT	47				3	GO TO	44				d	K				
4	GO TO	44				4	SUB	77				c	E = A _t / A _e				
5	SUB	77				5	7	07				b					
6	7	07				6	8	10				a					
7	8	10				7	CONT	47				9					
8	CONT	47				8	0	00				8					
9	0	00				9	CONT	47				7					
a	CONT	47				a	IF x > y	53				6					
b	IF x > y	53				b	4	04				5					
c	6	06				c	6	06				4					
d	8	10				d	CONT	47				3					
												2					
												1					
												0					

CALCULATION OF M_e AND I_r

PAGE 2 OF 2

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
80	-	34				00	CONT	47				30	x	36			
1	↓	25				1	STOP	41	M_e	M_e	M_e	1	↓	25			
2	X	36				2	$x \rightarrow ()$	23				2	+	33			
3	2	02				3	a	13				3	4	04			
4	+	33				4	X	36				4	.	21			
5	d	17				5	x	36				5	0	00			
6	↑	27				6	.	21				6	0	00			
7	1	01				7	1	01				7	7	07			
8	+	33				8	5	05				8	0	00			
9	↓	25				9	4	04				9	1	01			
a	$x \leftrightarrow y$	30				a	8	10				a	4	04			
b	÷	35				b	9	11				b	1	01			
c	d	17				c	2	02				c	-	34			
d	↑	27				d	0	00				d	↓	25			
90	1	01				10	1	01				40	↑	27			
1	-	34				1	X	36				1	↑	27			
2	2	02				2	a	13				2	STOP	41	I_r	I_r	I_r
3	X	36				3	↑	27				3	END	46			
4	$y \rightarrow ()$	40				4	X	36				4					
5	f	15				5	2	02				5					
6	d	17				6	.	21				6					
7	$x \leftrightarrow y$	30				7	2	02				7					
8	1	01				8	9	11				8					
9	+	33				9	4	04				9					
a	f	15				a	1	01				a					
b	÷	35				b	0	00				b					
c	↓	25				c	4	04				c					
d	$x \leftrightarrow y$	30				d	1	01				d					
a.0	$\ln x$	65				20	X	36				Storage					
1	X	36				1	↓	25				F					
2	↓	25				2	-	34				E					
3	e^x	74				3	a	13				d					
4	↑	27				4	↑	27				c					
5	e	12				5	1	01				b					
6	X	36				6	0	00				a					
7	C	16				7	.	21				9					
8	$x \leftrightarrow y$	30				8	6	06				8					
9	-	34				9	1	01				7					
a	RETURN	77				a	2	02				6					
b	CONT	47				b	0	00				5					
c	CONT	47				c	5	05				4					
d	CONT	47				d	9	11				3					
												2					
												1					
												0					

2.4 Axial Temperature Decay Curve (with Plot)

2.4.1 Purpose

To generate values for the slope and intercept of the Axial Temperature Decay Curve.

2.4.2 Inputs

M_e , D_e , T_c , X_{max} , T_{max}

The values for X_{max} and T_{max} should be for a 6 in. by 9 in. plot.

2.4.3 Outputs

M_t , I_t

Plot of stagnation temperature on axis vs distance downstream on the axis.

2.4.4 Equations

$$-m_t = .020042599M_e^3 - .24382049M_e^2 + 1.0618553M_e + .11169953 \text{ (Ref 3).}$$

$$I_t = 6.36 M_e - 2.874 \text{ (Ref 3).}$$

2.4.5 Description

After program has been entered, the values of M_e , D_e , T_c are entered in the Z, Y, X registers respectively. Press Continue and the value for M_t will be displayed in the Y register, value of I_t in the X register. Press Continue, then enter values for T_{max} and X_{max} in Y and X registers respectively for a 6 in. by 9 in. Plot. Press Continue for Plot.

2.4.6 AXIAL TEMPERATURE DECAY CURVE

PAGE 1 OF 3

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
00	CLEAR	20				30	8	10				60	7	07			
1	FMT	42				1	2	02				1	4	04			
2	↑	27				2	0	00				2	-	34			
3	1	01				3	4	04				3	2	02			
4	STOP	41	T _c	D _e	M _e	4	9	11				4	ROLL ↓	31			
5	x → ()	23				5	x	36				5	STOP	41	I _T	m ₁	
6	b	14				6	↓	25				6	x → ()	23			
7	1	01				7	-	34				7	+	33			
8	2	02				8	d	17				8	9	11			
9	÷	35				9	↑	27				9	y → ()	40			
a	y → ()	40				a	1	01				a	a	13			
b	c	16				b	.	21				b	x ↔ y	30			
c	↓	25				c	0	00				c	c	16			
d	y → ()	40				d	6	06				d	x	36			
10	d	17				40	1	01				70	y → ()	40			
1	GO TO	44				1	8	10				1	e	12			
2	SUB	77				2	5	05				2	1	01			
3	-	34				3	5	05				3	5	05			
4	0	00				4	3	03				4	x	36			
5	0	00				5	x	36				5	y → ()	40			
6	d	17				6	↓	25				6	d	17			
7	↑	27				7	+	33				7	b	14			
8	x	36				8	.	21				8	x ↔ y	30			
9	x	36				9	1	01				9	↑	27			
a	.	21				a	1	01				a	3	03			
b	0	00				b	1	01				b	ROLL ↓	31			
c	2	02				c	6	06				c	STOP	41			
d	c	00				d	9	11				d	↑	27			
20	0	00				50	9	11				Storage					
1	4	04				1	5	05				F	AX				
2	2	02				2	3	03				E	X _i (FEET)				
3	5	05				3	+	33				d	M _e , X _{max} (FEET)				
4	9	11				4	d	17				c	D _e (FEET)				
5	9	11				5	↑	27				b	T _c (°F)				
6	x	36				6	6	06				a	M _T				
7	d	17				7	.	21				9	I _T				
8	↑	27				8	3	03				8					
9	x	36				9	6	06				7					
a	.	21				a	x	36				6					
b	2	02				b	2	02				5					
c	4	04				c	.	21				4					
d	3	03				d	8	10				3					
												2					
												1					
												0					

AXIAL TEMPERATURE DECAY CURVE

PAGE 2 OF 3

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
80	4	04				20	3	03				50	÷	35			
1	5	05				1	0	00				1	↓	25			
2	0	00				2	0	00				2	ln x	65			
3	0	00				3	0	00				3	↑	27			
4	x ↔ y	30				4	FMT	42				4	a	13			
5	÷	35				5	↓	25				5	x	36			
6	y → ()	40				6	4	04				6	↓	25			
7	-	34				7	5	05				7	e ^x	74			
8	d	17				8	0	00				8	↑	27			
9	Go To	44				9	0	00				9	b	14			
a	-	34				a	FMT	42				a	x	36			
b	3	03				b	↓	25				b	x ← ()	67			
c	2	02				c	0	00				c	-	34			
d	CONT	47				d	FMT	42				d	c	16			
00	CONT	47				30	↑	27				60	x	36			
1	1	01				1	RETURN	77				1	e	12			
2	5	05				2	↓	25				2	↑	27			
3	0	00				3	3	03				3	x ← ()	67			
4	0	00				4	0	00				4	-	34			
5	↑	27				5	0	00				5	d	17			
6	0	00				6	0	00				6	x	36			
7	FMT	42				7	x ↔ y	30				7	↓	25			
8	↓	25				8	÷	35				8	FMT	42			
9	3	03				9	y → ()	40				9	↓	25			
a	0	00				a	-	34				a	RCL	61			
b	0	00				b	c	16				b	+	33			
c	0	00				c	e	12				c	y → ()	40			
d	↑	27				d	↑	27				d	e	12			
10	0	00				40	.	21				Storage					
1	FMT	42				1	1	01				F					
2	↓	25				2	x	36				E					
3	0	00				3	y → ()	40				D					
4	↑	27				4	f	15				C					
5	0	00				5	CONT	47				b					
6	FMT	42				6	e	12				a					
7	↓	25				7	↑	27				9					
8	1	01				8	c	16				8					
9	5	05				9	÷	35				7					
a	0	00				a	x ← ()	67				6					
b	0	00				b	+	33				5					
c	FMT	42				c	9	11				4					
d	↓	25				d	x ↔ y	30				3					

AXIAL TEMPERATURE DECAY CURVE

PAGE 3 OF 3

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
0	d	17				0					0						
1	If x > y	53				1					1						
2	-	34				2					2						
3	4	04				3					3						
4	5	05				4					4						
5	CLEAR	20				5					5						
6	FMT	42				6					6						
7	↑	27				7					7						
8	END	46				8					8						
9						9					9						
a						a					a						
b						b					b						
c						c					c						
d						d					d						
0						0					0						
1						1					1						
2						2					2						
3						3					3						
4						4					4						
5						5					5						
6						6					6						
7						7					7						
8						8					8						
9						9					9						
a						a					a						
b						b					b						
c						c					c						
d						d					d						
0						0					Storage						
1						1					F						
2						2					E						
3						3					D						
4						4					C						
5						5					B						
6						6					A						
7						7					9						
8						8					8						
9						9					7						
a						a					6						
b						b					5						
c						c					4						
d						d					3						
											2						
											1						
											0						

2.5 Axial Pressure Decay Curve (with Plot)

2.5.1 Purpose

To generate values for the slope of the Axial Pressure Decay Curve and the length of the supersonic cone in the exhaust flow.

2.5.2 Inputs

M_e , D_e , P_c , K , $X_{\max}$, $q_{ms_{\max}}$

The dimensions of D_e should be in feet.

Values of $X_{\max}$ and $q_{ms_{\max}}$ should be for a 6 in. by 9 in. Plot.

2.5.3 Outputs

l_s , m_p , q_e , q_{ms}

2.5.4 Equations

$$l_s = 16.113M_e - 16.125 \quad (\text{Ref 3})$$

$$m_p = -.451667M_e - 1.375 \quad (\text{Ref 3})$$

$$q_{ms} = 14.7 \left[\left[\frac{K+1}{2} \right]^{\frac{K}{K-1}} - 1 \right] \quad (\text{Ref 3})$$

$$q_e = P_c \left\{ \left[\frac{\frac{K+1}{2} M_e^2}{1 + \frac{K-1}{2} M_e^2} \right]^{\frac{K}{K+1}} \left[\frac{2K}{K+1} M_e^2 - \frac{K-1}{K+1} \right]^{\frac{1}{1-K}} \right\} - 14.7 \quad (\text{Ref 3})$$

2.5.5 Description

After program is entered, the values of M_e , D_e , P_c are entered in the Z, Y, X registers respectively. Press Continue, the value for l_s in feet will be displayed in the Z register, l_s in inches in the Y register, m_p in the X register. Press Continue, enter value of K in X register, press Continue. The value for q_{ms} will be displayed in the Z register, $(q_m/q_e)s$ in the Y, q_e in the X. Press Continue, then enter $q_{ms_{\max}}$ in Y register, $X_{\max}$ in X register for a six inch by nine inch Plot. Press Continue for Plot.

2.5.6 AXIAL PRESSURE DECAY CURVE

PAGE 1 OF 3

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
00	CLEAR	20				30	X	36				60	3	03			
1	FMT	42				1	1	01				1	ROLL ↑	22			
2	↑	27				2	.	21				2	ln x	65			
3	1	01				3	3	03				3	ROLL ↑	22			
4	STOP	41	P _e	D _e	M _e	4	7	07				4	X	36			
5	X → ()	23				5	5	05				5	↓	25			
6	C	16				6	+	33				6	e ^x	74			
7	1	01				7	↓	25				7	↑	27			
8	2	02				8	CHG SIGN	32				8	1	01			
9	÷	35				9	X → ()	23				9	-	34			
a	y → ()	40				a	0	00				a	1	01			
b	d	17				b	CONT	47				b	4	04			
c	↓	25				c	1	01				c	.	21			
d	y → ()	40				d	2	02				d	7	07			
10	e	12				40	X	36				70	X	36			
1	1	01				1	X → ()	67				1	y → ()	40			
2	6	06				2	0	00				2	4	04			
3	.	21				3	STOP	41	m _p	l _e	l _m	3	X → ()	67			
4	1	01				4	0	00				4	2	02			
5	1	01				5	↑	27				5	↑	27			
6	3	03				6	↑	27				6	e	12			
7	X	36				7	2	02				7	X	36			
8	1	01				8	STOP	41	K			8	X	36			
9	6	06				9	X → ()	23				9	2	02			
a	.	21				a	1	01				a	+	33			
b	1	01				b	↑	27				b	X → ()	67			
c	2	02				c	↑	27				c	1	01			
d	5	05				d	1	01				d	↑	27			
20	-	34				50	+	33				Storage					
1	d	17				1	2	02				F	l _e				
2	X	36				2	÷	35				E	M _e				
3	y → ()	40				3	ROLL ↑	22				d	D _e (FEET)				
4	f	15				4	X ↔ y	30				c	P _e				
5	e	12				5	1	01				b					
6	↑	27				6	-	34				a					
7	.	21				7	X → ()	67				9					
8	4	04				8	1	01				8					
9	5	05				9	X ↔ y	30				7					
a	1	01				a	÷	35				6					
b	6	06				b	X → ()	23				5	U				
c	6	06				c	2	02				4	g _{ms}				
d	7	07				d	y → ()	40				3	K/K-1				
												2	K-1				
												1	K				
												0	m _p				

AXIAL PRESSURE DECAY CURVE

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Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
80	1	01				b0	↑	27				-20	↑	27			
1	+	33				1	x←()	67				1	0	00			
2	e	12				2	1	01				2	FMT	42			
3	x	36				3	↑	27				3	↓	25			
4	x	36				4	x←()	67				4	3	03			
5	↓	25				5	2	02				5	0	00			
6	x↔y	30				6	÷	35				6	0	00			
7	÷	35				7	x←()	67				7	0	00			
8	y←()	40				8	5	05				8	↑	27			
9	5	05				9	ln x	65				9	0	00			
a	x←()	67				a	GO TO	44				a	FMT	42			
b	1	01				b	-	34				b	↓	25			
c	↑	27				c	0	00				c	0	00			
d	↑	27				d	0	00				d	↑	27			
90	1	01				-0	x	36				-30	FMT	42			
1	+	33				1	↓	25				1	↓	25			
2	2	02				2	e ^x	74				2	1	01			
3	ROLL ↑	32				3	x↔y	30				3	5	05			
4	x	36				4	÷	35				4	0	00			
5	↓	25				5	c	16				5	0	00			
6	x↔y	30				6	x	36				6	FMT	42			
7	÷	35				7	1	01				7	↓	25			
8	e	12				8	4	04				8	3	03			
9	x	36				9	.	21				9	0	00			
a	x	36				a	7	07				a	0	00			
b	x←()	67				b	-	34				b	0	00			
c	2	02				c	x←()	67				c	FMT	42			
d	ROLL ↑	22				d	+	33				d	↓	25			
a0	÷	35				-10	4	04				Storage					
1	↓	25				1	x↔y	30				f					
2	-	34				2	↑	27				e					
3	1	01				3	↓	25				d					
4	↑	27				4	÷	35				c					
5	x←()	67				5	STOP	41	9 _e	($\frac{9}{2}$)	9 _{max}	b					
6	2	02				6	0	00				a					
7	÷	35				7	↑	27				9					
8	↓	25				8	FMT	42				8					
9	x↔y	30				9	↓	25				7					
a	ln x	65				a	1	01				6					
b	x	36				b	5	05				5					
c	↓	25				c	0	00				4					
d	e ^x	74				d	0	00				3					
												2					
												1					
												0					

AXIAL PRESSURE DECAY CURVE

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Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
40	4	04				70	0	00				00	+	33			
1	5	05				1	0	00				1	y→()	40			
2	0	00				2	0	00				2	e	12			
3	0	00				3	x↔y	30				3	↑	27			
4	FMT	42				4	÷	35				4	1	01			
5	↓	25				5	y→()	40				5	0	00			
6	0	00				6	+	33				6	0	00			
7	FMT	42				7	C	16				7	X	36			
8	↑	27				8	CONT	47				8	↓	25			
9	f	15				9	f	15				9	If x>y	53			
a	↑	27				a	↑	27				a	-	34			
b	y→()	40				b	1	01				b	7	07			
c	e	12				c	0	00				c	8	10			
d	.	21				d	x	36				d	CLEAR	20			
50	1	01				80	e	12				b0	FMT	42			
1	x	36				1	÷	35				1	↑	27			
2	y→()	40				2	↓	25				2	END	46			
3	f	15				3	ln x	65				3					
4	1	01				4	↑	27				4					
5	0	00				5	x←()	67				5					
6	0	00				6	+	33				6					
7	X	36				7	0	00				7					
8	x←()	67				8	x↔y	30				8					
9	+	33				9	y	55				9					
a	4	04				a	X	36				a					
b	↑	27				b	↓	25				b					
c	3	03				c	e ^x	74				c					
d	ROLL ↓	31				d	↑	27				d					
60	x↔y	30				90	x←()	67				Storage					
1	STOP	41				1	+	33				F	ΔX = 1.0				
2	↑	27				2	4	04				E	Xi = 2.				
3	4	04				3	X	36				d					
4	5	05				4	C	16				c					
5	0	00				5	X	36				b					
6	0	00				6	e	12				a					
7	x↔y	30				7	↑	27				3					
8	÷	35				8	d	17				8					
9	y→()	40				9	X	36				7					
a	+	33				a	↓	25				6					
b	d	17				b	FMT	42				5					
c	↓	25				c	↓	25				4					
d	3	03				d	RCL	61				3					
												2					
												1					
												0					

2.6 Boundary Coefficients (Region I)

2.6.1 Purpose

To generate coefficient values which determine the extent of the supersonic exhaust flow region (Region I).

2.6.2 Inputs

$M_e, D_e, D_t, P_c, K, \theta_e$

2.6.3 Outputs

a, b, c, M_b, r_1

2.6.4 Equations

$$a = \frac{r_1 - r_e \sec w}{1 - \sec w} \quad (\text{Ref 1})$$

$$b = \tan w (r_e - a) \quad (\text{Ref 1})$$

$$c = \left[(r_e - a)^2 + b^2 \right]^{\frac{1}{2}} \quad (\text{Ref 1})$$

$$M_b = \left\{ \frac{2}{K-1} \left[\left(\frac{P_c}{14.7} \right)^{\frac{K-1}{K}} - 1 \right] \right\}^{\frac{1}{2}} \quad (\text{Ref 1})$$

$$r_1 = \frac{1}{2} D_t \sqrt{\frac{1}{M_b}} \left\{ \frac{2}{K+1} \left[1 + \frac{M_b^2}{2} (K-1) \right] \right\}^{\frac{K+1}{4(K-1)}} \quad (\text{Ref 1})$$

2.6.5 Description

After program is entered, values for M_e, D_e, D_t are entered in Z, Y, X registers respectively. Press Continue, then enter P_c, K, θ_e in Z, Y, X registers respectively. Press Continue, and values for a, b, c will be displayed in the Z, Y, X registers respectively. Press Continue, values for M_b, r_1 will appear in Y, X registers respectively.

2.66 REGION I BOUNDARY COEFFICIENTS

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Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
00	CLEAR	20				30	↑	27				60	x←()	67			
1	FMT	42				1	1	01				1	2	02			
2	↑	27				2	-	34				2	↑	27			
3	1	01				3	2	02				3	x←()	67			
4	STOP	41	D _e	D _e	M _e	4	x	36				4	1	01			
5	x←()	23				5	b	14				5	÷	35			
6	f	15				6	↑	27				6	4	04			
7	y←()	40				7	1	01				7	÷	35			
8	d	17				8	-	34				8	↓	25			
9	↓	25				9	y←()	40				9	x	36			
a	↓	25				a	1	01				a	↓	25			
b	x	36				b	↓	25				b	e ^x	74			
c	1	01				c	÷	35				c	↑	27			
d	-	34				d	↓	25				d	1	01			
10	y←()	40				40	√x	76				70	↑	27			
1	e	12				1	x←()	23				1	x←()	67			
2	CONT	47				2	+	33				2	0	00			
3	2	02				3	0	00				3	÷	35			
4	STOP	41	Θ _e	K	P _e	4	x←()	67				4	↓	25			
5	x←()	23				5	1	01				5	√x	76			
6	c	16				6	↑	27				6	x	36			
7	y←()	40				7	x←()	67				7	f	15			
8	b	14				8	0	00				8	x	36			
9	↓	25				9	x	36				9	2	02			
a	1	01				a	x	36				a	÷	35			
b	4	04				b	2	02				b	y←()	40			
c	.	21				c	÷	35				c	b	14			
d	7	07				d	1	01				d	x←()	67			
20	÷	35				50	+	33				Storage					
1	↓	25				1	2	02				f	D _e , a, w, c				
2	ln x	65				2	x	36				E	h, a				
3	↑	27				3	b	14				d	D _e , (P ₀ /2) - a				
4	b	14				4	↑	27				c	Θ _e (ans), f, w, b				
5	↑	27				5	1	01				b	K, r				
6	1	01				6	+	33				a					
7	-	34				7	y←()	40				9					
8	b	14				8	2	02				8					
9	÷	35				9	↓	25				7					
a	↓	25				a	÷	35				6					
b	x	36				b	↓	25				5					
c	↓	25				c	ln x	65				4					
d	e ^x	74				d	↑	27				3					
												2	K+1				
												1	K-1, a ₀				
												0	M _L				

REGION I BOUNDARY COEFFICIENTS

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Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
80	1	01				00	÷	35				30	↓	25			
1	↑	27				1	ROLL ↑	22				1	x ↔ y	30			
2	x ← ()	67				2	√x'	76				2	-	34			
3	2	02				3	ARC	72				3	y → ()	40			
4	÷	35				4	TAN X	71				4	d	17			
5	↓	25				5	ROLL ↑	22				5	C	16			
6	√x'	76				6	+	33				6	TAN X	71			
7	x → ()	23				7	C	16				7	X	36			
8	f	15				8	√x'	76				8	y → ()	40			
9	C	16				9	ARC	72				9	C	16			
a	x → ()	23				a	TAN X	71				a	d	17			
b	1	01				b	-	34				b	↑	27			
c	x → ()	67				c	x → ()	67				c	X	36			
d	0	00				d	+	33				d	C	16			
90	↑	27				-10	1	01				-40	↑	27			
1	X	36				1	+	33				1	X	36			
2	1	01				2	y → ()	40				2	↓	25			
3	-	34				3	C	16				3	+	33			
4	y → ()	40				4	↓	25				4	↓	25			
5	C	16				5	cos x	73				5	√x'	76			
6	f	15				6	↑	27				6	x → ()	23			
7	X	36				7	b	14				7	f	15			
8	X	36				8	X	36				8	↑	27			
9	ROLL ↓	31				9	d	17				9	e	12			
a	√x'	76				a	↑	27				a	↑	27			
b	ARC	72				b	2	02				b	C	16			
c	TAN X	71				c	÷	35				c	ROLL ↑	22			
d	ROLL ↓	31				d	↓	25				d	STOP 41		c	b	a
a0	f	15				-20	-	34				Storage					
1	X	36				1	C	16				f					
2	e	12				2	cos x	73				e					
3	X	36				3	↑	27				d					
4	ROLL ↓	31				4	1	01				c					
5	√x'	76				5	-	34				b					
6	ARC	72				6	↓	25				a					
7	TAN X	71				7	÷	35				9					
8	-	34				8	y → ()	40				8					
9	f	15				9	e	12				7					
a	GO TO	44				a	d	17				6					
b	-	34				b	↑	27				5					
c	0	00				c	2	02				4					
d	0	00				d	÷	35				3					
												2					
												1					
												0					

REGION I BOUNDARY COEFFICIENTS

PAGE 3 OF 3

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
0	X ← ()	67				0						0					
1	+	33				1						1					
2	0	00				2						2					
3	↑	27				3						3					
4	↑	27				4						4					
5	b	14				5						5					
6	STOP	41	r	M _b	M _b	6						6					
7	END	46				7						7					
8						8						8					
9						9						9					
a						a						a					
b						b						b					
c						c						c					
d						d						d					
0						0						0					
1						1						1					
2						2						2					
3						3						3					
4						4						4					
5						5						5					
6						6						6					
7						7						7					
8						8						8					
9						9						9					
a						a						a					
b						b						b					
c						c						c					
d						d						d					
0						0						0					
1						1						1					
2						2						2					
3						3						3					
4						4						4					
5						5						5					
6						6						6					
7						7						7					
8						8						8					
9						9						9					
a						a						a					
b						b						b					
c						c						c					
d						d						d					
Storage																	
												f					
												e					
												d					
												c					
												b					
												a					
												9					
												8					
												7					
												6					
												5					
												4					
												3					
												2					
												1					
												0					

2.7 Nozzle Placement

2.7.1 Purpose

To generate a representation of a nozzle as a visual aid when plotting pressure fields in the exhaust.

2.7.2 Inputs

θ_e , D_e , D_t , SF_x , SF_y
 θ_e should be in degrees.

2.7.3 Outputs

Plot of nozzle

2.7.4 Description

After program is entered, enter θ_e , D_e , D_t , in Z, Y, X registers. Press Continue, enter SF_y , SF_x in Y, X registers. Press Continue to generate plot of nozzle.

27.5 NOZZLE PLACEMENT

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Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
00	CLEAR	20				30	↓	25				60	6	06			
1	FMT	42				1	f	15				1	5	05			
2	↑	27				2	ROLL ↑	22				2	0	00			
3	1	01				3	FMT	42				3	FMT	42			
4	STOP	41	D _e	D _e	θ _e	4	↓	25				4	↓	25			
5	x → ()	23				5	FMT	42				5	1	01			
6	f	15				6	↑	27				6	5	05			
7	2	02				7	x ↔ y	30				7	0	00			
8	÷	35				8	CHG SIGN	32				8	0	00			
9	y → ()	40				9	x ↔ y	30				9	FMT	42			
a	e	12				a	FMT	42				a	↓	25			
b	f	15				b	↓	25				b	0	00			
c	x ↔ y	30				c	ROLL ↑	22				c	↑	27			
d	2	02				d	CHG SIGN	32				d	FMT	42			
10	÷	35				40	x ↔ y	30				70	↑	27			
1	y → ()	40				1	FMT	42				1	END	46			
2	f	15				2	↓	25				2					
3	e	12				3	FMT	42				3					
4	x ↔ y	30				4	↑	27				4					
5	-	34				5	0	00				5					
6	↓	25				6	↑	27				6					
7	x ↔ y	30				7	FMT	42				7					
8	TAN X	71				8	↓	25				8					
9	÷	35				9	5	05				9					
a	2	02				a	0	00				a					
b	CONT	47				b	0	00				b					
c	STOP	41	SF _x	SF _y		c	FMT	42				c					
d	ROLL ↑	22				d	↓	25				d					
20	CHG SIGN	32				50	FMT	42				Storage					
1	x	36				1	↑	27				F	D _e , R _e , R _e				
2	f	15				2	5	05				E	R _e , R _e				
3	ROLL ↑	22				3	5	05				d					
4	x	36				4	0	00				c					
5	y → ()	40				5	FMT	42				a					
6	f	15				6	↓	25				9					
7	x ↔ y	30				7	6	06				8					
8	e	12				8	0	00				7					
9	x	36				9	0	00				6					
a	y → ()	40				a	FMT	42				5					
b	e	12				b	↓	25				4					
c	0	00				c	FMT	42				3					
d	FMT	42				d	↑	27				2					
												1					
												0					

2.8 Boundary Plot (Region I)

2.8.1 Purpose

To generate a plot showing the extent of Region I in the rocket exhaust flow field.

2.8.2 Inputs

a, b, c, Δx , SF_x , SF_y

A good value for Δx is $\frac{b}{50}$.

2.8.3 Outputs

Plot showing the exhaust plume boundary in the supersonic region (Region I).

2.8.4 Equations

$$c^2 = (r-a)^2 + (x-b)^2 \quad (\text{Ref 1})$$

2.8.5 Description

After program is entered, values for a, b, c are entered in the Z, Y, X registers. Press Continue, then enter Δx , SF_y , SF_x in the Z, Y, X registers. Press Continue and a plot of the Region I Boundary will be generated.

2.8.6 REGION I BOUNDARY PLOT

PAGE 1 OF 1

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
0	CLEAR	20				3	IF $x > y$	53				6	C	16			
1	FMT	42				1	I	01				1	↑	27			
2	↑	27				2	8	10				2	x	36			
3	I	01				3	CONT	47				3	b	14			
4	STOP	41	c	b	a	4	O	00				4	↑	27			
5	$x \rightarrow ()$	23				5	↑	27				5	x	36			
6	C	16				6	FMT	42				6	↓	25			
7	$y \rightarrow ()$	40				7	↑	27				7	-	34			
8	b	14				8	$x \rightarrow ()$	23				8	e	12			
9	↓	25				9	e	12				9	↑	27			
a	$y \rightarrow ()$	40				a	CONT	47				a	x	36			
b	a	13				b	GO TO	44				b	↓	25			
c	CLEAR	20				c	SUB	77				c	-	34			
d	2	02				d	6	06				d	2	02			
1	STOP	41	SF _x	SF _y	ΔX	4	O	00				7	↑	27			
1	$x \rightarrow ()$	23				1	↓	25				1	e	12			
2	9	11				2	CHG SIGN	32				2	x	36			
3	$y \rightarrow ()$	40				3	↑	27				3	b	14			
4	d	17				4	d	17				4	x	36			
5	↓	25				5	x	36				5	↓	25			
6	$y \rightarrow ()$	40				6	e	12				6	+	33			
7	f	15				7	↑	27				7	↓	25			
8	CONT	47				8	$x \rightarrow ()$	67				8	$\sqrt{x}$	76			
9	GO TO	44				9	9	11				9	↑	27			
a	SUB	77				a	x	36				a	a	13			
b	6	06				b	↓	25				b	+	33			
c	O	00				c	FMT	42				c	RETURN	77			
d	d	17				d	↓	25				d					
2	x	36				5	RCL	61				Storage					
1	e	12				1	+	33				F	ΔX				
2	↑	27				2	$y \rightarrow ()$	40				E	x _i				
3	$x \rightarrow ()$	67				3	e	12				D	SF _y				
4	9	11				4	b	14				C	C				
5	x	36				5	IF $x > y$	53				b	b				
6	↓	25				6	3	03				a	a				
7	FMT	42				7	a	13				9	SF _x				
8	↓	25				8	CLEAR	20				8					
9	RCL	61				9	FMT	42				7					
a	+	33				a	↑	27				6					
b	$y \rightarrow ()$	40				b	3	03				5					
c	e	12				c	STOP	41				4					
d	b	14				d	CONT	47				3					
												2					
												1					
												0					

2.9 Pressure Plume Plot (Region II)

2.9.1 Purpose

To generate the isobar plots in the mixing region (Region II).

2.9.2 Inputs

$I_r, b, D_e, l_s, r_1, \Delta x, SF_x, SF_y, |m_p|, q_{ms}, q_i$

2.9.3 Outputs

Isobar plots for Region II of the exhaust flow.

2.9.4 Equations

$$\Delta x = (l_s - b) \cdot 0.02 + 1 \cdot (10^{-6})$$

$$r = r_s + r_e \left[\frac{(x/D_e)}{I_r} \right]^{1.16} \left[\frac{1}{1.35} \ln \left(\frac{q_m}{q} \right) \right]^{\frac{1}{2}} \left[1 - e^{-0.2(x-b)} \right]$$

$$\text{where } q_m = \left(\frac{l_s}{x} \right)^{|m_p|} q_{ms}$$

$$r_s = r_1 + Nre \left[\frac{(b/D_e)}{I_r} \right]^{1.16} - Nre \left[\frac{(x/D_e)}{I_r} \right]^{1.16}$$

$$Nre = r_1 \left[\frac{1}{\left[\frac{(l_s/D_e)}{I_r} \right]^{1.16} - \left[\frac{(b/D_e)}{I_r} \right]^{1.16}} \right]$$

2.9.5 Description

After program is entered, enter I_r, b, D_e in Z, Y, X registers. Press Continue, enter $l_s, r_1, \Delta x$ in Z, Y, X registers. Press Continue, enter SF_y, SF_x in Y, X registers. Press Continue, enter $|m_p|, q_{ms}, q_i$ in Z, Y, X registers. Press Continue to generate plot of q_i . After each isobar is plotted, enter value for next q_i in X register and press Continue.

2.9.6 REGION II PRESSURE PLUME PLOT

PAGE 1 OF 3

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
00	CLEAR	20				310	1	01				60	f	15			
1	STOP	41	D _e	b	I _r	1	x←()	67				1	d	17			
2	x→()	23				2	0	00				2	↑	27			
3	a	13				3	x	36				3	e	12			
4	y→()	40				4	e	12				4	÷	35			
5	b	14				5	+	33				5	↓	25			
6	÷	35				6	y→()	40				6	ln x	65			
7	↓	25				7	2	02				7	↑	27			
8	y→()	40				8	STOP	41	SF _x	SF _y		8	x←()	67			
9	C	16				9	x→()	23				9	-	34			
a	x↔y	30				a	-	34				a	e	12			
b	GO TO	44				b	a	13				b	x	36			
c	SUB	77				c	y→()	40				c	↓	25			
d	-	34				d	-	34				d	e ^x	74			
10	5	05				40	b	14				70	↑	27			
1	2	02				1	STOP	41	g _i	g _{ms}	m _p	1	x←()	67			
2	x→()	23				2	x→()	23				2	-	34			
3	0	00				3	-	34				3	d	17			
4	STOP	41	Δx	r _i	g _i	4	C	16				4	x	36			
5	x→()	23				5	y→()	40				5	x←()	67			
6	f	15				6	-	34				6	-	34			
7	y→()	40				7	d	17				7	C	16			
8	e	12				8	↓	25				8	÷	35			
9	↓	25				9	y→()	40				9	↓	25			
a	y→()	40				a	-	34				a	ln x	65			
b	d	17				b	e	12				b	↑	27			
c	a	13				c	SET FLAG	54				c	1	01			
d	÷	35				d	b	14				d	.	21			
20	C	16				50	x→()	23				Storage					
1	GO TO	44				1	e	12				—					
2	SUB	77				2	e	12				F Δx			z		
3	-	34				3	↑	27				E r _i x:			m _p		
4	5	05				4	a	13				d g _i			g _{ms}		
5	2	02				5	÷	35				C I _r			g		
6	↑	27				6	C	16				b b			Y _{SE}		
7	x←()	67				7	GO TO	44				a D _e			X _{SE}		
8	0	00				8	SUB	77				9					
9	-	34				9	-	34				8					
a	e	12				a	5	05				7					
b	x↔y	30				b	2	02				6					
c	÷	35				c	x→()	23				5					
d	y→()	40				d	-	34				4					
												3	K				
												2	S				
												1	N, r _i				
												0	P				

REGION II PRESSURE PLUME PLOT

PAGE 2 OF 3

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
80	3	03				-110	X←()	67				-40	X←()	23			
1	5	05				1	+	33				1	-	34			
2	÷	35				2	2	02				2	C	16			
3	↓	25				3	X↔Y	30				3	GO TO	44			
4	√X	76				4	-	34				4	+	33			
5	↑	27				5	↓	25				5	4	04			
6	X←()	67				6	+	33				6	C	16			
7	-	34				7	X←()	67				7	RCL	61			
8	f	15				8	-	34				8	+	33			
9	X	36				9	b	14				9	Y←()	40			
a	a	13				a	X	36				a	e	12			
b	X	36				b	e	12				b	GO TO	44			
c	2	02				c	↑	27				c	+	33			
d	÷	35				d	X←()	67				d	5	05			
90	Y←()	40				-20	-	34				-50	2	02			
1	3	03				1	a	13				1	CONT	47			
2	GO TO	44				2	X	36				2	÷	35			
3	-	34				3	↓	25				3	↓	25			
4	G	06				4	FMT	42				4	ln X	65			
5	0	00				5	↓	25				5	↑	27			
6						6	d	17				6	1	01			
7						7	↑	27				7	.	21			
8						8	e	12				8	1	01			
9						9	IF X<Y	52				9	G	06			
a						a	-	34				a	X	36			
b						b	4	04				b	↓	25			
c						c	7	07				c	e ^x	74			
d						d	X←()	67				d	RETURN	77			
00	CONT	47				-30	-	34				Storage					
1	CONT	47				1	b	14				F					
2	X←()	67				2	CHG SIGN	32				E					
3	+	33				3	X←()	23				d					
4	3	03				4	-	34				c					
5	X	36				5	b	14				b					
6	X←()	67				6	FMT	42				a					
7	-	34				7	↑	27				9					
8	f	15				8	IF FLAG	43				8					
9	↑	27				9	GO TO	44				7					
a	X←()	67				a	+	33				6					
b	+	33				b	4	04				5					
c	1	01				c	d	17				4					
d	X	36				d	STOP	41	9:			3					
												2					
												1					
												0					

REGION II PRESSURE PLUME PLOT

PAGE 3 OF 3

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
60	e	12				0						0					
1	↑	27				1						1					
2	b	14				2						2					
3	-	34				3						3					
4	.	21				4						4					
5	2	02				5						5					
6	X	36				6						6					
7	↓	25				7						7					
8	CHG SIGN	32				8						8					
9	e ^x	74				9						9					
a	CHG SIGN	32				a						a					
b	↑	27				b						b					
c	1	01				c						c					
d	+	33				d						d					
70	GO TO	44				0						0					
1	-	34				1						1					
2	0	00				2						2					
3	2	02				3						3					
4						4						4					
5						5						5					
6						6						6					
7						7						7					
8						8						8					
9						9						9					
a						a						a					
b						b						b					
c						c						c					
d						d						d					
0						0						Storage					
1						1						f					
2						2						e					
3						3						d					
4						4						c					
5						5						b					
6						6						a					
7						7						9					
8						8						8					
9						9						7					
a						a						6					
b						b						5					
c						c						4					
d						d						3					
												2					
												1					
												0					

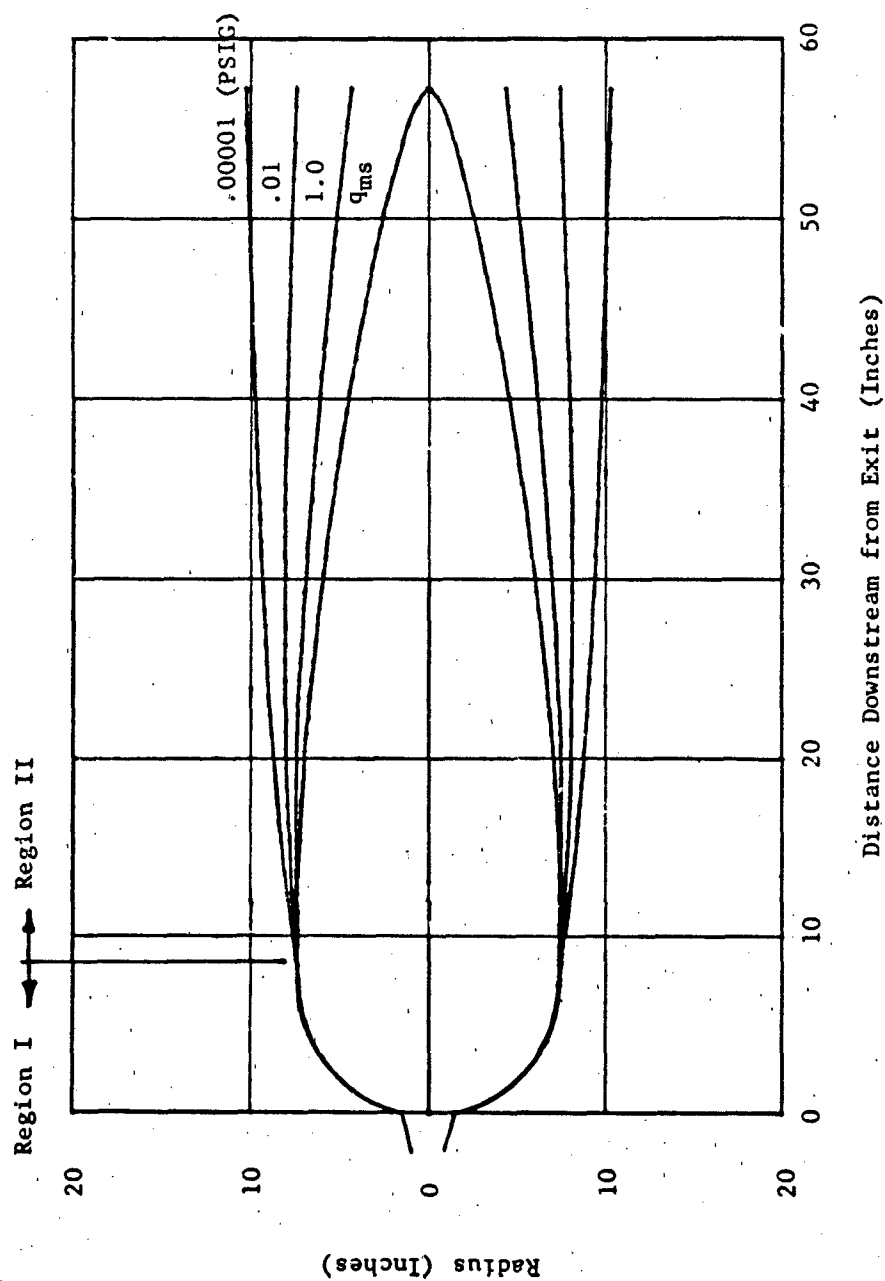


Figure 2-1. Nozzle Placement, Region I Pressure Plume and Region II Pressure Plume

2.10 Pressure Plume Plot (Region III)

2.10.1 Purpose

To generate a plot of isobars in the subsonic exhaust flow region (Region III).

2.10.2 Inputs

I_r , q_e , D_e , m_p , l_s , X_{max} , r_{max} , q , q_{ms}

Values of X_{max} and r_{max} should be for a five inch by fifteen inch plot.

2.10.3 Outputs

Isobar plots for downstream distances versus radial distances from center of nozzle exit.

2.10.4 Equations

$$r_o = r_e \left[\frac{(x/D_e)}{I_r} \right]^{1.16}$$

$$q_m = \left(\frac{l_s}{x} \right)^{|m_p|} q_{ms}$$

$$r = r_o \left[\frac{1}{1.35} \ln \left(\frac{q_m}{q} \right) \right]^{1/2}$$

2.10.5 Description

After program is entered, I_r , q_e , D_e are entered in Z, Y, X registers respectively. Press Continue, then enter m_p , l_s , q_{ms} in Z, Y, X registers respectively. Press Continue, then enter values of X_{max} and r_{max} for a five inch by fifteen inch plot. Press Continue, then enter in X register value of first isobar to be plotted. Press Continue for plot. Upon completion of plot, enter next isobar value and press Continue for plot.

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
00	CLEAR	20				310	0	00				60	STOP	41	9		
1	FMT	42				1	0	00				1	$x \rightarrow ()$	23			
2	$\uparrow$	27				2	CONT	47				2	-	34			
3	1	01				3	3	03				3	C	16			
4	STOP	41	D_e	q_e	I_e	4	$x \rightleftharpoons y$	30				4	$x \leftarrow ()$	67			
5	$y \rightarrow ()$	40				5	$\uparrow$	27				5	0	00			
6	a	13				6	e	12				6	$x \rightarrow ()$	23			
7	$x \rightleftharpoons y$	30				7	STOP	41				7	e	12			
8	2	02				8	$\uparrow$	27				8	CONT	47			
9	$\div$	35				9	7	07				9	GO TO	44			
a	$y \rightarrow ()$	40				a	5	05				a	SUB	77			
b	b	14				b	0	00				b	-	34			
c	$\downarrow$	25				c	0	00				c	0	00			
d	$y \rightarrow ()$	40				d	$x \rightleftharpoons y$	30				d	0	00			
10	C	16				40	$\div$	35				70	GO TO	44			
1	CLEAR	20				1	$y \rightarrow ()$	40				1	SUB	77			
2	2	02				2	2	02				2	-	34			
3	STOP	41	q_{ms}	I_s	m_e	3	CONT	47				3	6	06			
4	$y \rightarrow ()$	40				4	2	02				4	0	00			
5	0	00				5	5	05				5	$x \leftarrow ()$	67			
6	$x \rightarrow ()$	23				6	0	00				6	4	04			
7	d	17				7	0	00				7	IF $x < y$	52			
8	5	05				8	ROLL $\uparrow$	22				8	8	10			
9	X	36				9	$\div$	35				9	4	04			
a	$y \rightarrow ()$	40				a	$y \rightarrow ()$	40				a	$\downarrow$	25			
b	e	12				b	3	03				b	0	00			
c	CONT	47				c	$x \leftarrow ()$	67				c	IF $x = y$	50			
d	$\downarrow$	25				d	0	00				d	8	10			
20	$y \rightarrow ()$	40				50	$\uparrow$	27				Storage					
1	1	01				1	.	21				F	AX				
2	CLEAR	20				2	1	01				E	50, X:				
3	.	21				3	0	00				d	q_{ms}		r_0		
4	0	00				4	X	36				c	I_e		q_e		
5	0	00				5	$y \rightarrow ()$	40				b	r_e				
6	0	00				6	f	15				a	q_e				
7	5	05				7	e	12				9					
8	$x \rightarrow ()$	23				8	$x \rightarrow ()$	23				8					
9	-	34				9	4	04				7					
a	C	16				a	CONT	47				6					
b	GO TO	44				b	4	04				5					
c	SUB	77				c	$\uparrow$	27				4	$X_{max} = 5 I_s$				
d	-	34				d	$\uparrow$	27				3	SE_y				
												2	SE_x				
												1	m_e				
												0	I_s				

REGION III PRESSURE PLUME PLOT

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Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
80	4	04				10	.	21				40	1	01			
1	GO TO	44				1	1	01				1	.	21			
2	6	06				2	6	06				2	3	03			
3	8	10				3	X	36				3	5	05			
4	CLEAR X	37				4	↓	25				4	÷	35			
5	↑	27				5	e ^x	74				5	CONT	47			
6	FMT	42				6	↑	27				6	CONT	47			
7	↑	27				7	b	14				7	↓	25			
8	x ← ()	67				8	x	36				8	√x	76			
9	+	33				9	y → ()	40				9	↑	27			
a	0	00				a	-	34				a	x ← ()	67			
b	x → ()	23				b	d	17				b	-	34			
c	e	12				c	x ← ()	67				c	d	17			
d	CONT	47				d	+	33				d	x	36			
90	GO TO	44				20	0	00				50	RETURN	77			
1	SUB	77				1	↑	27				1	0	00			
2	-	34				2	e	12				2	↑	27			
3	0	00				3	÷	35				3	RETURN	77			
4	0	00				4	↓	25				4					
5	↓	25				5	ln x	65				5					
6	CHG SIGN	32				6	↑	27				6					
7	↑	27				7	x ← ()	67				7					
8	GO TO	44				8	+	33				8					
9	-	34				9	1	01				9					
a	8	10				a	x ↔ y	30				a					
b	0	00				b	y	55				b					
c	CONT	47				c	x	36				c					
d	CONT	47				d	↓	25				d					
00	e	12				30	e ^x	74				Storage					
1	↑	27				1	↑	27									
2	b	14				2	d	17									
3	↑	27				3	x	36									
4	2	02				4	x ← ()	67									
5	x	36				5	-	34									
6	↓	25				6	c	16									
7	÷	35				7	IF x > y	53									
8	c	16				8	5	05									
9	÷	35				9	1	01									
a	↓	25				a	÷	35									
b	ln x	65				b	↓	25									
c	↑	27				c	ln x	65									
d	1	01				d	↑	27									

REGION III PRESSURE PLUME PLOT

PAGE 3 OF 3

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
60	x←()	67				90	5	05				0					
1	3	03				1	GO TO	44				1					
2	X	36				2	+	33				2					
3	e	12				3	8	10				3					
4	↑	27				4	d	17				4					
5	x←()	67				5	CLEAR X	37				5					
6	2	02				6	↑	27				6					
7	X	36				7	FMT	42				7					
8	↓	25				8	↑	27				8					
9	FMT	42				9	GO TO	44				9					
a	↓	25				a	+	33				a					
b	↑	27				b	6	06				b					
c	RCL	61				c	0	00				c					
d	+	33				d	END	46				d					
70	y←()	40				0						0					
1	e	12				1						1					
2	RETURN	77				2						2					
3						3						3					
4						4						4					
5						5						5					
6						6						6					
7						7						7					
8						8						8					
9						9						9					
a						a						a					
b						b						b					
c						c						c					
d						d						d					
80	GO TO	44				0						Storage					
1	SUB	77				1						f					
2	-	34				2						e					
3	6	06				3						d					
4	0	00				4						c					
5	x←()	67				5						b					
6	4	04				6						a					
7	IF X<Y	52				7						9					
8	9	11				8						8					
9	5	05				9						7					
a	↓	25				a						6					
b	0	00				b						5					
c	IF X=Y	60				c						4					
d	9	11				d						3					

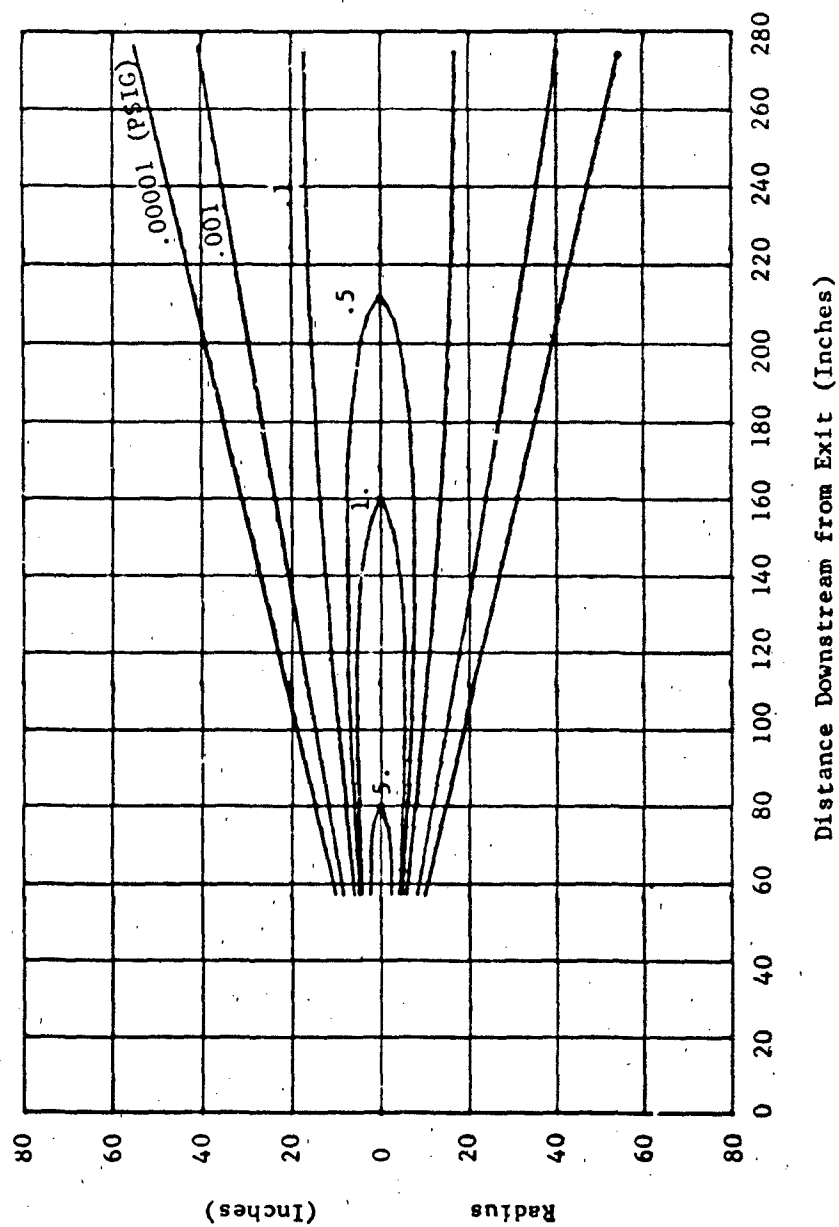


Figure 2-2. Pressure Plume Plot Region III

2.11 Calculation and Plot of Isotherms in Exhaust Field (Region II)

2.11.1 Purpose

To calculate and plot isotherms in the mixing region from the supersonic cone outwards.

2.11.2 Inputs

$D_e, I_r, l_s, I_t, m_t, T_e, SF_x, SF_y, T_a, \Delta x, X, T$

2.11.3 Outputs

T_{xs}^* - stagnation temperature on axis at end of supersonic cone.

Isotherms will be plotted on a radial versus axial distance scale.

2.11.4 Equations

$$T_{xs}^* = (T_c - T_a) \left[\frac{I_t}{(l_s/D)} \right]^{m_t} + T_a$$

$$r = \left[\frac{(X/D)}{I_r} \right]^{1.16} \left(\frac{r}{r_o} \right) (6D_e)$$

2.11.5 Description

This program is composed of five subprograms, $P_0 - P_4$, which are entered into the Extended Memory Unit. The Printer should be on with the Y button depressed. After program is entered make all inputs as shown for P_0 . Press Continue and a value will be printed for T_{xs}^* . Enter this value as shown for P_2 and the outline of the supersonic cone will be plotted. After each isotherm is plotted enter the value of the next isotherm to be plotted. These values must be less than T_{xs}^* . The curves will be drawn for the positive radius only.

2.11.6 REGION II EXHAUST FIELD ISOTHERM PLOT - P₀ PAGE 1 OF 5

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
00	CLEAR	20				30	e	12				0					
1	1	01				1	y → ()	40				1					
2	STOP	41	D _e	I _e	f _e	2	-	34				2					
3	x → ()	23				3	0	00				3					
4	-	34				4	1	01				4					
5	f	15				5	FMT	42				5					
6	y → ()	40				6	GO TO	44				6					
7	-	34				7	END	46				7					
8	e	12				8						8					
9	↓	25				9						9					
a	y → ()	40				a						a					
b	-	34				b						b					
c	d	17				c						c					
d	2	02				d						d					
10	STOP	41	I _T	m _T	T _e	0						0					
1	x → ()	23				1						1					
2	-	34				2						2					
3	c	16				3						3					
4	y → ()	40				4						4					
5	-	34				5						5					
6	b	14				6						6					
7	↓	25				7						7					
8	y → ()	40				8						8					
9	-	34				9						9					
a	0	13				a						a					
b	3	03				b						b					
c	STOP	41	SF _e	SF _y	T _e	c						c					
d	x → ()	23				d						d					
20	-	34				0											
1	9	11				1											
2	y → ()	40				2											
3	-	34				3											
4	8	10				4											
5	↓	25				5											
6	y → ()	40				6											
7	-	34				7											
8	7	07				8											
9	4	04				9											
a	STOP	41	AX	X		a											
b	x → ()	23				b											
c	f	15				c											
d	y → ()	40				d											

REGION II EXHAUST FIELD ISOTHERM PLOT - P_i

PAGE 2 OF 5

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
00	x←()	67				0						0					
1	-	34				1						1					
2	d	17				2						2					
3	↑	27				3						3					
4	x←()	67				4						4					
5	-	34				5						5					
6	f	15				6						6					
7	÷	35				7						7					
8	x←()	67				8						8					
9	-	34				9						9					
a	c	16				a						a					
b	x→y	30				b						b					
c	÷	35				c						c					
d	x←()	67				d						d					
10	-	34				0						0					
1	b	14				1						1					
2	x→y	30				2						2					
3	ln x	65				3						3					
4	x	36				4						4					
5	↓	25				5						5					
6	e ^x	74				6						6					
7	↑	27				7						7					
8	x←()	67				8						8					
9	-	34				9						9					
a	a	13				a						a					
b	↑	27				b						b					
c	x←()	67				c						c					
d	-	34				d						d					
20	7	07				0						0					
1	-	34				1						1					
2	↓	25				2						2					
3	x	36				3						3					
4	x←()	67				4						4					
5	-	34				5						5					
6	7	07				6						6					
7	+	33				7						7					
8	PRINT	45				8						8					
9	PRINT	45				9						9					
a	2	02				a						a					
b	FMT	42				b						b					
c	GO TO	44				c						c					
d	END	46				d						d					

REGION II EXHAUST FIELD ISOTHERM PLOT - P₂

PAGE 3 of 5

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
0	5	05				0						0					
1	STOP	41	T			1						1					
2	X→()	23				2						2					
3	-	34				3						3					
4	6	06				4						4					
5	3	03				5						5					
6	FMT	42				6						6					
7	GO TO	44				7						7					
8	END	46				8						8					
9						9						9					
a						a						a					
b						b						b					
c						c						c					
d						d						d					
0						0						0					
1						1						1					
2						2						2					
3						3						3					
4						4						4					
5						5						5					
6						6						6					
7						7						7					
8						8						8					
9						9						9					
a						a						a					
b						b						b					
c						c						c					
d						d						d					
0						0						0					
1						1						1					
2						2						2					
3						3						3					
4						4						4					
5						5						5					
6						6						6					
7						7						7					
8						8						8					
9						9						9					
a						a						a					
b						b						b					
c						c						c					
d						d						d					

Storage

REGION II EXHAUST FIELD ISOTHERM PLOT - P₃

PAGE 4 OF 5

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
0	e	12				3	x	36				6	y → ()	40			
1	↑	27				1	↓	25				1	-	34			
2	x ← ()	67				2	x ↔ y	30				2	4	04			
3	-	34				3	÷	35				3	4	04			
4	f	15				4	↓	25				4	FMT	42			
5	÷	35				5	ln x	65				5	GO TO	44			
6	y → ()	40				6	↑	27				6	END	46			
7	d	17				7	.	21				7					
8	x ← ()	67				8	5	05				8					
9	-	34				9	2	02				9					
a	b	14				a	÷	35				a					
b	x ↔ y	30				b	↓	25				b					
c	ln x	65				c	√x	76				c					
d	x	36				d	x → ()	23				d					
1	↓	25				4	-	34				0					
1	e ^x	74				1	5	05				1					
2	↑	27				2	d	17				2					
3	x ← ()	67				3	↑	27				3					
4	-	34				4	x ← ()	67				4					
5	6	06				5	-	34				5					
6	↑	27				6	e	12				6					
7	x ← ()	67				7	÷	35				7					
8	-	34				8	1	01				8					
9	7	07				9	.	21				9					
a	-	34				a	1	01				a					
b	↓	25				b	6	06				b					
c	x	36				c	x ↔ y	30				c					
d	x ← ()	67				d	ln x	65				d					
2	-	34				5	x	36									
3	c	16				1	↓	25									
4	ln x	65				2	e ^x	74									
5	↑	27				3	↑	27									
6	x ← ()	67				4	x ← ()	67									
7	-	34				5	-	34									
8	b	14				6	5	05									
9	x	36				7	x	36									
a	↓	25				8	6	06									
b	e ^x	74				9	x	36									
c	↑	27				a	x ← ()	67									
d	x ← ()	67				b	-	34									
1	-	34				c	f	15									
2	a	13				d	x	36									

REGION II EXHAUST FIELD ISOTHERM PLOT-P₄

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Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
00	e	12				30	END	46				0					
1	↑	27				1						1					
2	x←()	67				2						2					
3	-	34				3						3					
4	d	17				4						4					
5	IF x<y	52				5						5					
6	2	02				6						6					
7	4	04				7						7					
8	x←()	67				8						8					
9	-	34				9						9					
	9	11															
b	x	36															
c	x←()	67															
d	-	34															
10	4	04				0						0					
	↑	27										1					
	x←()	67				2						2					
	-	34				3						3					
	8	10				4						4					
	x	36				5						5					
6	↓	25				6						6					
7	x→y	30				7						7					
8	FMT	42				8						8					
	↓	25				9						9					
	RCL	61															
	+	33															
	y→()	40															
	e	12															
2	3	03															
	GO TO	44															
2	2	02				2											
3	c	16				3											
4	FMT	42				4											
5	↑	27				5											
6	x←()	67				6											
7	-	34				7											
8	0	00				8											
9	x→()	23				9											
	e	12															
b	2	02															
c	FMT	42															
d	GO TO	44															

Storage

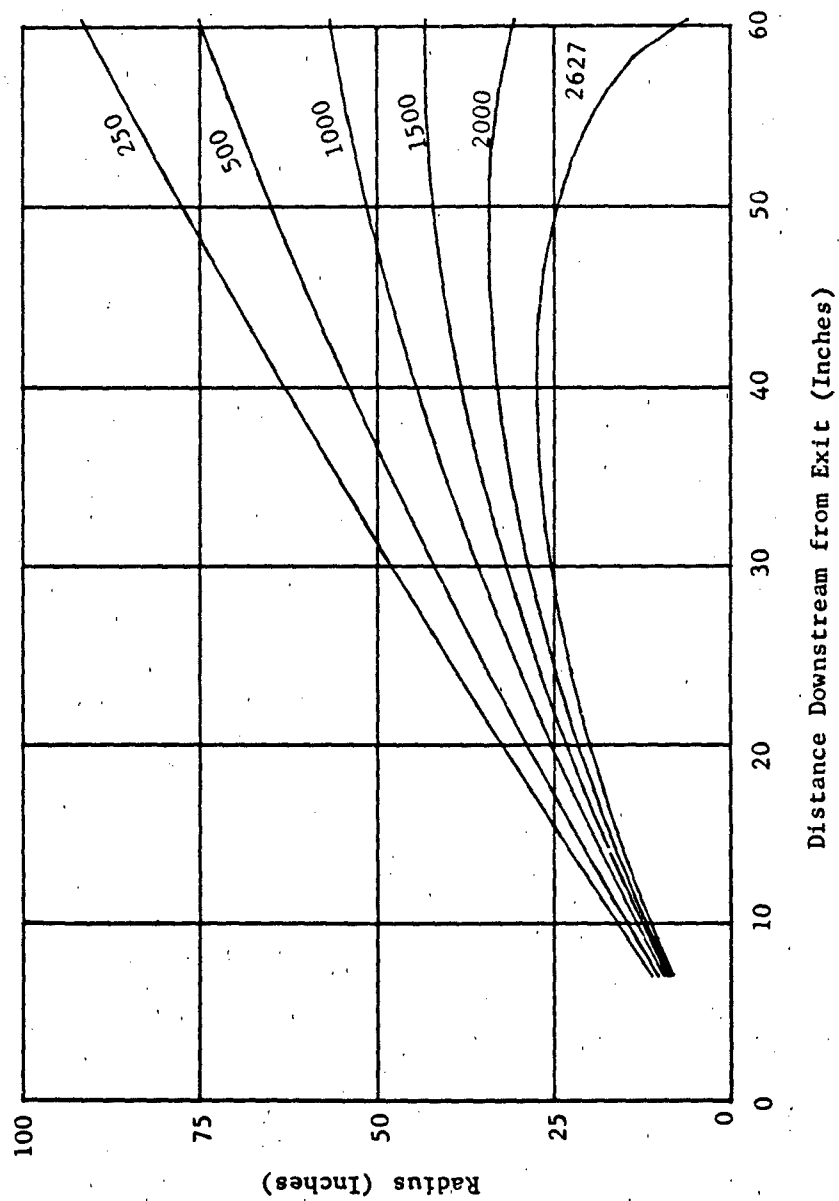


Figure 2-3. Isotherm Profile Plot Region II

2.12 Calculation and Plot of Isotherms in Exhaust Field (Region III)

2.12.1 Purpose

To calculate and plot isotherms in a rocket exhaust flow field in the region downstream of the end of the supersonic cone.

2.12.2 Inputs

D_e , I_r , l_s , I_t , m_t , T_c , SF_x , SF_y , Δx , X , T_a , T

2.12.3 Outputs

Isotherms will be plotted on a radial versus axial distance scale.

2.12.4 Equations

$$T = \left[e^{-.52 \left(\frac{r}{r_o} \right)^2} \right] \left\{ (T_c - T_a) \left[\frac{I_t}{(x/D_e)} \right]^{m_t} + T_a \right\}$$

$$r = \left(\frac{X}{D_e} \right)^{1.16} \left[\frac{6D_e}{I_r^{1.16}} \right] \left(\frac{r}{r_o} \right)$$

2.12.5 Description

After program is entered, all necessary inputs are made as indicated on program forms. For T , enter value of isotherm desired. After it is plotted enter next value of T and continue this procedure until plot is completed.

212.6 REGION III EXHAUST FIELD ISOTHERM PLOT

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Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
00	CLEAR	20				30	STOP	41	T			60	↓	25			
1	1	01				1	X→()	23				1	e ^x	74			
2	STOP	41	D	I _R	Q _S	2	-	34				2	↑	27			
3	X→()	23				3	d	17				3	X←()	67			
4	d	17				4	GO TO	44				4	-	34			
5	Y→()	40				5	SUB	77				5	f	15			
6	c	16				6	5	05				6	↑	27			
7	↓	25				7	2	02				7	X←()	67			
8	Y→()	40				8	0	00				8	-	34			
9	-	34				9	IF X>Y	63				9	9	11			
a	a	13				a	-	34				a	-	34			
b	2	02				b	6	06				b	↓	25			
c	STOP	41	I _T	m _T	T _c	c	8	10				c	X	36			
d	X→()	23				d	CLEARX	37				d	X←()	67			
10	b	14				40	GO TO	44				70	-	34			
1	Y→()	40				1	SUB	77				1	9	11			
2	a	13				2	8	10				2	+	33			
3	↓	25				3	3	03				3	X←()	67			
4	Y→()	40				4	GO TO	44				4	-	34			
5	-	34				5	SUB	77				5	d	17			
6	f	15				6	-	34				6	CONT	47			
7	3	03				7	1	01				7	÷	35			
8	STOP	41	SF _x	SF _y	T _c	8	d	17				8	↓	25			
9	X→()	23				9	RCL	61				9	ln X	65			
a	-	34				a	+	33				a	↑	27			
b	c	16				b	Y→()	40				b	.	21			
c	Y→()	40				c	e	12				c	5	05			
d	-	34				d	GO TO	44				d	2	02			
20	b	14				50	3	03				Storage					
1	↓	25				1	4	04				f	AX		T _c		
2	Y→()	40				2	b	14				e	X		f		
3	-	34				3	↑	27				d	D		T		
4	9	11				4	e	12				c	I _c		SF _x		
5	4	04				5	↑	27				b	I _r		SF _y		
6	FMT	42				6	d	17				a	m _T		Q _S		
7	↑	27				7	÷	35				9			T _c		
8	STOP	41	AX	X		8	↓	25				8					
9	X→()	23				9	÷	35				7					
a	f	15				a	a	13				6					
b	Y→()	40				b	X→Y	30				5					
c	e	12				c	ln X	65				4					
d	5	05				d	X	36				3					
												2					
												1					
												0%					

REGION III EXHAUST FIELD ISOTHERM PLOT

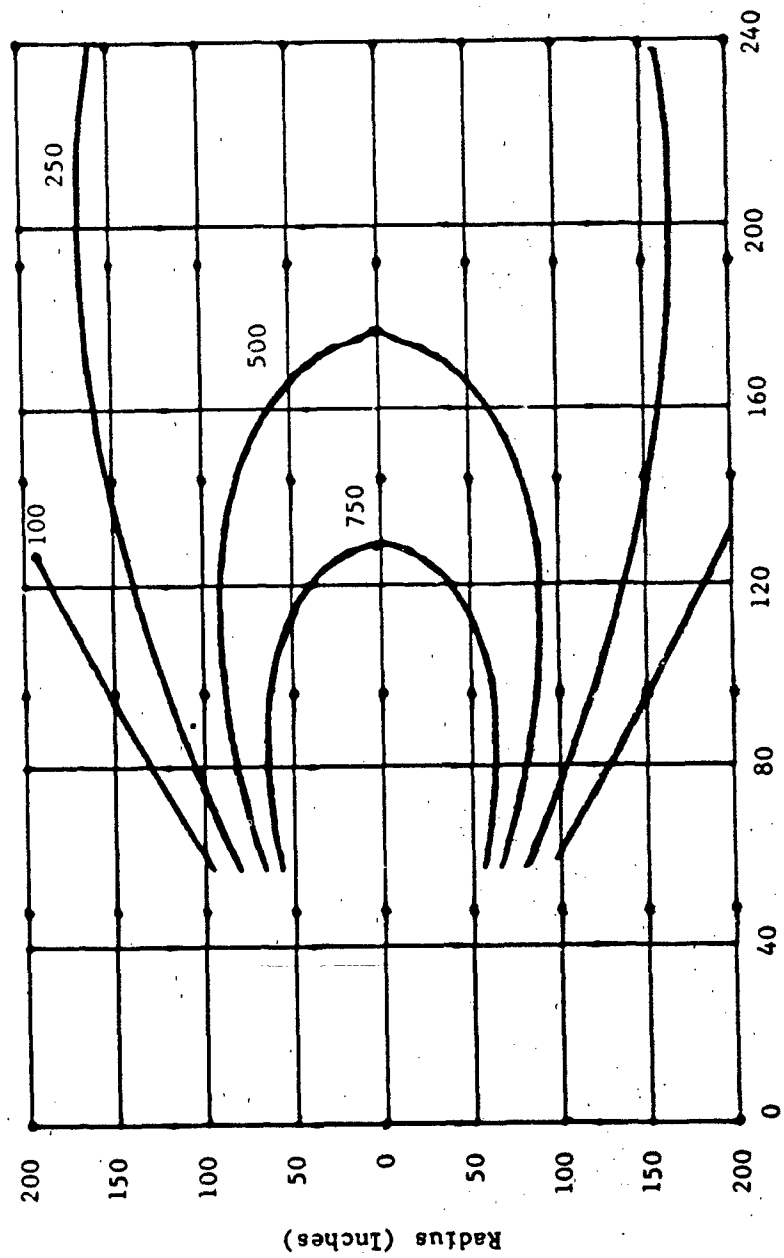
PAGE 2 OF 3

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
80	÷	35				110	↓	25				40	e	12			
1	RETURN	77				1	e ^x	74				1	Go To	44			
2	RETURN	77				2	x ↔ y	30				2	SUB	77			
3	↓	25				3	1	01				3	+	33			
4	√x ²	76				4	x ↔ y	30				4	5	05			
5	x →()	23				5	÷	35				5	2	02			
6	0	00				6	↓	25				6	0	00			
7	↑	27				7	x	36				7	If x=y	53			
8	6	06				8	y →()	40				8	-	34			
9	x	36				9	-	34				9	7	07			
a	d	17				a	e	12				a	b	14			
b	x	36				b	RETURN	77				b	CLEARX	37			
c	↑	27				c	RETURN	77				c	Go To	44			
d	e	12				d	x →()	67				d	SUB	77			
90	x ↔ y	30				20	-	34				50	+	33			
1	d	17				1	e	12				1	8	10			
2	÷	35				2	↑	27				2	3	03			
3	1	01				3	x →()	67				3	↓	25			
4	.	21				4	-	34				4	CHS SIGN	32			
5	1	01				5	b	14				5	x →()	23			
6	6	06				6	x	36				6	-	34			
7	x ↔ y	30				7	↑	27				7	e	12			
8	ln x	65				8	x →()	67				8	Go To	44			
9	x	36				9	+	33				9	SUB	77			
a	Go To	44				a	e	12				a	-	34			
b	-	34				b	x ↔ y	30				b	1	01			
c	0	00				c	x →()	67				c	d	17			
d	0	00				d	-	34				d	RCI	61			
00	↓	25				30	c	16				Storage					
1	e ^x	74				1	x	36									
2	x	36				2	↓	25									
3	↑	27				3	FMT	42									
4	x →()	67				4	↓	25									
5	+	33				5	RETURN	77									
6	c	16				6	RETURN	77									
7	ln x	65				7	FMT	42									
8	x ↔ y	30				8	↑	27									
9	1	01				9	x →()	67									
a	.	21				a	-	34									
b	1	01				b	a	13									
c	6	06				c	x →()	23									
d	x	36				d	+	33									

REGION III EXHAUST FIELD ISOTHERM PLOT

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Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
60	+	33				10						0					
1	y → ()	40				1						1					
2	+	33				2						2					
3	e	12				3						3					
4	Go To	44				4						4					
5	-	34				5						5					
6	4	04				6						6					
7	1	01				7						7					
8	0	00				8						8					
9	↑	27				9						9					
a	x ← ()	67				a						a					
b	+	33				b						b					
c	e	12				c						c					
d	↑	27				d						d					
70	x ← ()	67				0						0					
1	-	34				1						1					
2	c	16				2						2					
3	x	36				3						3					
4	↓	25				4						4					
5	FMT	42				5						5					
6	↓	25				6						6					
7	Go To	44				7						7					
8	-	34				8						8					
9	3	03				9						9					
a	7	07				a						a					
b	0	00				b						b					
c	↑	27				c						c					
d	x ← ()	67				d						d					
80	+	33				0						Storage					
1	e	12				1											
2	↑	27				2											
3	x ← ()	67				3											
4	-	34				4											
5	c	16				5											
6	x	36				6											
7	↓	25				7											
8	FMT	42				8											
9	↓	25				9											
a	Go To	44				a											
b	+	33				b											
c	2	02				c											
d	5	05				d											



Distance Downstream from Exit (Inches)

Figure 2-4 . Isotherm Profile Plot Region III

Section III. TUBE PRESSURE PROFILE AND RECOIL PREDICTION

3.1 Tube Pressure as a Function of Length

3.1.1 Discussion of Program

A method was developed whereby the pressure inside a launch tube due to missile exhaust gases could be predicted as a function of missile travel. The procedure used is discussed in the following.

A close fit was assumed between the missile motor nozzle and the walls of the launch tube, with no space available to allow the exhaust gases to expand around the nozzle rim in a forward direction. The pressure on the launch tube walls was thus assumed to be due to the component of exhaust gas flow parallel to the nozzle wall exerting a force on the launch tube walls. This program gives the pressure on the launch tube at the location of the rocket nozzle exit plane at the time the exit plane passes each given location.

This procedure does not account for shock wave buildup in the tube behind the nozzle nor for any effects attributable to them. This would be a consideration for future effort combining theoretical and test results.

3.1.2 Results and Discussion of Accuracy

The program as written will provide a prediction of tube pressure versus missile travel. The accuracy of the program will not be ascertainable until comparisons with actual test results can be performed.

The predictions may give lower than actual values since the effects of shock waves in the tube were not considered. Shock waves could cause pressure variations aft of the missile which may exceed predicted values. If test results seem to indicate this, a study could be undertaken to simulate shock wave effects.

3.1.3 Tube Pressure at Nozzle Exit Plane Versus Missile Travel

3.1.3.1 Purpose

To calculate and plot values for the pressure inside a launch tube, due to exhaust gases, at the nozzle exit plane as a function of missile travel.

3.1.3.2 Inputs

W - Effective Missile Weight (Pounds)
 P_r - P_{c1}/thrust_1

P_{xy} - $(q_e + 14.7)/P_c$
 θ_n - Nozzle half angle
 t_n - Time
 T_n - Thrust
 Δt - Time increment
 SF_y - Plot ordinate scale factor
 SF_x - Plot abscissa scale factor

3.1.3.3 Outputs

Plot of tube pressure (PSIG) versus missile travel in tube (inches).

3.1.3.4 Description

After program is entered, enter P_{xy} , P_r , W in Z, Y, X registers. Press Continue, enter θ_n , SF_y , SF_x , in Z, Y, X registers. Press Continue, enter Δt in X register. Press Continue, enter T_n , t_n , in Y, X registers. Press Continue, value of (tube pressure, missile travel) will be plotted, continue entering values for T_n , t_n until plot is completed.

3.1.3.5 TUBE PRESSURE AT NOZZLE EXIT

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Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
0	CLEAR	20				30	b	14				60	↑	27			
1	FMT	42				1	y→()	40				1	C	16			
2	↑	27				2		01				2	-	34			
3	1	01				3	x→()	23				3	↓	25			
4	STOP	41	W	P _R	P _{xy}	4	9	11				4	÷	35			
5	y→()	40				5	x→()	23				5	y→()	40			
6	-	34				6	8	10				6	3	03			
7	e	12				7	CLEAR	20				7	CONT	47			
8	x↔y	30				8	3	03				8	GO TO	44			
9	3	03				9	STOP	41	At			9	SUB	77			
a	2	02				a	x→()	23				a	-	34			
b	.	21				b	f	15				b	0	00			
c	2	02				c	CONT	47				c	0	00			
d	÷	35				d	0	00				d	CONT	47			
10	1	01				40	x→()	23				70	1	01			
1	x↔y	30				1	2	02				1	2	02			
2	÷	35				2	CONT	47				2	X	36			
3	y→()	40				3	a	13				3	x→()	67			
4	0	00				4	x→()	23				4	-	34			
5	↓	25				5	c	16				5	d	17			
6	y→()	40				6	b	14				6	X	36			
7	-	34				7	x→()	23				7	e	12			
8	f	15				8	d	17				8	↑	27			
9	CLEAR	20				9	CONT	47				9	C	16			
a	2	02				a	x→()	67				a	GO TO	44			
b	STOP	41	SF _x	SF _y	θ _N	b	+	33				b	-	34			
c	x→()	23				c	2	02				c	3	03			
d	-	34				d	↑	27				d	3	03			
20	d	17				50	1	01				Storage					
1	y→()	40				1	+	33				f	At		P _{xy}		
2	-	34				2	y→()	40				e	t _i		P _R		
3	C	16				3	2	02				d	T _{n-1}		X _{SE}		
4	ROLL ↑	22				4	↑	27				c	t _{n-1}		Y _{SE}		
5	↑	27				5	STOP	41	t _n	T _n		b	T _n				
6	SIN X	70				6	y→()	40				a	t _n				
7	x↔y	30				7	b	14				9	x _{ant}				
8	COS X	73				8	x→()	23				8	x _{ant}				
9	X	36				9	a	13				7					
a	0	00				a	SET RM	54				6					
b	x→()	23				b	d	17				5					
c	a	13				c	-	34				4					
d	x→()	23				d	a	13				3	m _n				
												2	n				
												1	SIN COS θ _N				
												0	1/M				

TUBE PRESSURE AT NOZZLE EXIT

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Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
00	CONT	47				30	↓	25				60	RCL	61			
1	e	12				1	+	33				1	+	33			
2	↑	27				2	RETURN	77				2	y→()	40			
3	C	16				3	CONT	47				3	e	12			
4	-	34				4	-	34				4	a	13			
5	x↔y	30				5	x←()	67				5	IF x=y	50			
6	↑	27				6	+	33				6	G	06			
7	x	36				7	3	03				7	C	16			
8	x	36				8	x	36				8	GO TO	44			
9	x↔y	30				9	d	17				9	+	33			
a	↑	27				a	+	33				a	G	06			
b	x←()	67				b	x←()	67				b	7	07			
c	+	33				c	-	34				c	GO TO	44			
d	3	03				d	e	12				d	SUB	77			
10	x	36				40	x	36				70	-	34			
1	G	06				1	x←()	67				1	0	00			
2	÷	35				2	-	34				2	0	00			
3	↓	25				3	f	15				3	CONT	47			
4	ROLL ↓	31				4	x	36				4	y←()	40			
5	x	36				5	1	01				5	+	33			
6	d	17				6	4	04				6	8	10			
7	x	36				7	.	21				7	e	12			
8	2	02				8	7	07				8	↑	27			
9	÷	35				9	-	34				9	C	16			
a	↓	25				a	x←()	67				a	-	34			
b	+	33				b	+	33				b	x↔y	30			
c	x←()	67				c	1	01				c	↑	27			
d	+	33				d	x	36				d	↑	27			
20	0	00				50	x←()	67				Storage					
1	x	36				1	-	34									
2	e	12				2	C	16									
3	↑	27				3	x	36									
4	C	16				4	↓	25									
5	-	34				5	x↔y	30									
6	x←()	67				6	IF FLAG	43									
7	+	33				7	5	05									
8	9	11				8	C	16									
9	x	36				9	GO TO	44									
a	x←()	67				a	6	06									
b	+	33				b	0	00									
c	8	10				c	FMT	42									
d	+	33				d	↓	25									

TUBE PRESSURE AT NOZZLE EXIT

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Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
80	X	36				0						0					
1	X←()	67				1						1					
2	+	33				2						2					
3	3	03				3						3					
4	X	36				4						4					
5	2	02				5						5					
6	÷	35				6						6					
7	ROLL ↑	22				7						7					
8	X↔Y	30				8						8					
9	d	17				9						9					
a	X	36				a						a					
b	↓	25				b						b					
c	+	33				c						c					
d	X←()	67				d						d					
90	+	33				0						0					
1	0	00				1						1					
2	X	36				2						2					
3	X←()	67				3						3					
4	+	33				4						4					
5	9	11				5						5					
6	+	33				6						6					
7	Y←()	40				7						7					
8	+	33				8						8					
9	9	11				9						9					
a	GO TO	44				a						a					
b	+	33				b						b					
c	4	04				c						c					
d	2	02				d						d					
20	END					0						Storage					
1						1											
2						2											
3						3											
4						4											
5						5											
6						6											
7						7											
8						8											
9						9											
a						a											
b						b											
c						c											
d						d											
												F					
												E					
												D					
												C					
												B					
												A					
												9					
												8					
												7					
												6					
												5					
												4					
												3					
												2					
												1					
												0					

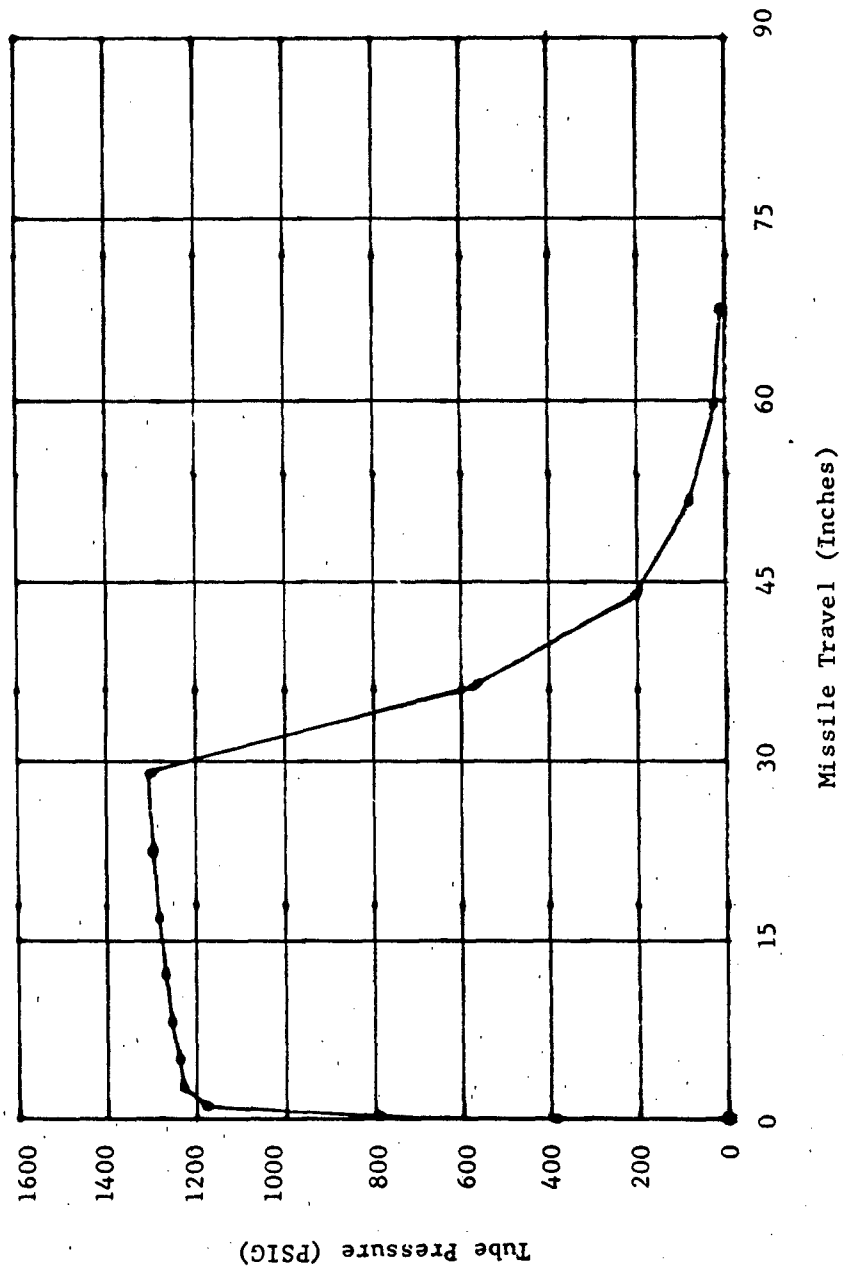


Figure 3-1 : Internal Tube Pressure at Nozzle Exit Versus Missile Travel

3.2 Recoil Prediction

The recoil force predictions are based on the following considerations: missile shoe frictional forces, gas friction forces on the walls of the launch tube, gas impingement on the internal step for a stepped telescoping launcher and gas impingement on the forward face of the tube at missile exit. These forces all contribute to a total force aft (recoil) during a missile firing. Any internal protrusion other than a step would also have to be accounted for in a recoil estimate.

The launch simulation program described in Section IV can be used to obtain the force-time histories of the shoe friction forces and the time at which the exhaust gas would begin to impinge on the step or any other internal protrusion whose location is known. For these times, the nozzle exit stagnation pressure can be determined and this, multiplied by the exposed area on which it acted would give the force. The time at which the missile exits the tube, thus giving exhaust impingement forces on the tube face, can also be found.

A good estimate of the recoil-time history can be obtained by plotting all the separate force-time histories on graph paper and summing to obtain the total force-time history. An example of the result of this process is shown in Figure 3-2 for a stepped telescoping tube.

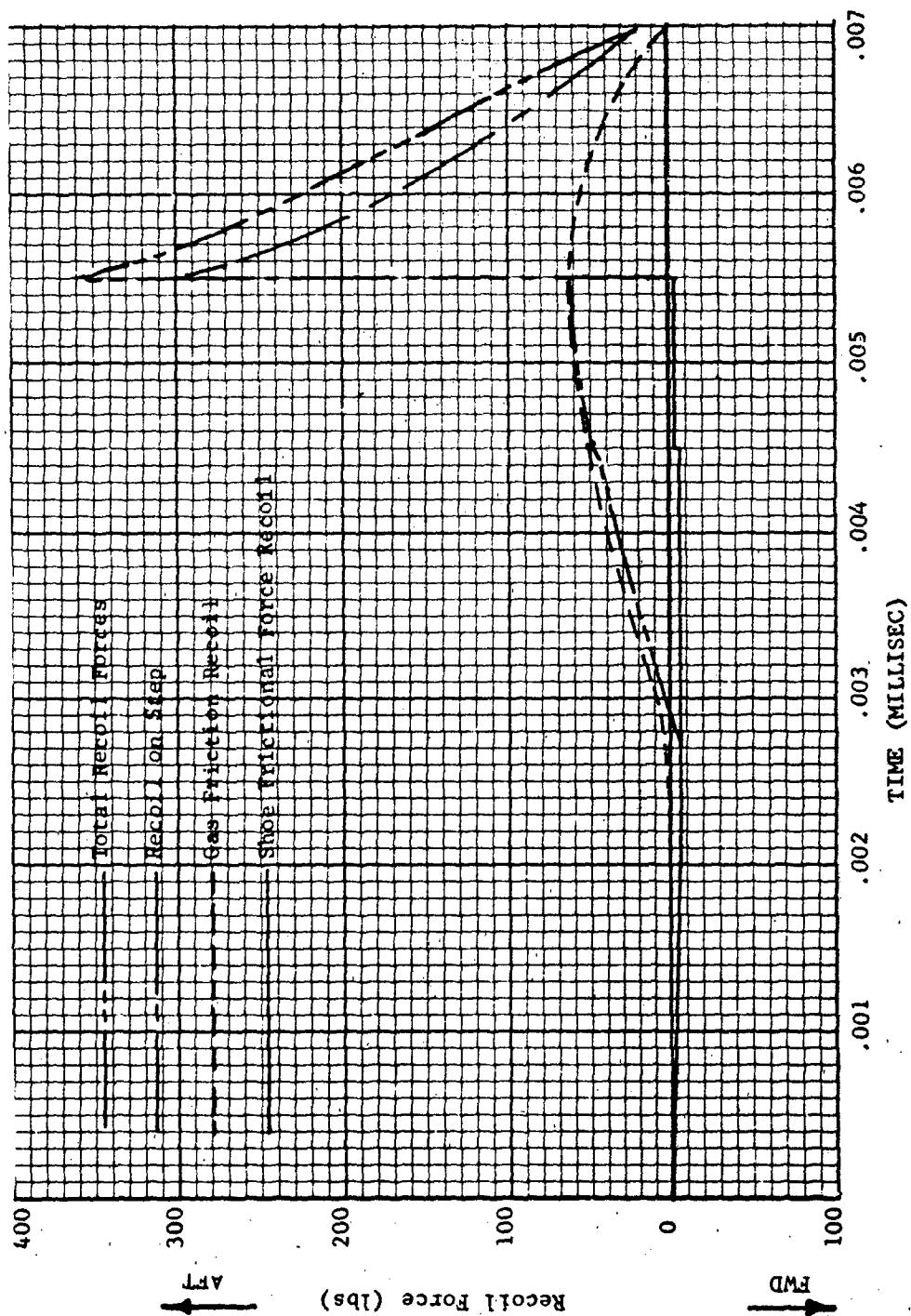


Figure 3-2. Estimation Method for Recoil Forces

Section IV. LAUNCHER SIMULATION

4.1 Introduction

A computer simulation program has been written which simulates launcher performance in the pitch plane. The program is capable of simulating both smooth-bore and stepped telescoping launchers. It has provisions for utilizing a recoil force-time history as an input and for studying the effects of thrust misalignment and center of gravity offset. Figure 4-1 is a representation of a missile and launcher showing the forces accounted for in the simulation program and the dimensional data required.

The basic assumption for the simulation model is that the gross motions of the system are due to the nonrigid support characteristics of a man. The man has been replaced, therefore, by a spring and a damper. Four firing positions were chosen as being readily simulated for various configurations. These positions are depicted in Figure 4-2. In each position a point which appears to have the least translational motion has been chosen as a virtual trunnion. The spring and damper are then converted to torsional equivalents about this point.

This simulation model is intended only to provide gross motions. A representative example of outputs from the program is shown in Figures 4-3, 4-4, 4-5. Results obtained by the use of this program are predictions only and have not been verified by test data. No plans have been made for verification tests at the present time.

4.2 Symbol Definitions

- $T_1 - T_5$: Time values associated with the missile thrust-time curve.
- $\tau_1 - \tau_4$: Thrust values associated with the missile thrust-time curve.
- F_c : Coefficient of friction for missile shoe friction forces.
- D_f : Damping factor for system dashpot.
- F_n : Natural frequency of vibration of system.
- I_l : Moment of inertia of launcher about trunnion.
- I_r : Roll moment of inertia of missile.
- I_m : Missile moment of inertia.
- I_t : Total system motion of inertia about trunnion.
- $U_1 - U_3$: Time values associated with blast force buildup (millisec).

$F_{61} - F_{62}$: Force values associated with blast force buildup.
 Δt : Integration time increment (sec).
 R_a : Angular location of thrust misalignment vector from zero reference (counterclockwise positive).
 R_c : Torque necessary to induce spin on the missile.
 W_1 : Weight of missile (lbs).
 W_2 : Weight of launcher (lbs).
 EA : Launcher elevation angle.
 D_1 : Distance along X-Axis from missile CG to front shoe (Application of F_1) (inches).
 D_2 : Distance along X-Axis from missile CG to rear shoe (Application of F_2) (inches).
 D_3 : Missile CG offset along Y-Axis (inches).
 D_4 : Missile thrust misalignment (inches).
 D_5 : Distance along Y-Axis from missile centerline to outer edge of shoe (inches).
 D_6 : Distance along Y-Axis from launcher tube centerline to trunnion (inches).
 D_7 : Distance along X-Axis from launcher trunnion to Application of F_1 (inches).
 D_8 : Distance along X-Axis from launcher trunnion to Application of F_2 (inches).
 D_9 : Distance along X-Axis from launcher trunnion to launcher CG (inches).
 D_{10} : Distance along Y-Axis from launcher trunnion to launcher CG (inches).
 D_{11} : Overall launch tube length for smooth bore launcher concept; guidance length (inside tube length) for telescoping launcher concept (inches).
 D_{12} : Outer tube length for telescoping launcher concept (inches).

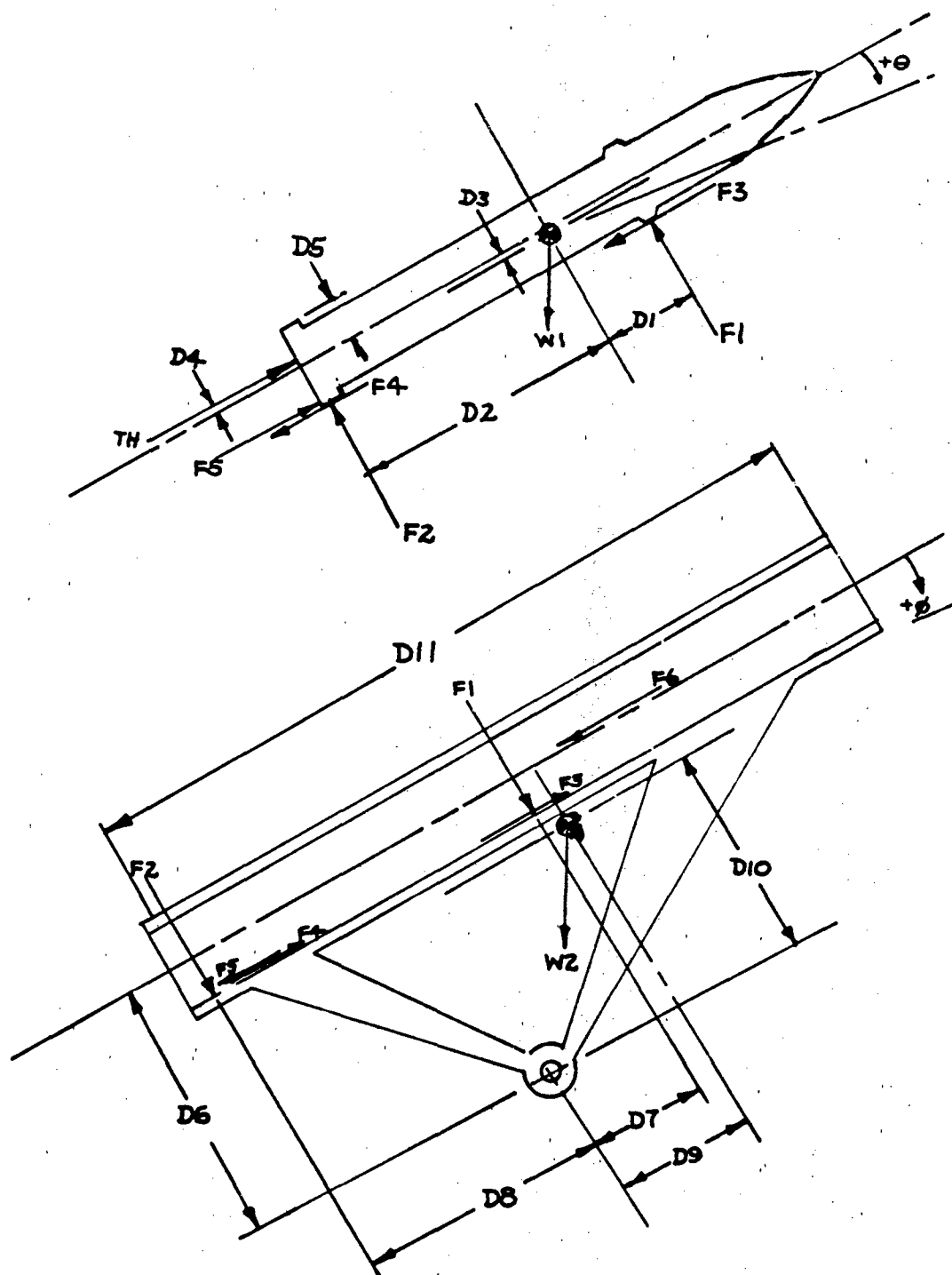


Figure 4-1. Launch Simulation Missile and Launcher Model

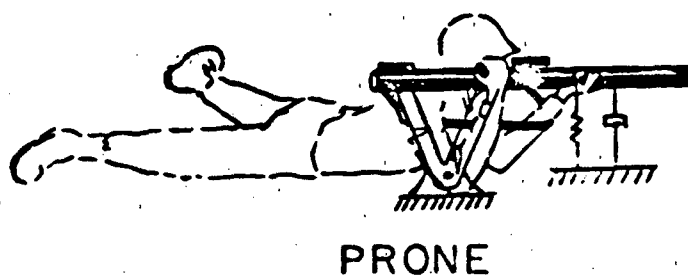
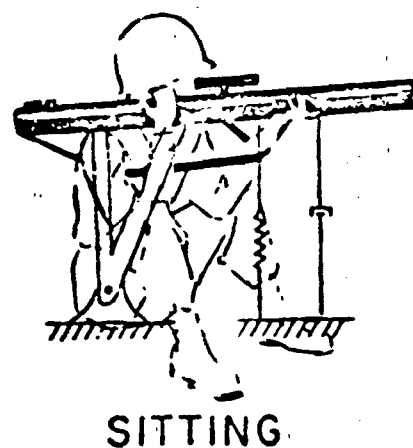
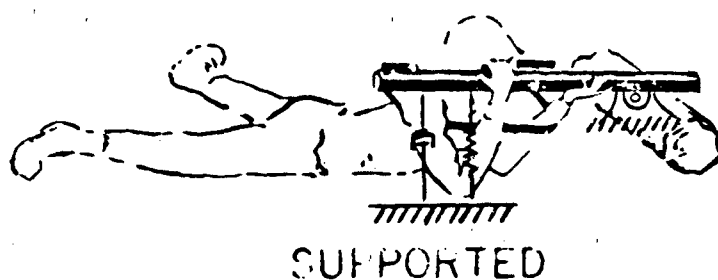


Figure 4-2. Firing Position Models for Launch Simulation

STEPPED TELESCOPING TUBE, HOT ROUND
THRUST MISALIGNMENT INDICATED ON CURVE

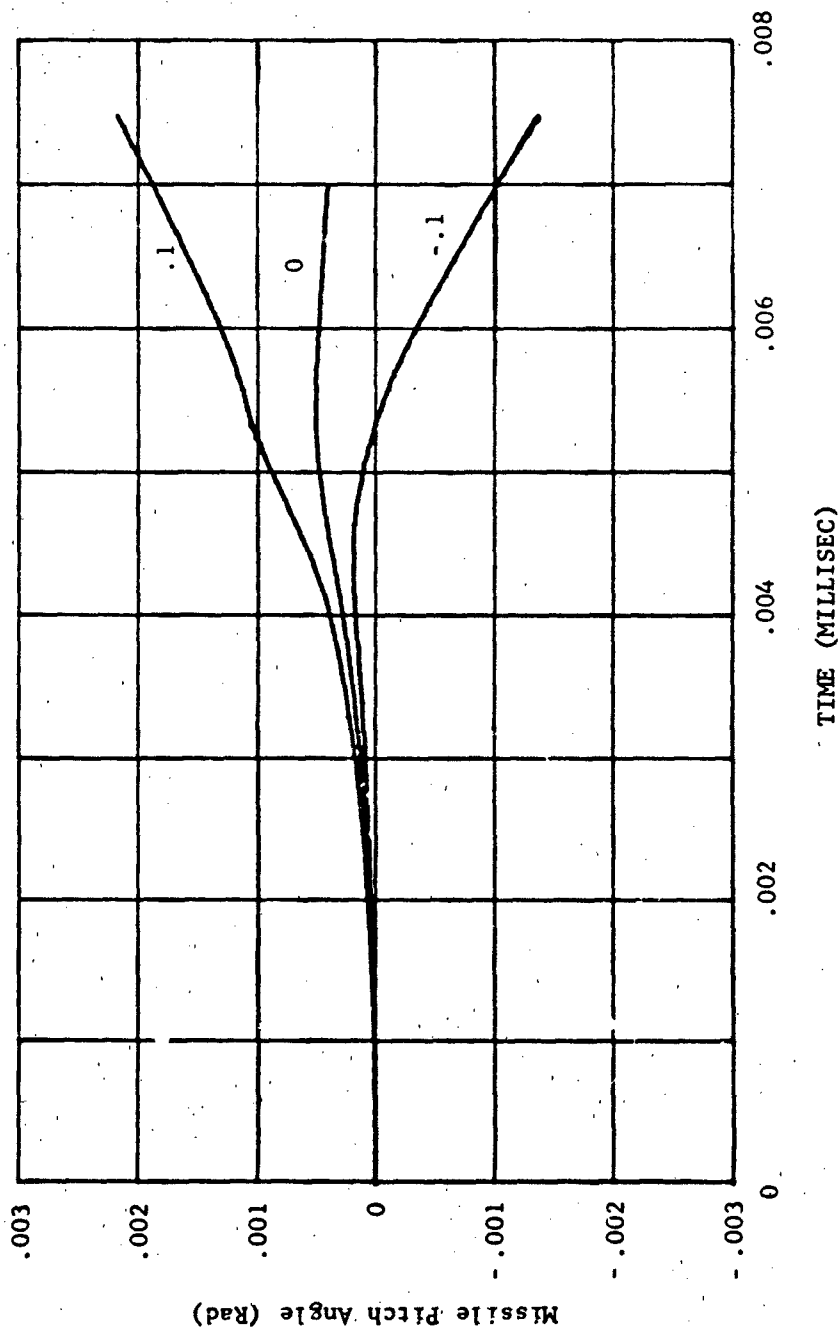


Figure 4-3. Missile Pitch Angle versus Time

STEPPED TELESCOPING TUBE, HOT ROUND
THRUST MISALIGNMENT INDICATED ON PLOT

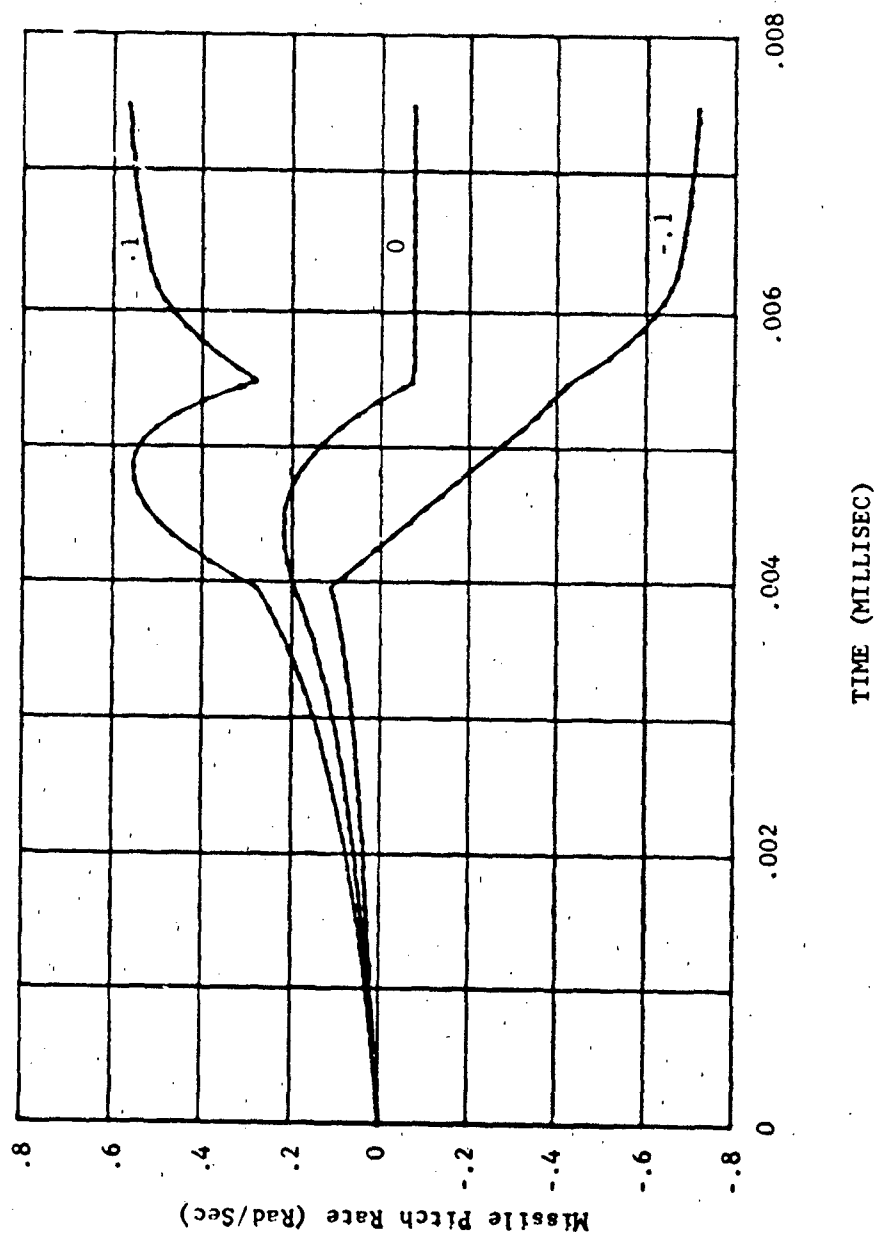


Figure 4-4. Missile Pitch Rate Versus Time

STEPPED TELESCOPING TUBE, HOT ROUND
THRUST MISALIGNMENT INDICATED ON PLOT

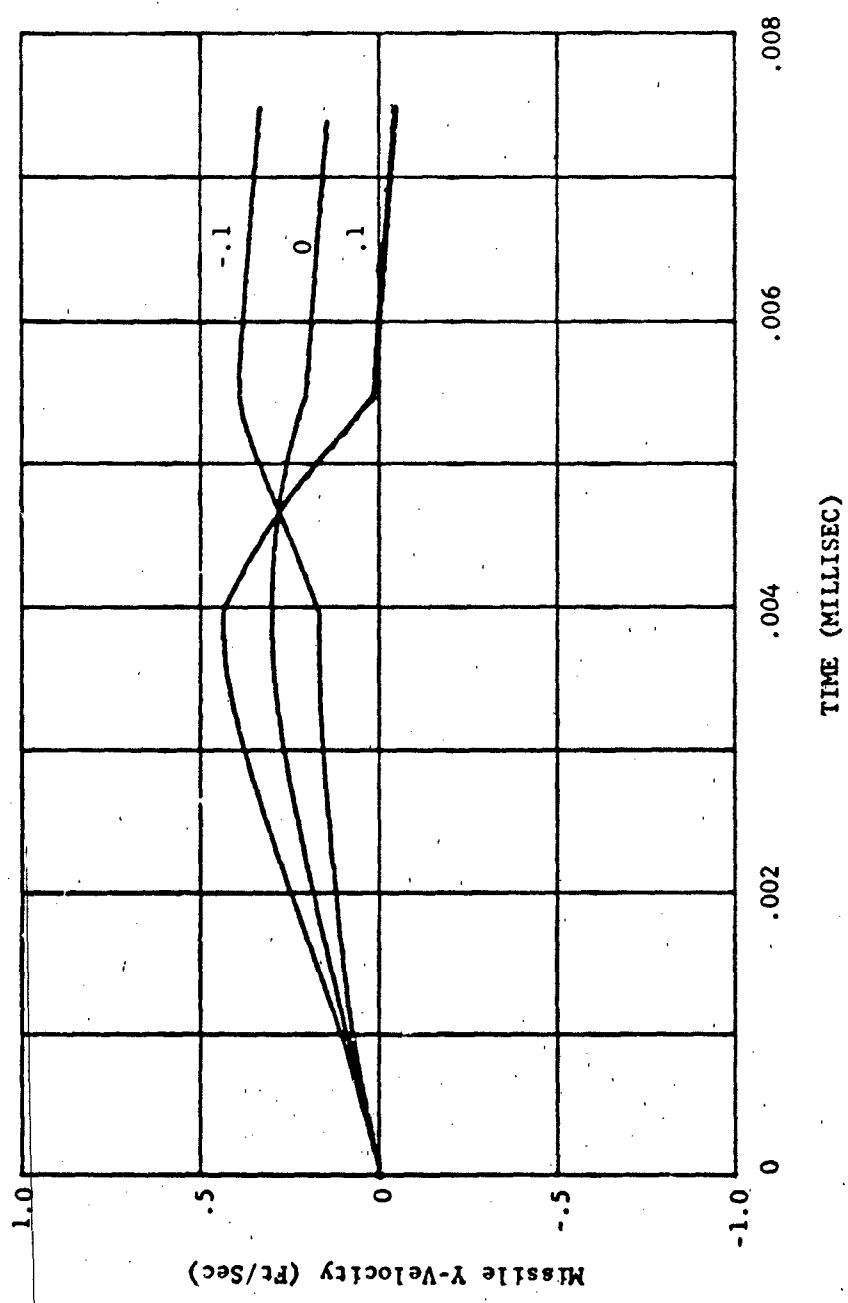


Figure 4-5. Missile Y-Velocity Versus Time

4.3 LAUNCH SIMULATION EQUATIONS

MISSILE EQUATIONS:

$$\Sigma M_{cg} = I_1 \ddot{\theta}$$

$$I_1 \ddot{\theta} = -F_1 D_1 + F_2 D_2 + (F_3 + F_4)(D_5 - D_3) + T_H(D_4 + D_3) - F_5(D_5 - D_3)$$

$$\Sigma F_x = M_1 \ddot{x}$$

$$M_1 \ddot{x} = (T_H + F_5 - F_3 - F_4 - W_1 \sin EA) \cos \theta + (F_1 + F_2 - W_1 \cos EA) \sin \theta$$

$$\Sigma F_y = M_1 \ddot{y}$$

$$M_1 \ddot{y} = (F_1 + F_2 - W_1 \cos EA) \cos \theta - (T_H + F_5 - F_3 - F_4 - W_1 \sin EA) \sin \theta$$

LAUNCHER EQUATIONS:

$$\Sigma M_T = I_2 \ddot{\psi}$$

$$I_2 \ddot{\psi} = s(\psi_s - \psi) - c\dot{\psi} + F_1(D_7 + x) - F_2(D_8 - x) + (F_3 + F_4)(D_6 - D_5) \\ - F_5(D_6 - D_5) - F_6 D_6 + W_2 \cos(EA - \psi) D - W_2 \sin(EA - \psi) D_{10}$$

RELATIVE MOTION:

$$y = -(D_6 - D_5)(1 - \cos \psi) + (D_8 - x) \sin \psi - (D_5 - D_3)(1 - \cos \theta) - D_2 \sin \theta$$

$$\dot{y} = -\dot{\psi}(D_6 - D_5) \sin \psi + \dot{\psi} D_8 \cos \psi - x \dot{\psi} \cos \psi - \dot{x} \sin \psi - \dot{\theta}(D_5 - D_3) \sin \theta - \dot{\theta} D_2 \cos \theta$$

$$\ddot{y} = -(D_6 - D_5) \dot{\psi}^2 \cos \psi - (D_6 - D_5) \ddot{\psi} \sin \psi - D_8 \dot{\psi}^2 \sin \psi + D_8 \ddot{\psi} \cos \psi \\ + x \dot{\psi}^2 \sin \psi - x \ddot{\psi} \cos \psi - 2 \dot{x} \dot{\psi} \cos \psi - \ddot{x} \sin \psi - (D_5 - D_3) \dot{\theta}^2 \cos \theta \\ - (D_5 - D_3) \ddot{\theta} \sin \theta + D_2 \dot{\theta}^2 \sin \theta - D_2 \ddot{\theta} \cos \theta$$

FOR THE MISSILE:

$$\begin{aligned}\text{LET } F_3 &= F_1 + FC \\ F_4 &= F_2 + FC\end{aligned}$$

THEN

$$I, \ddot{\theta} = -F_1 D_1 + F_2 D_2 + FC(F_1 + F_2)(D_5 - D_3) + TH(D_4 + D_3) - F_5(D_5 - D_3)$$

FROM SMALL ANGLE ASSUMPTION $\cos \theta \approx 1$
 $\sin \theta \approx \theta$

THEREFORE

$$\begin{aligned}M_1 \ddot{x} &= TH + F_5 - W_1 \sin EA - F_3 - F_4 \\ &= TH + F_5 - W_1 \sin EA - FC(F_1 + F_2)\end{aligned}$$

$$M_1 \ddot{y} = -W_1 \cos EA + F_1 + F_2 - TH \sin \theta$$

$$I, \ddot{\theta} = F_1[-D_1 + FC(D_5 - D_3)] + F_2[D_2 + FC(D_5 - D_3)] + TH(D_4 + D_3) - F_5(D_5 - D_3)$$

$$\begin{aligned}\text{LET } E_1 &= D_1 + FC(D_5 - D_3) \\ E_2 &= D_2 + FC(D_5 - D_3) \\ E_3 &= D_4 + D_3 \\ E_4 &= D_5 - D_3\end{aligned}$$

THEN

$$I, \ddot{\theta} = -E_1 F_1 + E_2 F_2 + E_3 TH - E_4 F_5$$

AND

$$F_1 + F_2 = M_1 \ddot{y} + TH \sin \theta + W_1 \cos EA$$

FOR THE LAUNCHER:

$$I_2 \ddot{\psi} = S(\psi_s - \psi) - C \dot{\psi} + F_1 D_7 - F_2 D_8 + (F_1 + F_2) X + F_3 \phi_1 + F_4 \phi_2 \\ - F_5 (D_6 - D_5) - F_6 D_6 + W_2 \cos(EA - \psi) D_9 - W_2 \sin(EA - \psi) D_{10}$$

WHERE IF F_1 IS + , $\phi_1 = D_6 - D_5$
 F_1 IS - , $\phi_1 = -(D_6 - D_5)$
 F_2 IS + , $\phi_2 = D_6 - D_5$
 F_2 IS - , $\phi_2 = -(D_6 - D_5)$

$$I_2 \ddot{\psi} = S(\psi_s - \psi) - C \dot{\psi} + F_1 D_7 - F_2 D_8 + (F_1 + F_2) X + F_1 F_C \phi_1 + F_2 F_C \phi_2 \\ - F_5 (D_6 - D_5) - F_6 D_6 + W_2 \cos(EA - \psi) D_9 - W_2 \sin(EA - \psi) D_{10}$$

$$I_2 \ddot{\psi} = S(\psi_s - \psi) - C \dot{\psi} + (D_7 + F_C \phi_1 + X) F_1 - (D_8 - F_C \phi_2 - X) F_2 \\ - F_5 (D_6 - D_5) - F_6 D_6 + W_2 \cos(EA - \psi) D_9 - W_2 \sin(EA - \psi) D_{10}$$

LET $X_1 = D_7 + F_C \phi_1 + X$
 $X_2 = D_8 - F_C \phi_2 - X$
 $Z_1 = -F_5 (D_6 - D_5) - F_6 D_6 + W_2 \cos(EA - \psi) D_9 - W_2 \sin(EA - \psi) D_{10}$

THEREFORE

$$I_2 \ddot{\psi} = S(\psi_s - \psi) - C \dot{\psi} + X_1 F_1 - X_2 F_2 + Z_1$$

FROM EQUATIONS FOR RELATIVE MOTION, GROUPING TERMS AND LETTING

$$z_2 = -(D_6 - D_5) \dot{\psi}^2 \cos \psi - D_8 \dot{\psi}^2 \sin \psi + \chi \dot{\psi}^2 \sin \psi - 2\dot{\chi} \dot{\psi} \cos \psi \\ - (D_5 - D_3) \dot{\theta}^2 \cos \theta + D_2 \dot{\theta}^2 \sin \theta$$

$$\chi_3 = D_8 \cos \psi - (D_6 - D_5) \sin \psi - \chi \cos \psi$$

$$\chi_4 = (D_5 - D_3) \sin \theta + D_2 \cos \theta$$

WE HAVE

$$\ddot{Y} = \chi_3 \ddot{\psi} - \chi_4 \ddot{\theta} - \ddot{\chi} \sin \psi + z_2$$

SINCE

$$F_1 + F_2 = M_1 \ddot{Y} + TH \sin \theta + W_1 \cos \epsilon A$$

$$= M_1 [\chi_3 \ddot{\psi} - \chi_4 \ddot{\theta} - \ddot{\chi} \sin \psi + z_2] + TH \sin \theta + W_1 \cos \epsilon A$$

LETTING

$$z_3 = -M_1 \ddot{\chi} \sin \psi + M_1 z_2 + TH \sin \theta + W_1 \cos \epsilon A$$

GIVES

$$F_1 + F_2 = M_1 \chi_3 \ddot{\psi} - M_1 \chi_4 \ddot{\theta} + z_3$$

SOLVING FOR F_1 :

$$I_1 \ddot{\theta} = -E_1 F_1 + E_2 F_2 + E_3 TH - E_4 F_5$$

$$E_1 F_1 - E_2 F_2 = -I_1 \ddot{\theta} + E_3 TH - E_4 F_5$$

$$E_2 F_1 + E_2 F_2 = E_2 M_1 X_3 \ddot{\psi} - E_2 M_1 X_4 \ddot{\theta} + E_2 z_3$$

$$(E_1 + E_2) F_1 = E_2 M_1 X_3 \ddot{\psi} - (E_2 M_1 X_4 + I_1) \ddot{\theta} + E_2 z_3 + E_3 TH - E_4 F_5$$

$$F_1 = \frac{E_2 M_1}{E_1 + E_2} X_3 \ddot{\psi} - \left[\frac{E_2 M_1}{E_1 + E_2} X_4 + \frac{I_1}{E_1 + E_2} \right] \ddot{\theta} + \frac{E_2}{E_1 + E_2} z_3 + \frac{E_3}{E_1 + E_2} TH - \frac{E_4}{E_1 + E_2} F_5$$

LETTING

$$E_5 = \frac{E_2 M_1}{E_1 + E_2}$$

$$E_7 = \frac{E_2}{E_1 + E_2}$$

$$E_9 = \frac{E_4}{E_1 + E_2}$$

$$E_6 = \frac{I_1}{E_1 + E_2}$$

$$E_8 = \frac{E_3}{E_1 + E_2}$$

$$F_1 = E_5 X_3 \ddot{\psi} - (E_5 X_4 + E_6) \ddot{\theta} + E_7 z_3 + E_8 TH - E_9 F_5$$

SOLVING FOR F_2 :

$$F_2 = -E_{10} X_3 \ddot{\psi} + (E_{10} X_4 + E_6) \ddot{\theta} + E_{11} z_3 - E_8 TH + E_9 F_5$$

WHERE $E_{10} = E_5 - M_1$

$E_{11} = 1 - E_7$

THEN, WITH

$$X_5 = E_5 X_4 + E_6$$

$$X_6 = E_{10} X_4 + E_6$$

$$z_4 = E_7 z_3 + E_8 TH - E_9 F_5$$

$$z_5 = E_{11} z_3 - E_8 TH + E_9 F_5$$

WE HAVE

$$F_1 = E_5 X_3 \ddot{\psi} - X_5 \ddot{\theta} + z_4$$

$$F_2 = -E_{10} X_3 \ddot{\psi} + X_6 \ddot{\theta} + z_5$$

THERE ARE THREE CASES TO BE CONSIDERED

CASE I : MISSILE IN INNER TUBE ($\ddot{\psi} = \ddot{\theta}$)

CASE II : FRONT SHOES DROP OFF ($F_1 = 0$)

CASE III : REAR SHOES DROP OFF ($F_1 = F_2 = 0$)

CASE I : $\ddot{\psi} = \ddot{\theta}$

$$I_2 \ddot{\psi} = S(\psi_f - \psi) - C\dot{\psi} + X_1 [E_5 X_3 \ddot{\psi} - X_5 \ddot{\theta} + z_4] - X_2 [-E_{10} X_3 \ddot{\psi} + X_6 \ddot{\theta} + z_5] + z_1$$

$$\ddot{\psi} = [S(\psi_f - \psi) - C\dot{\psi} + X_1 z_4 - X_2 z_5 + z_1] / [I_2 - E_5 X_1 X_3 + X_1 X_5 - E_{10} X_2 X_3 + X_2 X_6]$$

$$\ddot{\gamma} = (X_3 - X_4) \ddot{\psi} - \ddot{\alpha} \sin \psi + z_2$$

$$F_1 = E_5 X_3 \ddot{\psi} - X_5 \ddot{\theta} + z_4$$

$$F_2 = -E_{10} X_3 \ddot{\psi} + X_6 \ddot{\theta} + z_5$$

CASE II: $F_1 = 0$

$$I_1 \ddot{\theta} = E_2 F_2 + E_3 T_H$$

$$F_2 = M_1 \chi_3 \ddot{\psi} - M_1 \chi_4 \ddot{\theta} + z_3$$

$$\therefore I_1 \ddot{\theta} = E_2 M_1 \chi_3 \ddot{\psi} - E_2 M_1 \chi_4 \ddot{\theta} + E_2 z_3 + E_3 T_H$$

$$\ddot{\theta} (I_1 + E_2 M_1 \chi_4) = E_2 M_1 \chi_3 \ddot{\psi} + E_2 z_3 + E_3 T_H$$

LET $\chi_9 = I_1 + E_2 M_1 \chi_4$

$$\chi_{10} = E_2 M_1 \chi_3$$

$$z_7 = E_2 z_3 + E_3 T_H$$

$$\therefore \chi_9 \ddot{\theta} = \chi_{10} \ddot{\psi} + z_7$$

$$I_2 \ddot{\psi} = s(\psi_f - \psi) - c\dot{\psi} - \chi_2 F_2 + z_1$$

$$= s(\psi_f - \psi) - c\dot{\psi} + z_1 - \chi_2 M_1 \chi_3 \ddot{\psi} + \chi_2 M_1 \chi_4 \ddot{\theta} - \chi_2 z_3$$

$$\ddot{\psi} (I_2 + \chi_2 \chi_3 M_1) = s(\psi_f - \psi) - c\dot{\psi} + z_1 + \chi_2 \chi_4 M_1 \ddot{\theta} - \chi_2 z_3$$

LET $\chi_7 = I_2 + \chi_2 \chi_3 M_1$

$$\chi_8 = M_1 \chi_2 \chi_4$$

$$z_6 = z_1 - \chi_2 z_3$$

$$\therefore \chi_7 \ddot{\psi} = s(\psi_f - \psi) - c\dot{\psi} + \chi_8 \ddot{\theta} + z_6$$

SOLVING FOR $\ddot{\theta}$ AND $\ddot{\psi}$:

$$\ddot{\theta} = [s(\psi_f - \psi)\chi_{10} - c\chi_{10}\dot{\psi} + \chi_{10}z_6 + \chi_7 z_7] / (\chi_7 \chi_9 - \chi_8 \chi_{10})$$

$$\ddot{\psi} = [s(\psi_f - \psi)\chi_9 - c\chi_9\dot{\psi} + \chi_8 z_7 + \chi_9 z_6] / (\chi_7 \chi_9 - \chi_8 \chi_{10})$$

$$F_2 = M_1 \chi_3 \ddot{\psi} - M_1 \chi_4 \ddot{\theta} + z_3$$

$$\ddot{Y} = \chi_3 \ddot{\psi} - \chi_4 \ddot{\theta} - \ddot{X} \sin \psi + z_2$$

$$\text{CASE III : } F_1 = F_2 = 0$$

$$I_1 \ddot{\theta} = E_3 T_H$$

$$\ddot{\theta} = \frac{E_3}{I_1} T_H$$

$$I_2 \ddot{\psi} = s(\psi_f - \psi) - c \dot{\psi} + z_1$$

$$\ddot{\psi} = \frac{1}{I_2} [s(\psi_f - \psi) - c \dot{\psi} + z_1]$$

$$\ddot{Y} = \chi_3 \ddot{\psi} - \chi_4 \ddot{\theta} - \ddot{X} \sin \psi + z_2$$

4.4 Description and Program

This launcher simulation program has been written for the Hewlett-Packard 9100B with Extended Memory and Card Reader Units. As such, it is composed of a number of programs which perform specific calculations. Since the calculations involved were so lengthy the basic program had to be broken into two different parts.

Part I consists of programs P_0 , P_1 , P_2 and P_3 . These are the input and initialization parts of the program. The input data controlled by these programs is entered into the machine via marked Data Cards. After data is input and initial conditions are set, Part II of the program is entered. Part II consists of programs P_{20} , P_{25} , P_{26} , P_{30} , P_{35} , P_{36} , P_{37} , P_{38} , P_{39} , P_{40} , P_{41} , P_{42} , P_{10} , P_{11} and P_{12} . These programs perform the integrations of the equations and calculate all output data. Program P_{20} calculates thrust values; P_{25} calculates missile roll; P_{26} calculates motions along X-Axis; P_{30} calculates friction blast; P_{35} , P_{36} , P_{37} , P_{38} , P_{39} calculate values for the $X_1 - X_{10}$, $Z_1 - Z_6$, and $E_1 - E_{11}$ terms; P_{40} , P_{41} and P_{42} Case I programs solve the equations for the Case I conditions, P_{40} , P_{41} , and P_{42} Case II programs handle the Case II equations and P_{40} , P_{41} , and P_{42} Case III programs handle the Case III equations; P_{10} is the plot program; P_{11} the time increment program and P_{12} the time comparison program.

When the Case II conditions are reached the program will halt execution and the programs for this condition must be entered. The same procedure occurs for Case III conditions.

For plots, when entering P_{10} follow this procedure: (1) Enter P_{10} in 9100 B Memory (2) Press STOP, END (3) Place switch on PROGRAM mode (4) Press STEP PROGRAM (5) Enter three-digit memory location of value to be plotted versus time and (6) Enter P_{10} in extended memory. This must be performed each time a different plot variable is desired.

TABLE 4-1 LAUNCH SIMULATION MEMORY MAP

0			50		100		150		200	$\ddot{y}$
1			51		101		151		201	SF_x
2			52		102	P_{38}	152		202	$\ddot{x}$
3			53		103		153	P_{10}	203	$\ddot{y}$
4			54		104		154		204	τ
5			55		105		155	P_{11}	205	F_1
6	P_0	P_{20}	56		106		156		206	F_2
7			57		107		157		207	F_3
8			58		108		158		208	F_4
9			59		109		159	P_{12}	209	R_c
10			60		110		160		210	Y_{nu}
11			61	P_{35}	111		161		211	F_{u2}
12			62		112		162	I_r	212	F_{u1}
13			63		113		163	R_a	213	U_2
14			64		114	P_{39}	164	Z_7	214	U_2
15			65		115		165	Z_6	215	U_1
16			66		116		166	Z_5	216	S
17			67		117		167	X_6	217	t_p
18	P_1		68		118		168	X_{11}	218	Δt
19			69		119		169	X_{10}	219	I_f
20		P_{25}	70		120		170	X_9	220	I_r
21			71		121		171	X_8	221	I_m
22			72		122		172	X_7	222	F_1
23			73		123		173	Z_4	223	DE
24			74	P_{36}	124		174	X_5	224	F_{u1}
25			75		125		175	Z_3	225	W_2
26			76		126		176	Z_2	226	W_1
27			77		127	P_{40}	177	X_4	227	T_4
28			78		128		178	X_3	228	T_3
29			79		129		179	Z_1	229	T_2
30			80		130		180	X_2	230	T_1
31	P_2		81		131		181	X_1	231	T_5
32		P_{26}	82		132		182	V_2	232	T_4
33			83		133		183	V_1	233	T_3
34			84		134		184	BC	234	T_2
35			85		135		185	TD	235	T_1
36			86		136		186	PF	236	D_{12}
37			87	P_{37}	137	P_{41}	187	SF_3	237	D_{11}
38			88		138		188	t	238	D_{10}
39			89		139		189	ϕ	239	D_9
40			90		140		190	ϕ	240	D_8
41			91		141		191	$\ddot{\phi}$	241	D_7
42			92		142		192	$\dot{\phi}$	242	D_6
43			93		143		193	ϕ	243	D_5
44			94		144		194	ϕ	244	D_4
45			95		145	P_{42}	195	x	245	D_3
46	P_3	P_{30}	96		146		196	$\dot{x}$	246	D_2
47			97		147		197	$\ddot{x}$	247	D_1
48			98		148		198	y		
49			99		149		199	$\dot{y}$		

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
00	CLEAR	20				30	↑	27				60	2	02			
1	1	01				1	2	02				11	3	03			
2	STOP	41	D ₃	D ₂	D ₁	2	4	04				2	8	10			
3	PAUSE	57				3	2	02				3	FMT	42			
4	x→()	23				4	FMT	42				4	y→()	40			
5	f	15				5	y→()	40				5	f	15			
6	2	02				6	CLEAR	20				6	↑	27			
7	4	04				7	3	03				7	2	02			
8	6	06				8	STOP	41	D ₀	D ₀	D ₁	8	3	03			
9	FMT	42				9	PAUSE	57				9	6	06			
a	y→()	40				a	x→()	23				a	FMT	42			
b	↓	25				b	f	15				b	y→()	40			
c	2	02				c	2	02				c	CLEAR	20			
d	4	04				d	4	04				d	5	05			
10	7	07				40	0	00				70	STOP	41	T ₃	T ₂	T ₁
1	FMT	42				1	FMT	42				1	PAUSE	57			
2	y→()	40				2	y→()	40				2	x→()	23			
3	f	15				3	↓	25				3	f	15			
4	↑	27				4	2	02				4	2	02			
5	2	02				5	4	04				5	3	03			
6	4	04				6	1	01				6	4	04			
7	5	05				7	FMT	42				7	FMT	42			
8	FMT	42				8	y→()	40				8	y→()	40			
9	y→()	40				9	f	15				9	↓	25			
a	CLEAR	20				a	↑	27				a	2	02			
b	2	02				b	2	02				b	3	03			
c	STOP	41	D ₄	D ₅	D ₄	c	3	03				c	5	05			
d	PAUSE	57				d	9	11				d	FMT	42			
20	x→()	23				50	FMT	42				Storage					
1	f	15				1	y→()	40									
2	2	02				2	CLEAR	20									
3	4	04				3	4	04									
4	3	03				4	STOP	41	D ₁₂	D ₁₁	D ₁₀						
5	FMT	42				5	PAUSE	57									
6	y→()	40				6	x→()	23									
7	↓	25				7	f	15									
8	2	02				8	2	02									
9	4	04				9	3	03									
a	4	04				a	7	07									
b	FMT	42				b	FMT	42									
c	y→()	40				c	y→()	40									
d	f	15				d	↓	25									

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
80	y→()	40				b0	y→()	40				0					
1	f	15				1	↓	25				1					
2	↑	27				2	2	02				2					
3	2	02				3	2	02				3					
4	3	03				4	9	11				4					
5	3	03				5	FMT	42				5					
6	FMT	42				6	y→()	40				6					
7	y→()	40				7	f	15				7					
8	CLEAR	20				8	↑	27				8					
9	6	06				9	2	02				9					
a	STOP	41	T ₁	T ₅	T ₄	a	2	02				a					
b	PAUSE	57				b	7	07				b					
c	x→()	23				c	FMT	42				c					
d	f	15				d	y→()	40				d					
90	2	02				C0	CLEAR	20				0					
1	3	03				1	8	10				1					
2	1	01				2	STOP	41				2					
3	FMT	42				3	PAUSE	57				3					
4	y→()	40				4	x→()	23				4					
5	↓	25				5	f	15				5					
6	2	02				6	2	02				6					
7	3	03				7	2	02				7					
8	2	02				8	5	05				8					
9	FMT	42				9	FMT	42				9					
a	y→()	40				a	y→()	40				a					
b	f	15				b	↓	25				b					
c	↑	27				c	2	02				c					
d	2	02				d	2	02				d					
00	3	03				d0	6	06				Storage					
1	0	00				1	FMT	42									
2	FMT	42				2	y→()	40									
3	y→()	40				3	f	15									
4	CLEAR	20				4	↑	27									
5	7	07				5	2	02									
6	STOP	41	T ₄	T ₃	T ₂	6	1	01									
7	PAUSE	57				7	6	06									
8	x→()	23				8	FMT	42									
9	f	15				9	y→()	40									
a	2	02				a	1	01									
b	2	02				b	FMT	42									
c	8	10				c	GO TO	44									
d	FMT	42				d	END	46									

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
00	CLEAR	20				30	f	15				60	FMT	42			
1	9	11				1	↑	27				1	y→()	40			
2	STOP	41	F _c	D _F	F _N	2	2	02				2	↓	25			
3	PAUSE	57				3	1	01				3	2	02			
4	x→()	23				4	9	11				4	1	01			
5	f	15				5	FMT	42				5	2	02			
6	2	02				6	y→()	40				6	FMT	42			
7	2	02				7	CLEAR	20				7	y→()	40			
8	3	03				8	1	01				8	f	15			
9	FMT	42				9	1	01				9	↑	27			
a	y→()	40				a	STOP	41	U ₃	U ₂	U ₁	a	2	02			
b	↓	25				b	PAUSE	57				b	1	01			
c	2	02				c	x→()	23				c	7	07			
d	2	02				d	f	15				d	FMT	42			
10	4	04				40	2	02				70	y→()	40			
1	FMT	42				1	1	01				1	CLEAR	20			
2	y→()	40				2	4	04				2	1	01			
3	f	15				3	FMT	42				3	3	03			
4	↑	27				4	y→()	40				4	STOP	41	at	R _c	R _a
5	2	02				5	↓	25				5	PAUSE	57			
6	2	02				6	2	02				6	x→()	23			
7	2	02				7	1	01				7	f	15			
8	FMT	42				8	5	05				8	2	02			
9	y→()	40				9	FMT	42				9	0	00			
a	CLEAR	20				a	y→()	40				a	9	11			
b	1	01				b	f	15				b	FMT	42			
c	0	00				c	↑	27				c	y→()	40			
d	STOP	41	I ₂	I _r	I _m	d	2	02				d	↓	25			
20	PAUSE	57				50	1	01				Storage					
1	x→()	23				1	3	03				f					
2	f	15				2	FMT	42				e					
3	2	02				3	y→()	40				d					
4	2	02				4	CLEAR	20				c					
5	0	00				5	1	01				b					
6	FMT	42				6	2	02				a					
7	y→()	40				7	STOP	41	t _p	F ₀₂	F ₀₁	9					
8	↓	25				8	PAUSE	57				8					
9	2	02				9	x→()	23				7					
a	2	02				a	f	15				6					
b	1	01				b	2	02				5					
c	FMT	42				c	1	01				4					
d	y→()	40				d	1	01				3					
												2					
												1					
												0					

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
8	0	1	01			0						0					
	1	6	06			1						1					
	2	3	03			2						2					
	3	FMT	42			3						3					
	4	y → ()	40			4						4					
	5	f	15			5						5					
	6	↑	27			6						6					
	7	2	02			7						7					
	8	1	01			8						8					
	9	8	10			9						9					
	a	FMT	42			a						a					
	b	y → ()	40			b						b					
	c	CLEAR	20			c						c					
	d	1	01			d						d					
9	0	4	04			0						0					
	1	STOP	41			1						1					
	2	PAUSE	57			2						2					
	3	x → ()	23			3						3					
	4	f	15			4						4					
	5	1	01			5						5					
	6	8	10			6						6					
	7	7	07			7						7					
	8	FMT	42			8						8					
	9	y → ()	40			9						9					
	a	↓	25			a						a					
	b	1	01			b						b					
	c	6	06			c						c					
	d	2	02			d						d					
a	0	FMT	42			0											
	1	y → ()	40			1											
	2	f	15			2											
	3	↑	27			3											
	4	2	02			4											
	5	0	00			5											
	6	1	01			6											
	7	FMT	42			7											
	8	y → ()	40			8											
	9	2	02			9											
	a	FMT	42			a											
	b	GO TO 94				b											
	c	END	46			c											
	d					d											

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
00	CONT	47				30	7	07				60	6	06			
1	2	02				1	FMT	42				1	FMT	42			
2	4	04				2	π	56				2	π	56			
3	3	03				3	ROLL $\uparrow$	22				3	X	36			
4	FMT	42				4	+	33				4	2	02			
5	π	56				5	$\downarrow$	25				5	0	00			
6	$\uparrow$	27				6	$\div$	35				6	5	05			
7	2	02				7	2	02				7	FMT	42			
8	4	04				8	0	00				8	π	56			
9	5	05				9	5	05				9	$\uparrow$	27			
a	FMT	42				a	FMT	42				a	y	55			
b	π	56				b	y $\rightarrow$ ()	40				b	2	02			
c	-	34				c	2	02				c	0	00			
d	2	02				d	1	01				d	6	06			
10	1	01				40	6	06				70	FMT	42			
1	6	06				1	FMT	42				1	π	56			
2	FMT	42				2	π	56				2	x $\leftrightarrow$ y	30			
3	π	56				3	COS X	73				3	y	55			
4	$\uparrow$	27				4	$\uparrow$	27				4	+	33			
5	ROLL $\downarrow$	31				5	2	02				5	2	02			
6	SIN X	70				6	2	02				6	2	02			
7	X	36				7	6	06				7	2	02			
8	ROLL $\uparrow$	22				8	FMT	42				8	FMT	42			
9	COS X	73				9	π	56				9	π	56			
a	x $\leftrightarrow$ y	30				a	X	36				a	X	36			
b	2	02				b	$\downarrow$	25				b	$\downarrow$	25			
c	4	04				c	x $\leftrightarrow$ y	30				c	+	33			
d	6	06				d	-	34				d	2	02			
20	FMT	42				50	2	02				Storage					
1	π	56				1	0	00									
2	X	36				2	6	06									
3	ROLL $\downarrow$	31				3	FMT	42									
4	x $\leftrightarrow$ y	30				4	y $\rightarrow$ ()	40									
5	-	34				5	2	02									
6	2	02				6	1	01									
7	2	02				7	6	06									
8	6	06				8	FMT	42									
9	FMT	42				9	π	56									
a	π	56				a	SIN X	70									
b	X	36				b	$\uparrow$	27									
c	2	02				c	2	02									
d	4	04				d	2	02									

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
8	0	00				b	0	11									
1	7	07				1	7	07				1					
2	FMT	42				2	FMT	42				2					
3	y→()	40				3	y→()	40				3					
4	0	00				4	1	01				4					
5	↑	27				5	9	11				5					
6	2	02				6	6	06				6					
7	0	00				7	FMT	42				7					
8	8	10				8	y→()	40				8					
9	FMT	42				9	1	01				9					
a	y→()	40				a	9	11				a					
b	2	02				b	5	05				b					
c	0	00				c	FMT	42				c					
d	4	04				d	y→()	40				d					
9	FMT	42				c	1	01				0					
1	y→()	40				1	9	11				1					
2	2	02				2	4	04				2					
3	0	00				3	FMT	42				3					
4	3	03				4	y→()	40				4					
5	FMT	42				5	1	01				5					
6	y→()	40				6	9	11				6					
7	2	02				7	3	03				7					
8	0	00				8	FMT	42				8					
9	2	02				9	y→()	40				9					
a	FMT	42				a	1	01				a					
b	y→()	40				b	9	11				b					
c	2	02				c	2	02				c					
d	0	00				d	FMT	42				d					
a	0	00				d	y→()	40				Storage					
1	FMT	42				1	1	01									
2	y→()	40				2	9	11									
3	1	01				3	1	01									
4	9	11				4	FMT	42									
5	9	11				5	y→()	40									
6	FMT	42				6	3	03									
7	y→()	40				7	FMT	42									
8	1	01				8	Go To 44										
9	9	11				9	END 44										
a	8	10				a											
b	FMT	42				b											
c	y→()	40				c											
d	1	01				d											

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
0	CONT	47				3	X	36				6	0	00			
1	0	00				1	2	02				1	7	07			
2	↑	27				2	1	01				2	FMT	42			
3	1	01				3	9	11				3	π	56			
4	9	11				4	FMT	42				4	X→y	30			
5	0	00				5	π	56				5	-	34			
6	FMT	42				6	X	36				6	↓	25			
7	y→()	40				7	y→()	40				7	X	36			
8	1	01				8	f	15				8	2	02			
9	8	10				9	2	02				9	0	00			
a	9	11				a	4	04				a	6	06			
b	FMT	42				b	2	02				b	FMT	42			
c	y→()	40				c	FMT	42				c	π	56			
d	1	01				d	π	56				d	↑	27			
1	8	10				4	↑	27				7	2	02			
1	8	10				1	2	02				1	4	04			
2	FMT	42				2	4	04				2	0	00			
3	y→()	40				3	3	03				3	FMT	42			
4	1	01				4	FMT	42				4	π	56			
5	6	06				5	π	56				5	X	36			
6	3	03				6	-	34				6	↓	25			
7	FMT	42				7	2	02				7	+	33			
8	π	56				8	0	00				8	2	02			
9	↑	27				9	5	05				9	4	04			
a	2	02				a	FMT	42				a	1	01			
b	1	01				b	π	56				b	FMT	42			
c	0	00				c	↑	27				c	π	56			
d	FMT	42				d	y→()	40				d	↑	27			
2	y→()	40				5	e	12				Storage					
1	2	02				1	2	02									
2	2	02				2	0	00									
3	4	04				3	6	06									
4	FMT	42				4	FMT	42									
5	π	56				5	π	56									
6	↑	27				6	+	33									
7	X	36				7	2	02									
8	3	03				8	2	02									
9	9	11				9	2	02									
a	.	21				a	FMT	42									
b	4	04				b	π	56									
c	7	07				c	X	36									
d	8	10				d	2	02									

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
80	e	12				b0	↓	25				0					
1	x	36				1	+	33				1					
2	↓	25				2	f	15				2					
3	-	34				3	÷	35				3					
4	2	02				4	1	01				4					
5	1	01				5	8	10				5					
6	6	06				6	6	06				6					
7	FMT	42				7	FMT	42				7					
8	π	56				8	y→()	40				8					
9	x→()	23				9	CLEAR	20				9					
a	e	12				a	↑	27				a					
b	cos x	73				b	1	01				b					
c	↑	27				c	8	10				c					
d	2	02				d	5	05				d					
90	2	02				c0	FMT	42				0					
1	5	05				1	y→()	40				1					
2	FMT	42				2	STOP	41				2					
3	π	56				3	END	46				3					
4	x	36				4						4					
5	2	02				5						5					
6	3	03				6						6					
7	9	11				7						7					
8	FMT	42				8						8					
9	π	56				9						9					
a	x	36				a						a					
b	↓	25				b						b					
c	-	34				c						c					
d	e	12				d						d					
0	SIN X	70				0						Storage					
1	↑	27				1						f					
2	2	02				2						e					
3	2	02				3						d					
4	5	05				4						c					
5	FMT	42				5						b					
6	π	56				6						a					
7	x	36				7						9					
8	2	02				8						8					
9	3	03				9						7					
a	B	10				a						6					
b	FMT	42				b						5					
c	π	56				c						4					
d	x	36				d						3					
												2					
												1					
												0					

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
00	1	01				30	-	34				60	-	34			
1	8	10				1	ROLL ↑	22				1	ROLL ↑	22			
2	8	10				2	$x \Rightarrow y$	30				2	$x \Rightarrow y$	30			
3	FMT	42				3	-	34				3	-	34			
4	π	56				4	↓	25				4	↓	25			
5	$x \rightarrow ()$	23				5	$x \Rightarrow y$	30				5	$x \Rightarrow y$	30			
6	f	15				6	÷	35				6	÷	35			
7	↑	27				7	2	02				7	2	02			
8	2	02				8	3	03				8	2	02			
9	3	03				9	0	00				9	8	10			
a	5	05				a	FMT	42				a	FMT	42			
b	FMT	42				b	π	56				b	π	56			
c	π	56				c	↑	27				c	↑	27			
d	IF $x < y$	52				d	2	02				d	2	02			
10	2	02				40	2	02				70	2	02			
1	0	00				1	9	11				1	9	11			
2	÷	35				2	FMT	42				2	FMT	42			
3	↑	27				3	π	56				3	π	56			
4	2	02				4	$x \Rightarrow y$	30				4	-	34			
5	3	03				5	-	34				5	ROLL ↓	31			
6	0	00				6	ROLL ↓	31				6	x	36			
7	FMT	42				7	x	36				7	↓	25			
8	π	56				8	↓	25				8	+	33			
9	ROLL ↑	22				9	+	33				9	GO TO	44			
a	x	36				a	GO TO	44				a	d	17			
b	GO TO	44				b	d	17				b	2	02			
c	d	17				c	2	02				c	e	12			
d	2	02				d	e	12				d	↑	27			
20	↑	27				50	↑	27				Storage					
1	2	02				1	f	15				F	t				
2	3	03				2	↑	27				E	T2, T3, T4				
3	4	04				3	2	02				d					
4	FMT	42				4	3	03				c					
5	π	56				5	3	03				b					
6	$x \rightarrow ()$	23				6	FMT	42				a					
7	e	12				7	π	56				9					
8	ROLL ↑	22				8	$x \rightarrow ()$	23				8					
9	$x \Rightarrow y$	30				9	e	12				7					
a	IF $x < y$	52				a	IF $x < y$	52				6					
b	4	04				b	7	07				5					
c	d	17				c	c	16				4					
d	ROLL ↑	22				d	ROLL ↑	22				3					
												2					
												1					
												0					

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
80	f	15				b0	↑	27				0					
1	↑	27				1	2	02				1					
2	2	02				2	3	03				2					
3	3	03				3	1	01				3					
4	2	02				4	FMT	42				4					
5	FMT	42				5	π	56				5					
6	π	56				6	IF x<y	52				6					
7	x→y	23				7	d	17				7					
8	e	12				8	0	00				8					
9	IF x<y	52				9	ROLL ↑	22				9					
a	a	13				a	-	34				a					
b	b	14				b	ROLL ↑	22				b					
c	ROLL ↑	22				c	x↔y	30				c					
d	-	34				d	-	34				d					
90	ROLL ↑	22				c0	↓	25				0					
1	x↔y	30				1	x↔y	30				1					
2	-	34				2	÷	35				2					
3	↓	25				3	2	02				3					
4	x↔y	30				4	2	02				4					
5	÷	35				5	7	07				5					
6	2	02				6	FMT	42				6					
7	2	02				7	π	56				7					
8	7	07				8	X	36				8					
9	FMT	42				9	x↔y	30				9					
a	π	56				a	-	34				a					
b	↑	27				b	GO TO	44				b					
c	2	02				c	d	17				c					
d	2	02				d	2	02				d					
a0	B	10				d0	CLEAR X	37				Storage					
1	FMT	42				1	↑	27				c					
2	π	56				2	2	02				b					
3	-	34				3	0	00				d					
4	ROLL ↓	31				4	4	04				c					
5	X	36				5	FMT	42				b					
6	↓	25				6	y→0	40				a					
7	+	33				7	2	02				9					
8	GO TO	44				8	5	05				8					
9	d	17				9	FMT	42				7					
a	2	02				a	GO TO	44				6					
b	e	12				b	END	46				5					
c	↑	27				c						4					
d	f	15				d						3					
												2					
												1					
												0					

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
0	CONT	47				3	π	56				6	$\uparrow$	27			
1	2	02				1	X	36				1	2	02			
2	0	00				2	2	02				2	0	00			
3	3	03				3	0	00				3	$\div$	11			
4	FMT	42				4	6	06				4	FMT	42			
5	π	56				5	FMT	42				5	π	56			
6	X $\rightarrow$ ()	23				6	π	56				6	X	36			
7	f	15				7	$\uparrow$	27				7	$\downarrow$	25			
8	2	02				8	y	55				8	X $\rightarrow$ y	30			
9	1	01				9	$\downarrow$	25				9	-	34			
a	0	00				a	+	33				a	2	02			
b	FMT	42				b	2	02				b	4	04			
c	π	56				c	0	00				c	5	05			
d	SINX	70				d	5	05				d	FMT	42			
1	$\uparrow$	27				4	FMT	42				7	π	56			
1	y	55				1	π	56				1	$\uparrow$	27			
2	2	02				2	$\uparrow$	27				2	X	36			
3	2	02				3	y	55				3	e	12			
4	6	06				4	$\downarrow$	25				4	X	36			
5	FMT	42				5	+	33				5	2	02			
6	π	56				6	2	02				6	2	02			
7	$\uparrow$	27				7	2	02				7	0	00			
8	3	03				8	2	02				8	FMT	42			
9	2	02				9	FMT	42				9	π	56			
a	.	21				a	π	56				a	+	33			
b	2	02				b	X	36				b	$\downarrow$	25			
c	$\div$	35				c	1	01				c	$\div$	35			
d	y $\rightarrow$ ()	40				d	8	10				d	y $\rightarrow$ ()	40			
2	e	12				5	4	04				Storage					
1	$\downarrow$	25				1	FMT	42				F	i				
2	X	36				2	y $\rightarrow$ ()	40				E	X	M			
3	2	02				3	2	02				d					
4	0	00				4	4	04				c					
5	2	02				5	3	03				b					
6	FMT	42				6	FMT	42				a					
7	π	56				7	π	56				9					
8	X	36				8	X	36				8					
9	X	36				9	2	02				7					
a	2	02				a	0	00				6					
b	4	04				b	4	04				5					
c	5	05				c	FMT	42				4					
d	FMT	42				d	π	56				3					
												2					
												1					
												0					

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
B0	-	34				b0	8	10				0					
1	e	12				1	FMT	42				1					
2	2	02				2	π	56				2					
3	0	00				3	x	36				3					
4	3	03				4	2	02				4					
5	FMT	42				5	1	01				5					
6	y $\rightarrow$ ()	40				6	0	00				6					
7	2	02				7	FMT	42				7					
8	0	00				8	π	56				8					
9	2	02				9	+	33				9					
a	FMT	42				a	2	02				a					
b	π	56				b	1	01				b					
c	x $\rightarrow$ ()	23				c	0	00				c					
d	-	34				d	FMT	42				d					
90	f	15				C0	y $\rightarrow$ ()	40				0					
1	f	15				1	2	02				1					
2	+	33				2	6	06				2					
3	2	02				3	FMT	42				3					
4	$\div$	35				4	GO TO	44				4					
5	2	02				5	END	46				5					
6	1	01				6						6					
7	8	10				7						7					
8	FMT	42				8						8					
9	π	56				9						9					
a	x	36				a						a					
b	x $\rightarrow$ ()	67				b						b					
c	-	34				c						c					
d	f	15				d						d					
a0	+	33				0						Storage					
1	2	02				1											
2	0	00				2											
3	2	02				3											
4	FMT	42				4											
5	y $\rightarrow$ ()	40				5											
6	x $\rightarrow$ ()	67				6											
7	-	34				7											
8	f	15				8											
9	+	33				9											
a	2	02				a											
b	$\div$	35				b											
c	2	02				c											
d	1	01				d											

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
0	CONT	47				3						6	7	07			
1	1	01				1						1	FMT	42			
2	B	10				2						2	π	56			
3	4	04				3						3	$x \rightarrow y$	30			
4	FMT	42				4						4	-	34			
5	π	56				5						5	2	02			
6	$\uparrow$	27				6						6	0	00			
7	2	02				7						7	4	04			
8	0	00				8						8	FMT	42			
9	4	04				9						9	π	56			
a	FMT	42				a						a	+	33			
b	π	56				b						b	2	02			
c	-	34				c						c	2	02			
d	2	02				d	CONT	47				d	6	06			
1	1	01				4	1	01				7	FMT	42			
1	6	06				1	9	11				1	π	56			
2	FMT	42				2	7	07				2	$\uparrow$	27			
3	π	56				3	FMT	42				3	3	03			
4	SIN X	70				4	π	56				4	2	02			
5	$\uparrow$	27				5	$x \rightarrow ()$	23				5	.	21			
6	2	02				6	f	15				6	2	02			
7	2	02				7	2	02				7	$\div$	35			
8	6	06				8	1	01				8	$\downarrow$	25			
9	FMT	42				9	6	06				9	$\div$	35			
a	π	56				a	FMT	42				a	$y \rightarrow ()$	40			
b	X	36				b	π	56				b	e	12			
c	$\downarrow$	25				c	SIN X	70				c	1	01			
d	+	33				d	$\uparrow$	27				d	9	11			
2	0	00				5	2	02				Storage					
1	IF X=y	52				1	2	02									
2	2	02				2	6	06									
3	5	05				3	FMT	42									
4	$\uparrow$	27				4	π	56									
5	2	02				5	X	36									
6	0	00				6	1	01									
7	7	07				7	8	10									
8	FMT	42				8	4	04									
9	$y \rightarrow ()$	40				9	FMT	42									
a	CONT	47				a	π	56									
b						b	+	33									
c						c	2	02									
d						d	0	00									

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
80	7	07				b0	5	05				0					
1	FMT	42				1	FMT	42				1					
2	y → ()	40				2	y → ()	40				2					
3	f	15				3	3	03				3					
4	+	33				4	0	00				4					
5	2	02				5	FMT	42				5					
6	÷	35				6	GO TO	44				6					
7	2	02				7	END	46				7					
8	1	01				8						8					
9	8	10				9						9					
a	FMT	42				a						a					
b	π	56				b						b					
c	x	36				c						c					
d	↑	27				d						d					
90	ROLL ↓	31				0						0					
1	1	01				1						1					
2	9	11				2						2					
3	6	06				3						3					
4	FMT	42				4						4					
5	π	56				5						5					
6	+	33				6						6					
7	x → ()	23				7						7					
8	f	15				8						8					
9	1	01				9						9					
a	9	11				a						a					
b	6	06				b						b					
c	FMT	42				c						c					
d	y → ()	40				d						d					
0	f	15				0						Storage					
1	+	33				1											
2	2	02				2											
3	÷	35				3											
4	↓	25				4											
5	x	36				5											
6	1	01				6											
7	9	11				7											
8	5	05				8											
9	FMT	42				9											
a	π	56				a											
b	+	33				b											
c	1	01				c											
d	9	11				d											

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
0	CONT	47				3	0	01				6	0	01			
1	2	02				1	8	10				1	5	05			
2	4	04				2	3	03				2	FMT	42			
3	3	03				3	FMT	42				3	π	56			
4	FMT	42				4	y → ()	40				4	If x < y	52			
5	π	56				5	2	02				5	6	06			
6	↑	27				6	0	00				6	d	17			
7	2	02				7	6	06				7	CONT	47			
8	4	04				8	FMT	42				8	0	00			
9	2	02				9	π	56				9	↑	27			
a	FMT	42				a	↑	27				a	GO TO	44			
b	π	56				b	0	00				b	c	16			
c	x → ()	23				c	If x < y	52				c	8	10			
d	e	12				d	4	04				d	↑	27			
1	y → ()	40				4	b	14				7	↓	25			
1	f	15				1	e	12				1	-	34			
2	2	02				2	↑	27				2	y → ()	40			
3	0	00				3	f	15				3	f	15			
4	5	05				4	+	33				4	↓	25			
5	FMT	42				5	↓	25				5	2	02			
6	π	56				6	CHG SIGN	32				6	1	01			
7	↑	27				7	↑	27				7	4	04			
8	0	00				8	GO TO	44				8	FMT	42			
9	If x < y	52				9	5	05				9	π	56			
a	2	02				a	1	01				a	If x < y	52			
b	9	11				b	e	12				b	9	11			
c	CONT	47				c	↑	27				c	4	04			
d	f	15				d	f	15				d	↑	27			
2	↑	27				5	-	34				Storage					
1	e	12				1	CONT	47				F	D ₀ x-u, x-u ₀				
2	+	33				2	1	01				E	D ₀				
3	↓	25				3	8	10				D					
4	CHG SIGN	32				4	2	02				C					
5	↑	27				5	FMT	42				b					
6	GO TO	44				6	y → ()	40				a					
7	2	02				7	1	01				9					
8	d	17				8	9	11				8					
9	e	12				9	5	05				7					
a	↑	27				a	FMT	42				6					
b	f	15				b	π	56				5					
c	-	34				c	↑	27				4					
d	CONT	47				d	2	02				3					

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
B0	2	02				b0	FMT	42				0					
1	1	01				1	π	56				1					
2	5	05				2	$\uparrow$	27				2					
3	FMT	42				3	2	02				3					
4	π	56				4	1	01				4					
5	-	34				5	2	02				5					
6	2	02				6	FMT	42				6					
7	1	01				7	π	56				7					
8	2	02				8	-	34				8					
9	FMT	42				9	ROLL $\downarrow$	31				9					
a	π	56				a	$x \rightarrow y$	30				a					
b	$x \rightarrow y$	30				b	$\div$	35				b					
c	$\div$	35				c	f	15				c					
d	f	15				d	x	36				d					
90	x	36				c0	$\downarrow$	25				0					
1	Go TO	44				1	+	33				1					
2	c	16				2	Go TO	44				2					
3	B	10				3	c	16				3					
4	$\uparrow$	27				4	B	10				4					
5	$\downarrow$	25				5	CONT	47				5					
6	-	34				6	0	00				6					
7	$y \rightarrow ()$	40				7	$\uparrow$	27				7					
8	f	15				8	CONT	47				8					
9	$\downarrow$	25				9	2	02				9					
a	2	02				a	0	00				a					
b	1	01				b	8	10				b					
c	3	03				c	FMT	42				c					
d	FMT	42				d	$y \rightarrow ()$	40				d					
a0	π	56				d0	3	03				Storage					
1	IF $x \neq y$	52				1	5	05									
2	c	16				2	FMT	42									
3	5	05				3	Go TO	44									
4	$\uparrow$	27				4	END	46									
5	2	02				5											
6	1	01				6											
7	4	04				7											
8	FMT	42				8											
9	π	56				9											
a	-	34				a											
b	2	02				b											
c	1	01				c											
d	1	01				d											

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
00	CONT	47				30	+	33				60	SIN X	70			
1	I	01				1	↓	25				1	x→()	23			
2	9	11				2	CHK SKN	32				2	-	34			
3	5	05				3	↑	27				3	d	17			
4	FMT	42				4	2	02				4	x→y	30			
5	π	56				5	4	04				5	e	12			
6	↑	27				6	0	00				6	x	36			
7	x→()	23				7	FMT	42				7	↓	25			
8	f	15				8	π	56				8	+	33			
9	2	02				9	+	33				9	2	02			
a	4	04				a	I	01				a	3	03			
b	I	01				b	8	10				b	9	11			
c	FMT	42				c	0	00				c	FMT	42			
d	π	56				d	FMT	42				d	π	56			
10	+	33				40	y→()	40				70	x	36			
1	I	01				1	2	02				1	y→()	40			
2	8	10				2	I	01				2	-	34			
3	3	03				3	6	06				3	c	16			
4	FMT	42				4	FMT	42				4	e	12			
5	π	56				5	π	56				5	↑	27			
6	↑	27				6	↑	27				6	x→()	67			
7	2	02				7	cos x	73				7	-	34			
8	2	02				8	x→y	30				8	e	12			
9	2	02				9	SIN X	70				9	x	36			
a	FMT	42				a	x→()	23				a	x→()	67			
b	π	56				b	e	12				b	-	34			
c	x	36				c	y→()	40				c	f	15			
d	ROLL ↓	31				d	-	34				d	↑	27			
20	+	33				50	f	15				Storage					
1	I	01				1	I	01				F	X:		H1		
2	8	10				2	9	11				E	H2, W1		H5		
3	I	01				3	2	02				d			H6		
4	FMT	42				4	FMT	42				c			D ₀ P1		
5	y→()	40				5	π	56				b			D _x -D _y		
6	↓	25				6	↑	27				a			D _x -D _y H _y		
7	I	01				7	ROLL ↓	31				9			H4		
8	8	10				8	cos x	73				8			H3		
9	2	02				9	x→()	23				7			22A		
a	FMT	42				a	-	34				6					
b	π	56				b	e	12				5					
c	x	36				c	x	36				4					
d	f	15				d	ROLL ↑	22				3					
												2					
												1					
												0					

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
80	X ← C	67				b0	FMT	42				0					
1	-	34				1	π	56				1					
2	d	17				2	X	36				2					
3	X	36				3	↓	25				3					
4	↓	25				4	-	34				4					
5	-	34				5	1	01				5					
6	2	02				6	4	04				6					
7	3	03				7	2	02				7					
8	8	10				8	FMT	42				8					
9	FMT	42				9	π	56				9					
a	π	56				a	↑	27				a					
b	X	36				b	2	02				b					
c	CONT	47				c	0	00				c					
d	X ← C	67				d	8	10				d					
90	-	34				c0	FMT	42				0					
1	C	16				1	π	56				1					
2	X → y	30				2	X	36				2					
3	-	34				3	↓	25				3					
4	2	02				4	-	34				4					
5	2	02				5	1	01				5					
6	5	05				6	7	07				6					
7	FMT	42				7	9	11				7					
8	π	56				8	FMT	42				8					
9	X	36				9	y → C	40				9					
a	2	02				a	3	03				a					
b	4	04				b	6	06				b					
c	2	02				c	FMT	42				c					
d	FMT	42				d	Go To	44				d					
a0	π	56				d0	END	46				Storage					
1	↑	27				1						f					
2	2	02				2						a					
3	4	04				3						d					
4	3	03				4						c					
5	FMT	42				5						b					
6	π	56				6						a					
7	-	34				7						9					
8	y → C	40				8						8					
9	-	34				9						7					
a	b	14				a						6					
b	2	02				b						5					
c	0	00				c						4					
d	7	07				d						3					
												2					
												1					
												0					

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			X	Y	Z				X	Y	Z				X	Y	Z
00	CONT	47				30	COS X	73				60	7	07			
1	2	02				1	↑	27				1	FMT	42			
2	4	04				2	2	02				2	y → ()	40			
3	0	00				3	4	04				3	2	02			
4	FMT	42				4	5	05				4	4	04			
5	π	56				5	FMT	42				5	0	00			
6	↑	27				6	π	56				6	FMT	42			
7	x ← ()	67				7	X	36				7	π	56			
8	-	34				8	↓	25				8	↑	27			
9	e	12				9	-	34				9	±	15			
a	x	36				a	y → ()	40				a		4			
b	↑	27				b	-	34				b	Δ	67			
c	f	15				c	α	13				c	-	34			
d	x	36				d	1	01				d	d	17			
10	↓	25				40	B	10				70	X	36			
1	-	34				1	9	11				1	x ← ()	67			
2	x ← ()	67				2	FMT	42				2	-	34			
3	-	34				3	π	56				3	e	12			
4	b	14				4	↑	27				4	↑	27			
5	↑	27				5	SIN X	70				5	x ← ()	67			
6	x ← ()	67				6	x → y	30				6	-	34			
7	-	34				7	COS X	73				7	b	14			
8	d	17				8	y → ()	40				8	X	36			
9	X	36				9	-	34				9	↓	25			
a	↓	25				a	9	11				a	+	33			
b	-	34				b	x → ()	23				b	1	01			
c	1	01				c	-	34				c	9	11			
d	7	07				d	B	10				d	3	03			
20	B	10				50	ROLL ↓	31				Storage					
1	FMT	42				1	X	36									
2	y → ()	40				2	ROLL ↑	22									
3	2	02				3	x → y	30									
4	4	04				4	2	02									
5	3	03				5	4	04									
6	FMT	42				6	6	06									
7	π	56				7	FMT	42									
8	↑	27				8	π	56									
9	2	02				9	X	36									
a	1	01				a	↓	25									
b	0	00				b	+	33									
c	FMT	42				c	1	01									
d	π	56				d	7	07									

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
B 0	FMT	41				b 0	9	11				0					
1	π	56				1	3	03				1					
2	X	36				2	FMT	42				2					
3	CHK SIG	32				3	π	56				3					
4	X	36				4	X	36				4					
5	X $\rightarrow$ ()	67				5	1	01				5					
6	-	34				6	9	11				6					
7	0	13				7	6	06				7					
8	$\uparrow$	27				8	FMT	42				8					
9	X $\rightarrow$ ()	67				9	π	56				9					
a	-	34				a	X	36				a					
b	8	10				b	2	02				b					
c	X	36				c	X	36				c					
d	ROLL $\downarrow$	31				d	$\downarrow$	25				d					
9 0	y $\rightarrow$ ()	40				C 0	+	33				0					
1	-	34				1	X $\rightarrow$ ()	67				1					
2	7	07				2	-	34				2					
3	ROLL $\uparrow$	22				3	7	07				3					
4	2	02				4	X $\rightarrow$ y	30				4					
5	4	04				5	-	34				5					
6	6	06				6	1	01				6					
7	FMT	42				7	7	07				7					
8	π	56				8	6	06				8					
9	$\uparrow$	27				9	FMT	42				9					
a	X $\rightarrow$ ()	67				a	y $\rightarrow$ 0	40				a					
b	-	34				b	2	02				b					
c	9	11				c	2	22				c					
d	X	36				d	6	06				d					
a 0	$\downarrow$	25				d 0	FMT	42				Storage					
1	-	34				1	π	56									
2	1	01				2	X $\rightarrow$ ()	23									
3	9	11				3	e	12									
4	0	00				4	3	03									
5	FMT	42				5	7	07									
6	π	56				6	FMT	42									
7	X	36				7	GO TO 44										
8	X	36				8	END 46										
9	X $\rightarrow$ ()	67				9											
a	-	34				a											
b	e	12				b											
c	$\uparrow$	27				c											
d	1	01				d											

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
00	CONT	47				30	↓	25				60	y→()	40			
1	e	12				1	↑	33				1	2	02			
2	↑	27				2	x←()	67				2	4	04			
3	3	03				3	-	34				3	7	07			
4	2	02				4	9	11				4	FMT	42			
5	.	21				5	↑	27				5	π	56			
6	2	02				6	2	02				6	↑	27			
7	÷	35				7	0	00				7	2	02			
8	y→()	40				8	4	04				8	4	04			
9	f	15				9	FMT	42				9	3	03			
a	2	02				a	π	56				a	FMT	42			
b	1	01				b	x	36				b	π	56			
c	c	00				c	↓	25				c	↑	27			
d	FMT	42				d	+	33				d	2	02			
10	π	56				40	1	01				70	2	02			
1	cos x	73				1	7	07				1	2	02			
2	↑	27				2	6	06				2	FMT	42			
3	x←()	67				3	FMT	42				3	π	56			
4	-	34				4	π	56				4	x	36			
5	B	10				5	↑	27				5	↓	25			
6	x	36				6	f	15				6	-	34			
7	f	15				7	x	36				7	y→()	40			
8	x	36				8	↓	25				8	-	34			
9	2	02				9	+	33				9	f	15			
a	0	00				a	x←()	67				a	↑	27			
b	2	02				b	-	34				b	2	02			
c	FMT	42				c	d	17				c	4	04			
d	π	56				d	↑	27				d	6	06			
20	x	36				50	1	01				Storage					
1	x	36				1	9	11				F	FMT		E1		
2	2	02				2	7	07				B	WI		E2		
3	4	04				3	FMT	42				d			E3		
4	5	05				4	π	56				c			E5		
5	FMT	42				5	x	36				b			E6		
6	π	56				6	f	15				a			E4		
7	x	36				7	x	36				9			E7		
8	x←()	67				8	↓	25				8			E8		
9	-	34				9	-	34				7			E9		
a	f	15				a	1	01				6			S		
b	↑	27				b	7	07				5					
c	e	12				c	5	05				4					
d	x	36				d	FMT	42				3					
												2					
												1					
												0					

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
80	FMT	42				b0	y→()	40				0					
1	π	56				1	-	34				1					
2	+	33				2	C	16				2					
3	y→()	40				3	↑	27				3					
4	-	34				4	2	02				4					
5	e	12				5	2	02				5					
6	2	02				6	1	01				6					
7	4	04				7	FMT	42				7					
8	4	04				8	π	56				8					
9	FMT	42				9	x→y	30				9					
a	π	56				a	÷	35				a					
b	↑	27				b	y→()	40				b					
c	2	02				c	-	34				c					
d	4	04				d	b	14				d					
90	5	05				c0	↑	27				0					
1	FMT	42				1	x→()	67				1					
2	π	56				2	-	34				2					
3	+	33				3	e	12				3					
4	2	02				4	x→y	30				4					
5	1	01				5	÷	35				5					
6	0	00				6	y→()	40				6					
7	FMT	42				7	-	34				7					
8	π	56				8	9	11				8					
9	cos x	73				9	↑	27				9					
a	x	36				a	x→()	67				a					
b	y→()	40				b	-	34				b					
c	-	34				c	d	17				c					
d	d	17				d	x→y	30				d					
a0	x→()	67				d0	÷	35				Storage					
1	-	34				1	y→()	40									
2	f	15				2	-	34									
3	↑	27				3	8	10									
4	x→()	67				4	ROLL ↓	31									
5	-	34				5	↓	25									
6	e	12				6	↓	25									
7	+	33				7	CONT	47									
8	↑	27				8	CONT	47									
9	f	15				9	3	03									
a	x	36				a	8	10									
b	↓	25				b	FMT	42									
c	x→y	30				c	so To	44									
d	÷	35				d	END	46									

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
00	CONT	47				30	FMT	42				60	9	11			
1	↓	25				1	π	56				1	FMT	42			
2	x←()	67				2	↑	27				2	π	56			
3	-	34				3	x←()	67				3	+	33			
4	a	13				4	-	34				4	1	01			
5	x↔y	30				5	8	10				5	7	07			
6	÷	35				6	x	36				6	2	02			
7	y←()	40				7	↓	25				7	FMT	42			
8	-	34				8	+	33				8	y←()	40			
9	7	07				9	2	02				9	1	01			
a	x←()	67				a	0	00				a	7	07			
b	-	34				b	7	07				b	7	07			
c	c	16				c	FMT	42				c	FMT	42			
d	↑	27				d	π	56				d	π	56			
10	1	01				40	↑	27				70	↑	27			
1	7	07				1	x←()	67				1	1	01			
2	7	07				2	-	34				2	8	10			
3	FMT	42				3	7	07				3	0	00			
4	π	56				4	x	36				4	FMT	42			
5	x	36				5	↓	25				5	π	56			
6	x←()	67				6	-	34				6	x	36			
7	-	34				7	1	01				7	f	15			
8	b	14				8	7	07				8	x	36			
9	+	33				9	3	03				9	1	01			
a	1	01				a	FMT	42				a	7	07			
b	7	07				b	y←()	40				b	1	01			
c	4	04				c	1	01				c	FMT	42			
d	FMT	42				d	8	10				d	y←()	40			
20	y←()	40				50	0	00				Storage					
1	1	01				1	FMT	42				f					
2	7	07				2	π	56				e					
3	5	05				3	↑	27				d					
4	FMT	42				4	1	01				c					
5	π	56				5	7	07				b					
6	↑	27				6	8	10				a					
7	x←()	67				7	FMT	42				9					
8	-	34				8	π	56				8					
9	9	11				9	x	36				7					
a	x	36				a	f	15				6					
b	2	02				b	x	36				5					
c	0	00				c	2	02				4					
d	4	04				d	1	01				3					
												2					
												1					
												0					

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
80	1	01				b0	1	01				0					
1	7	07				1	FMT	42				1					
2	7	07				2	TI	56				2					
3	FMT	42				3	X	36				3					
4	TI	56				4	1	01				4					
5	↑	27				5	7	07				5					
6	f	15				6	0	00				6					
7	X	36				7	FMT	42				7					
8	X←()	67				8	TI	56				8					
9	-	34				9	↑	27				9					
a	c	12				a	1	01				a					
b	X	36				b	7	07				b					
c	2	02				c	2	02				c					
d	2	02				d	FMT	42				d					
90	1	01				c0	TI	56				0					
1	FMT	42				1	X	36				1					
2	TI	56				2	↓	25				2					
3	+	33				3	X←y	30				3					
4	1	01				4	-	34				4					
5	7	07				5	1	01				5					
6	0	00				6	6	06				6					
7	FMT	42				7	8	10				7					
8	y←x()	40				8	FMT	42				8					
9	1	01				9	y←()	40				9					
a	7	07				a	1	01				a					
b	8	10				b	7	07				b					
c	FMT	42				c	7	07				c					
d	TI	56				d	FMT	42				d					
00	↑	27				d0	TI	56				Storage					
1	f	15				1	↑	27									
2	X	36				2	↑	27									
3	X←()	67				3	3	03									
4	-	34				4	9	11									
5	c	12				5	FMT	42									
6	X	36				6	Go TO	44									
7	1	01				7	END	46									
8	6	06				8											
9	9	11				9											
a	FMT	42				a											
b	y←x()	40				b											
c	1	01				c											
d	7	07				d											

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
00	CONT	47				30	↑	27				60	↑	27			
1	↓	25				1	x←()	67				1	x←()	67			
2	x←()	67				2	-	34				2	-	34			
3	-	34				3	9	11				3	d	17			
4	c	16				4	-	34				4	x	36			
5	↑	27				5	1	01				5	1	01			
6	f	15				6	7	07				6	7	07			
7	-	34				7	5	05				7	5	05			
8	↓	25				8	FMT	42				8	FMT	42			
9	x	36				9	π	56				9	π	56			
a	x←()	67				a	x	36				a	↑	27			
b	-	34				b	ROLL ↓	31				b	x←()	67			
c	b	14				c	+	33				c	-	34			
d	+	33				d	1	01				d	e	12			
10	1	01				40	6	06				70	↓	25			
1	6	06				1	6	06				1	↓	25			
2	7	07				2	FMT	42				2	+	33			
3	FMT	42				3	y←()	40				3	1	01			
4	y←()	40				4	↓	25				4	6	06			
5	2	02				5	1	01				5	4	04			
6	0	00				6	8	10				6	FMT	42			
7	7	07				7	0	00				7	y←()	40			
8	FMT	42				8	FMT	42				8	2	02			
9	π	56				9	π	56				9	2	02			
a	↑	27				a	CHK SIGN	32				a	4	04			
b	x←()	67				b	x	36				b	FMT	42			
c	-	34				c	1	01				c	π	56			
d	7	07				d	7	07				d	↑	27			
20	x	36				50	9	11				Storage					
1	2	02				1	FMT	42				F					
2	0	00				2	π	56				B					
3	4	04				3	+	33				d					
4	FMT	42				4	1	01				c					
5	π	56				5	6	06				b					
6	↑	27				6	5	05				a					
7	x←()	67				7	FMT	42				9					
8	-	34				8	y←()	40				8					
9	8	10				9	2	02				7					
a	x	36				a	0	00				6					
b	↓	25				b	4	04				5					
c	-	34				c	FMT	42				4					
d	1	01				d	π	56				3					
												2					
												1					
												0					

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
8	0	X	36			0						0					
	1	π	56			1						1					
	2	↑	27			2						2					
	3	X	36			3						3					
	4	4	04			4						4					
	5	X	36			5						5					
	6	↓	25			6						6					
	7	X	36			7						7					
	8	1	01			8						8					
	9	6	06			9						9					
	a	2	02			a						a					
	b	FMT	42			b						b					
	c	π	56			c						c					
	d	X	36			d						d					
9	0	y-x)	40			0						0					
	1	-	34			1						1					
	2	6	06			2						2					
	3	X	36			3						3					
	4	4	04			4						4					
	5	X	36			5						5					
	6	2	02			6						6					
	7	2	02			7						7					
	8	3	03			8						8					
	9	FMT	42			9						9					
	a	π	56			a						a					
	b	X	36			b						b					
	c	X	36			c						c					
	d	↓	25			d						d					
a	0	√x	76			0						Storage					
	1	x-y)	23			1											
	2	-	34			2											
	3	5	05			3											
	4	4	04			4											
	5	0	00			5											
	6	FMT	42			6											
	7	GO TO	44			7											
	8	END	46			8											
	9					9											
	a					a											
	b					b											
	c					c											
	d					d											
												F					
												E					
												D					
												C					
												B					
												A					
												9					
												8					
												7					
												6					
												5					
												4					
												3					
												2					
												1					
												0					

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
00	CONT	47				30	X←()	67				60	Z	02			
1	I	01				1	-	34				1	FMT	42			
2	9	11				2	C	16				2	Π	56			
3	4	04				3	↑	27				3	-	34			
4	FMT	42				4	f	15				4	X←()	67			
5	Π	56				5	-	34				5	-	34			
6	X→()	23				6	I	01				6	G	06			
7	e	12				7	7	07				7	X	36			
8	2	02				8	8	10				8	I	01			
9	I	01				9	FMT	42				9	9	11			
a	9	11				a	Π	56				a	3	03			
b	FMT	42				b	X	36				b	FMT	42			
c	Π	56				c	I	01				c	Π	56			
d	↑	27				d	B	10				d	↑	27			
10	X←()	67				40	O	00				70	X←()	67			
1	-	34				1	FMT	42				1	-	34			
2	C	16				2	Π	56				2	5	05			
3	↑	27				3	X	36				3	X	36			
4	I	01				4	ROLL↓	31				4	↓	25			
5	7	07				5	-	34				5	-	34			
6	8	10				6	ROLL↑	22				6	I	01			
7	FMT	42				7	X↔y	30				7	B	10			
8	Π	56				8	I	01				8	I	01			
9	X	36				9	6	06				9	FMT	42			
a	I	01				a	7	07				a	Π	56			
b	B	10				b	FMT	42				b	↑	27			
c	I	01				c	Π	56				c	I	01			
d	FMT	42				d	X	36				d	7	07			
20	Π	56				50	↓	25				Storage					
1	X	36				1	+	33				F	XMI				
2	ROLL↓	31				2	y→()	40				E	6				
3	-	34				3	-	34				d					
4	ROLL↑	22				4	4	04				c					
5	X↔y	30				5	↑	27				b					
6	I	01				6	I	01				a					
7	7	07				7	8	10				9					
8	4	04				8	6	06				8					
9	FMT	42				9	FMT	42				7					
a	Π	56				a	Π	56				6					
b	X	36				b	↑	27				5					
c	↓	25				c	I	01				4					
d	+	33				d	9	11				3					
												2					
												1					
												0					

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
80	3	03				b0	e	12				0					
1	FMT	42				1	+	33				1					
2	π	56				2	2	02				2					
3	X	36				3	÷	35				3					
4	↓	25				4	2	02				4					
5	+	33				5	1	01				5					
6	1	01				6	8	10				6					
7	8	10				7	FMT	42				7					
8	0	00				8	π	56				8					
9	FMT	42				9	X	36				9					
a	π	56				a	f	15				a					
b	↑	27				b	+	33				b					
c	1	01				c	1	01				c					
d	6	06				d	9	11				d					
90	6	06				c0	3	03				0					
1	FMT	42				1	FMT	42				1					
2	π	56				2	y → ()	40				2					
3	X	36				3	f	15				3					
4	↓	25				4	+	33				4					
5	-	34				5	2	02				5					
6	1	01				6	÷	35				6					
7	7	07				7	2	02				7					
8	9	11				8	1	01				8					
9	FMT	42				9	8	10				9					
a	π	56				a	FMT	42				a					
b	+	33				b	π	56				b					
c	x → ()	67				c	X	36				c					
d	-	34				d	1	01				d					
a0	4	04				d0	9	11				Storage					
1	÷	35				1	2	02				f					
2	1	01				2	FMT	42				e					
3	9	11				3	π	56				d					
4	4	04				4	+	33				c					
5	FMT	42				5	4	04				b					
6	y → ()	40				6	1	01				a					
7	1	01				7	FMT	42				9					
8	9	11				8	Go To	44				8					
9	3	03				9	END	46				7					
a	FMT	42				a						6					
b	π	56				b						5					
c	x → ()	23				c						4					
d	f	15				d						3					
												2					
												1					
												0					

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
0	CONT	47				3	0	00				0					
1	1	01				1	5	05				1					
2	9	11				2	FMT	42				2					
3	2	02				3	y→()	40				3					
4	FMT	42				4	1	01				4					
5	y→()	40				5	9	11				5					
6	x←()	67				6	3	03				6					
7	-	34				7	FMT	42				7					
8	C	16				8	π	56				8					
9	↑	27				9	↑	27				9					
a	1	01				a	1	01				a					
b	7	07				b	9	11				b					
c	8	10				c	0	00				c					
d	FMT	42				d	FMT	42				d					
1	π	56				4	y→()	40				0					
1	x	36				1	1	01				1					
2	1	01				2	9	11				2					
3	7	07				3	2	02				3					
4	4	04				4	FMT	42				4					
5	FMT	42				5	π	56				5					
6	π	56				6	↑	27				6					
7	-	34				7	1	01				7					
8	1	01				8	8	10				8					
9	9	11				9	9	11				9					
a	4	04				a	FMT	42				a					
b	FMT	42				b	y→()	40				b					
c	π	56				c	4	04				c					
d	x	36				d	2	02				d					
2	↑	27				5	FMT	42				Storage					
1	1	01				1	GO TO	44									
2	9	11				2	END	46									
3	1	01				3											
4	FMT	42				4											
5	y→()	40				5											
6	↓	25				6											
7	1	01				7											
8	7	07				8											
9	3	03				9											
a	FMT	42				a											
b	π	56				b											
c	+	33				c											
d	2	02				d											

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
00	CONT	47				30	6	06				60	-	34			
1	2	02				1	FMT	42				1	1	01			
2	2	02				2	y → ()	40				2	7	07			
3	6	06				3	2	02				3	6	06			
4	FMT	42				4	0	00				4	FMT	42			
5	π	56				5	0	00				5	π	56			
6	↑	27				6	FMT	42				6	+	33			
7	3	03				7	π	56				7	2	02			
8	2	02				8	x → ()	23				8	0	00			
9	.	21				9	e	12				9	0	00			
a	2	02				a	1	01				a	FMT	42			
b	÷	35				b	7	07				b	y → ()	40			
c	x → ()	47				c	8	10				c	1	01			
d	-	34				d	FMT	42				d	9	11			
10	C	16				40	π	56				70	9	11			
1	-	34				1	↑	27				1	FMT	42			
2	1	01				2	1	01				2	π	56			
3	7	07				3	7	07				3	x → ()	23			
4	8	10				4	7	07				4	f	15			
5	FMT	42				5	FMT	42				5	e	12			
6	π	56				6	π	56				6	+	33			
7	X	36				7	-	34				7	2	02			
8	1	01				8	1	01				8	÷	35			
9	6	06				9	9	11				9	2	02			
a	7	07				a	4	04				a	1	01			
b	FMT	42				b	FMT	42				b	8	10			
c	π	56				c	π	56				c	FMT	42			
d	÷	33				d	X	36				d	π	56			
20	1	01				50	1	01				Storage					
1	9	11				1	9	11									
2	4	04				2	7	07									
3	FMT	42				3	FMT	42									
4	π	56				4	π	56									
5	X	36				5	↑	27									
6	1	01				6	1	01									
7	6	06				7	9	11									
8	6	06				8	2	02									
9	FMT	42				9	FMT	42									
a	π	56				a	π	56									
b	+	33				b	SIN X	70									
c	2	02				c	X	36									
d	0	00				d	↓	25									

Title

LAUNCH SIMULATION

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CASE I

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Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
80	X	36				510	4	04				0					
1	f	15				1	6	06				1					
2	+	33				2	FMT	42				2					
3	1	01				3	π	56				3					
4	9	11				4	-	34				4					
5	9	11				5	y $\rightarrow$ ()	40				5					
6	FMT	42				6	-	34				6					
7	y $\rightarrow$ ()	40				7	1	01				7					
8	f	15				8	+	33				8					
9	+	33				9	1	01				9					
a	2	02				a	2	02				a					
b	$\div$	35				b	FMT	42				b					
c	2	02				c	GO TO	44				c					
d	1	01				d	END	46				d					
910	8	10				0						0					
1	FMT	42				1						1					
2	π	56				2						2					
3	X	36				3						3					
4	1	01				4						4					
5	9	11				5						5					
6	8	10				6						6					
7	FMT	42				7						7					
8	π	56				8						8					
9	+	33				9						9					
a	1	01				a						a					
b	9	11				b						b					
c	8	10				c						c					
d	FMT	42				d						d					
a0	y $\rightarrow$ ()	40				0						Storage					
1	2	02				1						f					
2	3	03				2						e					
3	7	07				3						d					
4	FMT	42				4						c					
5	π	56				5						b					
6	$\uparrow$	27				6						a					
7	2	02				7						9					
8	4	04				8						8					
9	7	07				9						7					
a	FMT	42				a						6					
b	π	56				b						5					
c	-	34				c						4					
d	2	02				d						3					
												2					
												1					
												0					

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
0	0	CONT	47			10						0					
1	1	01				1						1					
2	9	11				2						2					
3	0	00				3						3					
4	FMT	42				4						4					
5	π	56				5						5					
6	↑	27				6						6					
7	1	01				7						7					
8	8	10				8						8					
9	7	07				9						9					
a	FMT	42				a						a					
b	π	56				b						b					
c	x	36				c						c					
d	1	01				d						d					
10	8	10				0						0					
1	8	10				1						1					
2	FMT	42				2						2					
3	π	56				3						3					
4	↑	27				4						4					
5	2	02				5						5					
6	0	00				6						6					
7	1	01				7						7					
8	FMT	42				8						8					
9	π	56				9						9					
a	x	36				a						a					
b	↓	25				b						b					
c	FMT	42				c						c					
d	↓	25				d						d					
20	0	00				0						Storage					
1	1	27				1											
2	1	01				2											
3	8	10				3											
4	5	05				4											
5	FMT	42				5											
6	y → ()	40				6											
7	1	01				7											
8	1	01				8											
9	FMT	42				9											
a	GO TO	44				a											
b	END	46				b											
c						c											
d						d											

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
0	CONT	47				0						0					
1	1	01				1						1					
2	8	10				2						2					
3	8	10				3						3					
4	FMT	42				4						4					
5	IT	56				5						5					
6	↑	27				6						6					
7	2	02				7						7					
8	1	01				8						8					
9	8	10				9						9					
a	FMT	42				a						a					
b	IT	56				b						b					
c	+	33				c						c					
d	1	01				d						d					
0	8	10				0						0					
1	8	10				1						1					
2	FMT	42				2						2					
3	y→()	40				3						3					
4	2	02				4						4					
5	0	00				5						5					
6	FMT	42				6						6					
7	GO TO 44					7						7					
8	END	46				8						8					
9						9						9					
a						a						a					
b						b						b					
c						c						c					
d						d						d					
0						0						Storage					
1						1						f					
2						2						e					
3						3						d					
4						4						c					
5						5						b					
6						6						a					
7						7						9					
8						8						8					
9						9						7					
a						a						6					
b						b						5					
c						c						4					
d						d						3					
												2					
												1					
												0					

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
0	CONT	47				3	GO TO	44				0					
1	1	01				1	4	04				1					
2	9	11				2	2	02				2					
3	5	05				3	CONT	47				3					
4	FMT	42				4	1	01				4					
5	π	56				5	1	01				5					
6	$\uparrow$	27				6	GO TO	44				6					
7	$x \rightarrow ()$	67				7	4	04				7					
8	-	34				8	2	02				8					
9	1	01				9	CONT	47				9					
a	TEXSY	52				a	1	01				a					
b	3	03				b	$\uparrow$	27				b					
c	9	11				c	0	00				c					
d	CONT	47				d	$\uparrow$	27				d					
10	1	01				40	STOP	41				0					
1	B	10				1	CONT	47				1					
2	5	05				2	FMT	42				2					
3	FMT	42				3	GO TO	44				3					
4	π	56				4	END	46				4					
5	$\uparrow$	27				5						5					
6	2	02				6						6					
7	1	01				7						7					
8	B	10				8						8					
9	FMT	42				9						9					
a	π	56				a						a					
b	$\uparrow$	33				b						b					
c	1	01				c						c					
d	B	10				d						d					
20	5	05				0						Storage					
1	FMT	42				1						F					
2	$y \rightarrow ()$	40				2						E					
3	2	02				3						d					
4	1	01				4						c					
5	7	07				5						b					
6	FMT	42				6						a					
7	π	56				7						9					
8	TEXSY	53				8						8					
9	3	03				9						7					
a	3	03				a						6					
b	CONT	47				b						5					
c	1	01				c						4					
d	0	00				d						3					
												2					
												1					
												0					

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
00	CONT	47				30	1	01				60	1	01			
1	0	05				1	9	11				1	9	11			
2	↑	27				2	3	03				2	1	01			
3	2	02				3	FMT	42				3	FMT	42			
4	0	00				4	π	56				4	y→()	40			
5	5	05				5	x	36				5	1	01			
6	FMT	42				6	↓	25				6	9	11			
7	y→()	40				7	-	34				7	0	00			
8	1	01				8	1	01				8	FMT	42			
9	9	11				9	6	06				9	π	56			
a	1	01				a	9	11				a	x→()	23			
b	FMT	42				b	FMT	42				b	f	15			
c	π	56				c	π	56				c	e	12			
d	x→()	23				d	↑	27				d	+	33			
10	e	12				40	1	01				70	2	02			
1	1	01				1	6	06				1	÷	35			
2	8	10				2	5	05				2	2	02			
3	6	06				3	FMT	42				3	1	01			
4	FMT	42				4	π	56				4	8	10			
5	π	56				5	x	36				5	FMT	42			
6	↑	27				6	↓	25				6	π	56			
7	1	01				7	+	33				7	x	36			
8	9	11				8	1	01				8	f	15			
9	2	02				9	6	06				9	+	33			
a	FMT	42				a	4	04				a	1	01			
b	π	56				b	FMT	42				b	9	11			
c	-	34				c	π	56				c	0	00			
d	x→()	67				d	↑	27				d	FMT	42			
20	-	34				50	1	01				Storage					
1	6	06				1	7	07				f	0.				
2	x	36				2	2	02				e	0.				
3	1	01				3	FMT	42				d					
4	6	06				4	π	56				c					
5	9	11				5	x	36				b					
6	FMT	42				6	↓	25				a					
7	π	56				7	+	33				9					
8	x	36				8	1	01				8					
9	↑	27				9	6	06				7					
a	x→()	67				a	8	10				6					
b	-	34				b	FMT	42				5					
c	5	05				c	π	56				4					
d	x	36				d	÷	35				3					
												2					
												1					
												0					

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
80	y→U	40				0						0					
1	f	15				1						1					
2	+	33				2						2					
3	2	02				3						3					
4	÷	35				4						4					
5	2	02				5						5					
6	1	01				6						6					
7	B	10				7						7					
8	FMT	42				8						8					
9	π	56				9						9					
a	x	36				a						a					
b	1	01				b						b					
c	8	10				c						c					
d	9	11				d						d					
90	FMT	42				0						0					
1	π	56				1						1					
2	+	33				2						2					
3	1	01				3						3					
4	B	10				4						4					
5	9	11				5						5					
6	FMT	42				6						6					
7	y→U	40				7						7					
8	4	04				8						8					
9	1	01				9						9					
a	FMT	42				a						a					
b	GO TO	44				b						b					
c	END	46				c						c					
d						d						d					
c						0						Storage					
1						1						F					
2						2						E					
3						3						d					
4						4						c					
5						5						b					
6						6						a					
7						7						9					
8						8						8					
9						9						7					
a						a						6					
b						b						5					
c						c						4					
d						d						3					
												2					
												1					
												0					

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
0	CONT	47				3	-	34				6	3	03			
1	1	01				1	1	01				1	FMT	42			
2	9	11				2	7	07				2	π	56			
3	4	04				3	1	01				3	X→()	23			
4	FMT	42				4	FMT	42				4	f	15			
5	π	56				5	π	56				5	e	12			
6	X→()	23				6	↑	27				6	+	33			
7	e	12				7	1	01				7	2	02			
8	1	01				8	6	06				8	÷	35			
9	8	10				9	4	04				9	2	02			
a	6	06				a	FMT	42				a	1	01			
b	FMT	42				b	π	56				b	8	10			
c	π	56				c	X	36				c	FMT	42			
d	↑	27				d	↓	25				d	π	56			
1	1	01				4	+	33				7	X	36			
1	9	11				1	1	01				1	f	15			
2	2	02				2	6	06				2	+	33			
3	FMT	42				3	5	05				3	1	01			
4	π	56				4	FMT	42				4	9	11			
5	-	34				5	π	56				5	3	03			
6	X→()	67				6	↑	27				6	FMT	42			
7	-	34				7	1	01				7	y→()	40			
8	6	06				8	7	07				8	f	15			
9	X	36				9	0	00				9	+	33			
a	1	01				a	FMT	42				a	2	02			
b	7	07				b	π	56				b	÷	35			
c	0	00				c	X	36				c	2	02			
d	FMT	42				d	↓	25				d	1	01			
2	π	56				5	+	33				Storage					
1	X	36				1	1	01				f	φ				
2	↑	27				2	6	06				e	φ				
3	X→()	67				3	8	10				d					
4	-	34				4	FMT	42				c					
5	5	05				5	π	56				b					
6	X	36				6	÷	35				a					
7	1	01				7	1	01				9					
8	9	11				8	9	11				8					
9	3	03				9	4	04				7					
a	FMT	42				a	FMT	42				6					
b	π	56				b	y→()	40				5					
c	X	36				c	1	01				4					
d	↓	25				d	9	11				3					
												2					
												1					
												0					

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
B0	8	10				b0	2	02				0					
1	FMT	42				1	6	06				1					
2	π	56				2	FMT	42				2					
3	X	36				3	π	56				3					
4	↑	01				4	↑	27				4					
5	9	11				5	3	03				5					
6	2	02				6	2	02				6					
7	FMT	42				7	.	21				7					
8	π	56				8	2	02				8					
9	+	33				9	÷	35				9					
a	1	01				a	↓	25				a					
b	9	11				b	X	36				b					
c	2	02				c	1	01				c					
d	FMT	42				d	7	07				d					
90	y→U	40				c0	5	05				0					
1	1	01				1	FMT	42				1					
2	7	07				2	π	56				2					
3	8	10				3	+	33				3					
4	FMT	42				4	2	02				4					
5	π	56				5	0	00				5					
6	↑	27				6	6	06				6					
7	1	01				7	FMT	42				7					
8	9	11				8	y→U	40				8					
9	4	04				9	4	04				9					
a	FMT	42				a	2	02				a					
b	π	56				b	FMT	42				b					
c	X	36				c	GO TO	44				c					
d	1	01				d	END	46				d					
a0	7	07				0						Storage					
1	7	07				1						f					
2	FMT	42				2						B					
3	π	56				3						d					
4	↑	27				4						c					
5	1	01				5						b					
6	9	11				6						a					
7	1	01				7						9					
8	FMT	42				8						8					
9	π	56				9						7					
a	X	36				a						6					
b	↓	25				b						5					
c	-	34				c						4					
d	2	02				d						3					
												2					
												1					
												0					

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
0	CONT	47				3	2	02				6	f	15			
1	2	02				1	FMT	42				1	+	33			
2	0	00				2	π	56				2	2	02			
3	0	00				3	SIN X	70				3	$\div$	35			
4	FMT	42				4	X	36				4	2	02			
5	π	56				5	$\downarrow$	25				5	1	01			
6	X $\rightarrow$ ()	23				6	-	34				6	8	10			
7	e	12				7	1	01				7	FMT	42			
8	1	01				8	7	07				8	π	56			
9	7	07				9	6	06				9	X	36			
a	8	10				a	FMT	42				a	1	01			
b	FMT	42				b	π	56				b	9	11			
c	π	56				c	+	33				c	8	10			
d	$\uparrow$	27				d	2	02				d	FMT	42			
10	1	01				4	0	00				7	π	56			
1	9	11				1	0	00				1	+	33			
2	4	04				2	FMT	42				2	1	01			
3	FMT	42				3	y $\rightarrow$ ()	40				3	9	11			
4	π	56				4	1	01				4	8	10			
5	X	36				5	9	11				5	FMT	42			
6	1	01				6	9	11				6	y $\rightarrow$ ()	40			
7	7	07				7	FMT	42				7	2	02			
8	7	07				8	π	56				8	3	03			
9	FMT	42				9	X $\rightarrow$ ()	23				9	7	07			
a	π	56				a	f	15				a	FMT	42			
b	$\uparrow$	27				b	e	12				b	π	56			
c	1	01				c	+	33				c	X $\rightarrow$ ()	23			
d	9	11				d	2	02				d	-	34			
20	1	01				5	$\div$	35				Sta. 100					
1	FMT	42				1	2	02				f	Y.				
2	π	56				2	1	01				e	Y.				
3	X	36				3	8	10				d					
4	$\downarrow$	25				4	FMT	42				c					
5	-	34				5	π	56				b					
6	1	01				6	X	36				a					
7	9	11				7	f	15				9					
8	7	07				8	+	33				8					
9	FMT	42				9	1	01				7					
a	π	56				a	9	11				6					
b	$\uparrow$	27				b	9	11				5					
c	1	01				c	FMT	42				4					
d	9	11				d	y $\rightarrow$ ()	40				3					
												2					
												1					
												0					

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
0	1	01				0						0					
1	+	33				1						1					
2	1	01				2						2					
3	2	02				3						3					
4	FMT	42				4						4					
5	Go To	44				5						5					
6	END	46				6						6					
7						7						7					
8						8						8					
9						9						9					
a						a						a					
b						b						b					
c						c						c					
d						d						d					
0						0						0					
1						1						1					
2						2						2					
3						3						3					
4						4						4					
5						5						5					
6						6						6					
7						7						7					
8						8						8					
9						9						9					
a						a						a					
b						b						b					
c						c						c					
d						d						d					
0						0						Storage					
1						1						F					
2						2						B					
3						3						d					
4						4						c					
5						5						b					
6						6						a					
7						7						9					
8						8						8					
9						9						7					
a						a						6					
b						b						5					
c						c						4					
d						d						3					
												2					
												1					
												0					

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
00	CONT	47				30	9	11				60	FMT	42			
1	0	00				1	0	00				1	y → ()	40			
2	↑	27				2	FMT	42				2	4	04			
3	2	02				3	π	56				3	1	01			
4	0	00				4	x → ()	23				4	FMT	42			
5	5	05				5	f	15				5	Go To	44			
6	FMT	42				6	e	12				6	END	46			
7	y → ()	40				7	+	33				7					
8	2	02				8	2	02				8					
9	0	00				9	÷	35				9					
a	6	06				a	2	02				a					
b	FMT	42				b	1	01				b					
c	y → ()	40				c	8	10				c					
d	1	01				d	FMT	42				d					
10	9	11				40	π	56				0					
1	1	01				1	x	36				1					
2	FMT	42				2	f	15				2					
3	π	56				3	+	33				3					
4	x → ()	23				4	1	01				4					
5	e	12				5	9	11				5					
6	x → ()	67				6	0	00				6					
7	-	34				7	FMT	42				7					
8	d	17				8	y → ()	40				8					
9	↑	27				9	f	15				9					
a	2	02				a	+	33				a					
b	0	00				b	2	02				b					
c	4	04				c	÷	35				c					
d	FMT	42				d	2	02				d					
20	π	56				50	1	01				Storage					
1	x	36				1	8	10									
2	2	02				2	FMT	42									
3	2	02				3	π	56									
4	1	01				4	x	36									
5	FMT	42				5	1	01									
6	π	56				6	8	10									
7	÷	35				7	9	11									
8	1	01				8	FMT	42									
9	9	11				9	π	56									
a	1	01				a	+	33									
b	FMT	42				b	1	01									
c	y → ()	40				c	8	10									
d	1	01				d	9	11									

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
00	CONT	47				30	2	02				60	FMT	42			
1	1	01				1	2	02				1	π	56			
2	9	11				2	1	01				2	X	36			
3	4	04				3	FMT	42				3	1	01			
4	FMT	42				4	π	56				4	9	11			
5	π	56				5	÷	35				5	2	02			
6	X → ()	23				6	1	01				6	FMT	42			
7	e	12				7	9	11				7	π	56			
8	1	01				8	4	04				8	+	33			
9	B	10				9	FMT	42				9	1	01			
a	6	06				a	y → ()	40				a	9	11			
b	FMT	42				b	1	01				b	2	02			
c	π	56				c	9	11				c	FMT	42			
d	↑	27				d	3	03				d	y → ()	40			
10	1	01				40	FMT	42				70	4	04			
1	9	11				1	π	56				1	2	02			
2	2	02				2	X → ()	23				2	FMT	42			
3	FMT	42				3	f	15				3	GO TO 44				
4	π	56				4	e	12				4	END	46			
5	-	34				5	+	33				5					
6	X → ()	67				6	2	02				6					
7	-	34				7	÷	35				7					
8	6	06				8	2	02				8					
9	X	36				9	1	01				9					
a	X → ()	67				a	B	10				a					
b	-	34				b	FMT	42				b					
c	5	05				c	π	56				c					
d	↑	27				d	X	36				d					
20	1	01				50	f	15				Storage					
1	9	11				1	+	33				F	4				
2	3	03				2	1	01				E	2				
3	FMT	42				3	9	11				d					
4	π	56				4	3	03				c					
5	X	36				5	FMT	42				b					
6	↓	25				6	y → ()	40				a					
7	-	34				7	f	15				9					
8	1	01				8	+	33				8					
9	7	07				9	2	02				7					
a	9	11				a	÷	35				6					
b	FMT	42				b	2	02				5					
c	π	56				c	1	01				4					
d	+	33				d	8	10				3					
												2					
												1					
												0					

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
0	CONT	47				3	0	FMT	42			6	0	2	02		
1	2	02				1	π	56				1	1	01			
2	0	00				2	COS X	73				2	0	00			
3	0	00				3	X	36				3	FMT	42			
4	FMT	42				4	1	01				4	π	56			
5	π	56				5	8	10				5	COS X	73			
6	X → ()	23				6	9	11				6	X	36			
7	E	12				7	FMT	42				7	1	01			
8	2	02				8	π	56				8	8	10			
9	2	02				9	COS X	73				9	9	11			
a	6	06				a	X	36				a	FMT	42			
b	FMT	42				b	↓	25				b	π	56			
c	π	56				c	-	34				c	COS X	73			
d	X → ()	23				d	2	02				d	X	36			
10	d	17				4	0	04				7	0	↓	25		
1	↑	27				1	5	05				1	-	34			
2	2	02				2	FMT	42				2	d	17			
3	1	01				3	π	56				3	÷	35			
4	6	06				4	↑	27				4	2	02			
5	FMT	42				5	2	02				5	0	00			
6	π	56				6	0	00				6	0	00			
7	SIN X	70				7	2	02				7	FMT	42			
8	X	36				8	FMT	42				8	y → ()	40			
9	2	02				9	π	56				9	1	01			
a	0	00				a	X	36				a	9	11			
b	4	04				b	X	36				b	9	11			
c	FMT	42				c	↓	25				c	FMT	42			
d	π	56				d	y → ()	24				d	π	56			
20	X ↔ y	30				5	0	d	17			Storage					
1	-	34				1	X ↔ y	30									
2	1	01				2	↑	27									
3	8	10				3	3	03									
4	9	11				4	2	02									
5	FMT	42				5	.	21									
6	π	56				6	2	02									
7	SIN X	70				7	÷	35									
8	X	36				8	y → ()	24									
9	d	17				9	d	17									
a	↑	27				a	roll ↑	22									
b	2	02				b	X ↔ y	30									
c	1	01				c	d	17									
d	6	06				d	X	36									

Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
80	x → ()	23				b0	7	07				0					
1	f	15				1	FMT	42				1					
2	e	12				2	π	56				2					
3	+	33				3	↑	27				3					
4	2	02				4	2	02				4					
5	÷	35				5	3	03				5					
6	2	02				6	6	06				6					
7	1	01				7	FMT	42				7					
8	B	10				8	π	56				8					
9	FMT	42				9	+	33				9					
a	π	56				a	.	21				a					
b	x	36				b	2	02				b					
c	f	15				c	+	33				c					
d	+	33				d	y → ()	40				d					
90	1	01				C0	-	34				0					
1	9	11				1	1	01				1					
2	9	11				2	+	33				2					
3	FMT	42				3	1	01				3					
4	y → ()	40				4	2	02				4					
5	f	15				5	FMT	42				5					
6	+	33				6	GO TO	44				6					
7	2	02				7	END	46				7					
8	÷	35				8						8					
9	2	02				9						9					
a	1	01				a						a					
b	B	10				b						b					
c	FMT	42				c						c					
d	π	56				d						d					
a0	x	36				0						Storage					
1	1	01				1						f					
2	9	11				2						e					
3	B	10				3						d					
4	FMT	42				4						c					
5	π	56				5						b					
6	+	33				6						a					
7	1	01				7						9					
8	9	11				8						8					
9	B	10				9						7					
a	FMT	42				a						6					
b	y → ()	40				b						5					
c	2	02				c						4					
d	3	03				d						3					
												2					
												1					
												0					

Section V. CONCLUSIONS

The programs presented herein can be utilized to obtain an idea of the stagnation temperatures and pressures that may be imposed on a launch tube and the surrounding area by a given rocket, the internal pressure in the launcher at the rocket nozzle exit, and the effects on missile and launcher actions of various dimensional offsets and misalignments and different firing positions. These programs are intended for use in design efforts and were written for the Hewlett-Packard 9100B to enable in-house efforts of this nature to be more efficiently realized.

It must again be stated that the results of these programs have not as yet been compared with actual data to determine accuracy.

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-RBL	5
-RPR	1
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