

U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

AD-A035 505

COMPUTER PROGRAMS FOR TETHERED-BALLOON
SYSTEM DESIGN AND PERFORMANCE EVALUATION

AIR FORCE GEOPHYSICS LABORATORY
HANSCOM AIR FORCE BASE, MASSACHUSETTS

26 AUGUST 1976

ADA03505

AFOT-TP-76-000
INSTRUMENTATION PAPER NO. 267

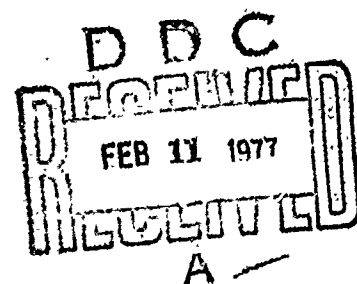


Computer Programs for Tethered-Balloon System Design and Performance Evaluation

JOHN B. WRIGHT

26 August 1976

Approved for public release; distribution unlimited.



AEROSPACE INSTRUMENTATION DIVISION PROJECT 6665
AIR FORCE GEOPHYSICS LABORATORY
HANSCOM AFB, MASSACHUSETTS 01731

AIR FORCE SYSTEMS COMMAND, USAF



AIR FORCE (1) FEBRUARY 20, 1977--499

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

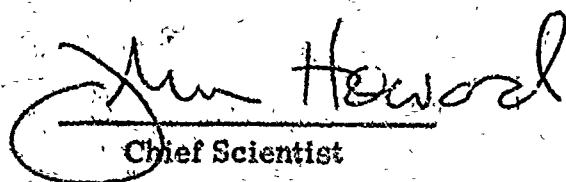
Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFGL-TR-76-0195	2. GOVT ACCESSION NO.	3. PERIODICITY CATALOG NUMBER
4. TITLE (and Subtitle) COMPUTER PROGRAMS FOR TETHERED-BALLOON SYSTEM DESIGN AND PERFORMANCE EVALUATION		5. TYPE OF REPORT & PERIOD COVERED Scientific. Interim.
		6. PERFORMING ORG. REPORT NUMBER IP 249
7. AUTHOR(s) John B. Wright		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORG. ORGANIZATION NAME AND ADDRESS Air Force Geophysics Laboratories (LCB) Hanscom AFB, Massachusetts 01731		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62101F 66650902
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Geophysics Laboratories (LCB) Hanscom AFB, Massachusetts 01731		12. REPORT DATE 26 August 1976
		13. NUMBER OF PAGES 147
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Tethered-balloons Cable forces High-altitude tethered-balloons Aerodynamic forces Computer programs Hewlett-Packard Balloon trim Balloon forces		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Six computer programs were developed to provide both standardized methods for solution of typical tethered-balloon performance problems and improved techniques sufficient to study the very high altitude tethered-balloon system design problem. The programs are written for an HP-9810A desk computer but are fully documented for conversion to other types of equipment. Preliminary results are shown indicating the feasibility of a balloon tethered at an altitude of 20 km.		

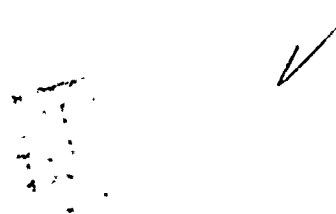
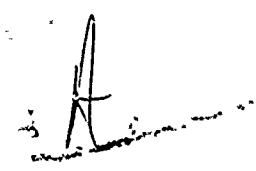
This technical report has been reviewed and
is approved for publication.

FOR THE COMMANDER:


Chief Scientist

Qualified requestors may obtain additional copies from the
Defense Documentation Center. All other should apply to the
National Technical Information Service.

2

Contents

1. INTRODUCTION	7
2. TETHERED-BALLOON COMPUTER PROGRAMS	8
3. COMPUTER PROGRAMS	14
3.1 Program No. 76.001 - Tethered Balloon Basic Buoyancy, Ballonet Check, Multiple Tether	14
3.1.1 General Description	14
3.1.2 Definitions and Development	15
3.1.3 Flow Chart	18
3.1.4 Operating Instructions	20
3.1.5 Sample Input Data Form	23
3.1.6 Program	24
3.1.7 Sample Input/Output Print	30
3.2 Program No. 76.002 - General Tethered Balloon Trim, Single Altitude, Zero Wind, Optional Matrix	32
3.2.1 General Description	32
3.2.2 Development of Program and Equations	33
3.2.3 Flow Chart	35
3.2.4 Operating Instructions	36
3.2.5 Sample Input Data Form	38
3.2.6 Program	39
3.2.7 Sample Input/Output Print	42
3.3 Program No. 76.003 - General Tethered Balloon Trim, Variable Altitude and Wind Profile	43
3.3.1 General Description	43
3.3.2 Definitions and Development	44
3.3.3 Flow Chart	49
3.3.4 Operating Instructions	52
3.3.5 Sample Input Data Form	56
3.3.6 Program	57
3.3.7 Sample Input/Output Print	65
3.3.8 Notes	68

Contents

3.4	Program No. 76.004 Family - Family-2 Tethered Balloon Trim and Single Altitude, Design Condition: Ballonet Empty	70
3.4.1	General Description	70
3.4.2	Definitions and Development	71
3.4.3	Flow Chart	74
3.4.4	Operating Instructions	76
3.4.5	Sample Input Data Form	78
3.4.6	Program	79
3.4.7	Sample Input/Output Print	86
3.4.8	Notes	87
3.5	Program No. 76.005 - Family-2 Tethered Balloon Trim, Variable Altitude and Wind Profile	89
3.5.1	General Description	89
3.5.2	Definitions and Development	91
3.5.3	Flow Chart	97
3.5.4	Operating Instructions	100
3.5.5	Sample Input Data Form	103
3.5.6	Program	104
3.5.7	Sample Input/Output Print	112
3.5.8	Notes	114
3.6	Program No. 76.006 - Tether Cable, Two Dimensional Case, Variable Wind Profile	117
3.6.1	General Description	117
3.6.2	Definitions and Development	118
3.6.3	Flow Chart	122
3.6.4	Operating Instructions	124
3.6.5	Sample Input Data Form	127
3.6.6	Program	128
3.6.7	Sample Input/Output Print	134
3.6.8	Notes	136
4.	EXAMPLE OF CONVENTIONAL TETHERED-BALLOON PROBLEM	137
5.	PRELIMINARY PARAMETRIC STUDIES OF THE HIGH-ALTITUDE TETHERED BALLOON PROBLEM	139
APPENDIX A:	Density Ratio	143
APPENDIX B:	Symbols and Definitions	145

Illustrations

1.	Wind Profiles - High Altitude Tethered Balloon	140
----	--	-----

Tables

1. Tethered Balloon Computer Programs	10
2. Definition of Program Codes	11
3. High Altitude Tether-Cable	141

Computer Programs for Tethered-Balloon System Design and Performance Evaluation

1. INTRODUCTION

In 1974 several agencies expressed interest in being able to loft several kinds of payloads on a balloon to very high altitudes and keep them overhead for periods of time ranging from several days to several weeks. The French government had partial success with a tethered balloon concept whereby the tether cable on its reel was carried up with a free balloon. It was programmed to drop its reel during ascent for ocean recovery and to continue its ascent to 18 km as a tethered system. This concept, demonstrated in equatorial latitudes, minimizes the drag loads since relative winds on ascending balloon and cable are very small.

The Aerospace Instrumentation Division of AFGL decided that a method involving a fixed ground station such as would be required at a missile test site must be evaluated. An altitude of 20 km was selected because of its desirability for several kinds of projects. A series of tests to select an optimum Kevlar cable was begun and will be reported in a separate document. A balloon design has been selected and will undergo a preliminary test as a free-balloon early in 1977. The results of this test as well as the actual tether feasibility test to be made in August 1977 will also be separately reported.

(Received for publication 25 August 1976)

This report covers an outgrowth of the study of the high-altitude system design. One of the needed parameters is the tether-cable length in order to have a proper amount available and a balloon sized to lift both the payload and the cable under many different atmospheric conditions. Many other quantities are also needed for a realistic and scientific approach in the design of a high altitude tethered balloon system. It was found that several existing computer programs were based on limited assumptions of, for example, constant cable drag coefficients or winds.

In deriving a more realistic cable program, it became apparent that two of the principal inputs defining the upper-end condition of the cable were the total balloon upward force, and its angle to the horizon. The balloon provides buoyant and aerodynamic lift in the vertical direction and drag in the horizontal direction. The two aerodynamic forces change with a balloon's angle of attack and this angle in turn is governed by not only aerodynamic characteristics but other design parameters as well.

Hence other programs were developed to provide the balloon characteristics for any range of altitudes or balloon types. This report describes those programs developed to date in sufficient detail to allow their use directly or, by adaptation, with any computer system. In Section 5, some results of the study of the high-altitude, tethered-balloon using one of the computer programs are examined.

2. TETHERED-BALLOON COMPUTER PROGRAMS

As is found in many special technological fields, there are many day-to-day tethered-balloon problems requiring repetitive calculations. Some of these are quite simple in nature, some are practically solvable only by means of a computer, and many lie somewhere between the above extremes. Each problem may be set up differently each time it is encountered depending on the time allowed to answer some question, the particular predilections of the person undertaking the task, and the mathematical aids used.

This report attempts to provide some uniformity in techniques, assumptions, and precision by offering a series of tethered-balloon programs designed for an office type of computer. Most organizations engaged in such work have a large digital computer department. However, certain formalities in procedures, lack of personal control by the user, and some degree of awe by many engineers do not yet allow the master computer to be a universally acceptable tool capable of fast response.

A desk computer of the capacity considered herein is a remarkably capable machine for solution of the most lengthy and reiterative problems encountered in designing or analyzing existing tethered-balloon systems. Its closeness to the

engineer allows its use for an immediate answer. Due to familiarity generated by complete user control, it becomes amenable to experimentation with many variations in program input or even content when properly documented. In addition, the nature of balloons requires that some field operations be conducted in remote areas of the world where only a desk computer can be made available as a part of the ground base equipment.

The programs presented herein were developed for use in a Hewlett-Packard Model 9810A desk calculator/computer. The particular instrument used has 2036 program steps (Option 003), 111 storage registers (Option 001) and a tape printer (Option 004). All programs require the MATH-ROM (No. 11210A). Some programs require less than the full number of program steps and storage registers as can be noted in their respective descriptions.

The programs can be converted to other models or brands of desk computers using Reverse Polish or none RP logic or units having fewer program steps. With the latter in mind, the programs were written with minimum use of subroutines so that they may be divided more easily into several shorter complete programs. They are not meant to be models of programming efficiency and do not utilize every nuance of logic or operation which the HP 9810A offers. They are meant to be utilized by engineers who may wish to change some internal elements or constants but without having to develop a new program.

Each program is documented in subsections as follows:

- (1) Description of physical problems,
- (2) Description of the program development including the detailed mathematics, physics, aerodynamics, etc., involved in the problem solution.
- (3) Flow chart,
- (4) Operating instructions,
- (5) Input data form,
- (6) Program listing,
- (7) Sample of printed output,
- (8) Notes for user, including possible changes in program.

Table 1 provides an overview of the six programs presented with a brief description of their usage and capability. Program No. 76.001 can be used typically for a rapid determination of what balloon in an inventory is capable of performing a special task. It treats the no-wind condition which is indicative of the smallest balloon capable of the particular task. It also provides for multi-cable geometry and checks the balloonet for adequacy to cover the specified altitude range.

Program No. 76.002 is also a no-wind program for examination of the effects of center-of-gravity and center-of-buoyancy position relationships. Programs 76.003, 004, and 005 may also be used for similar studies although they were primarily designed with wind to calculate all balloon forces and to obtain the net total

force and its angle when the balloon is at the trim condition for input into 76.006, the tether-cable program. No. 76.003 is intended for any balloon type or shape whereas 76.004 and 76.005 are specialized for the Family-2 balloon design. These latter two are shown as written for a 45,000 CF balloon but directions are provided for simple changes to cover universal applications.

A typical balloon problem was established and used in Program Nos. 76.001, 004, 005 and 006 to illustrate their printed input and output information.

Table 1. Tethered-Balloon Computer Programs

USAGE		PROGRAM	
Selecting Min. Stock Balloon For Given Payload and Test Config.		<u>76.001 BASIC BUOYANCY</u> Wind = 0, Any single altitude and surface altitude, 1 to 5 cable configuration Checks: Ballonet/Altitude Acceptability Provides: Gross and Net Lift at Surface Multi-Cable Geometric Parameters	
Analysis of Balloon Geometry		<u>76.002 GENERAL T-BALLOON</u> Trim, Wind = 0, any single altitude, optional matrix variation of CG and CB locations Provides α trim at input or matrix values of CG and CB locations.	
Analysis of System Flight Conditions	Balloon Trim and Total Force Req'd for		<u>76.004 FAMILY-2 T-BALLOON</u> Trim, any wind value, design altitude condition where ballonet empty Provides: α trim, F_T , θ
		<u>76.003 GENERAL T-BALLOON</u> Trim, any set of wind profiles, any altitude range from ballonet empty to full Provides: α trim, F_T , θ , etc, over range of altitudes.	<u>76.005 FAMILY-2 T-BALLOON</u> Trim, any set of wind profiles, any altitude range from ballonet empty to full Provides: α trim, F_T , θ , etc, over range of altitudes.
	Tether Cable Parameters	<u>76.006 TETHER CABLE, TWO DIMENSIONAL</u> Single cable, any set of wind profiles, (F_T and θ input required) Provides: Tension, angle, and space position of all points of cable from balloon to surface.	

Table 2 is provided in order to fully define the program listings which are direct copies of the output tape (less number code). As can be noted, certain codes in the listing have double meaning depending on whether the system is in or not in an alpha-numeric print mode.

Table 2. Definitions of Program Codes

A. Standard Mode	
In the explanation below, x, y, and z represent the contents of display registers x, y, and z, respectively; a and b represent the contents of memory registers a and b, respectively. The mnemonics and their respective functions are shown below:	
<u>Mnemonic</u>	<u>Function</u>
π	$\pi \rightarrow x$
b	$b \rightarrow x$
a	$a \rightarrow x$
YTO	$y \rightarrow$ memory address which follows
XTO	$x \rightarrow$ memory address which follows
1/X	$1/x \rightarrow x$
IND	Used for indirect addressing
XFR	Puts the value in the following memory address into x
XSQ	$x^2 \rightarrow x$
RUP	$x \rightarrow y, y \rightarrow z, z \rightarrow x$
DN	$z \rightarrow y, y \rightarrow x, z \rightarrow z$
XEY	$y \rightarrow x, x \rightarrow y, z \rightarrow z$
UP	$x \rightarrow y, y \rightarrow z, x \rightarrow x$
$\sqrt{\quad}$	$\sqrt{x} \rightarrow x$
DIV	$y/x \rightarrow y$
X	$xy \rightarrow y$
-	$y - x \rightarrow y$
+	$y + x \rightarrow y$
CHS	$-x \rightarrow x$
EEX	Used when assigning an exponent to a number being entered into x.
CLX	Set x to 0.
0 through 9	0 through 9, respectively, into x.
	Used to put a decimal point in a number being entered into x.

CLR	Set to 0, x, y, z, a and b.
CNT	Used as a null operation within a program. Used to run a program.
LBL	Used in conjunction with a following symbol to indicate a position in the program memory.
FMT	Used to enter (FMT, FMT) and leave (FMT) the print mode.
PNT	Prints the value of x; when multiple PNT's are used, lines are skipped after x is printed.
X<Y	If $x < y$, jump to the address indicated by the number given in the next 4 steps; if not, skip the next 4 steps.
X=Y	If $x = y$, jump to the address indicated by the number given in the next 4 steps; if not, skip the next 4 steps.
X>Y	If $x > y$, jump to the address indicated by the number given in the next 4 steps; if not, skip the next 4 steps.
GTO	Go to memory location specified in the next steps.
END	Used as the last step of a program; sets point of operation location 0000.
PSE	Causes program to pause and x, y, and z to be displayed.
STP	Causes program to stop.
A	Conversion from rectangular to polar coordinates; $A \rightarrow y$, $r \rightarrow x$.
H	$x^y \rightarrow x$
I	Natural logarithm of $x \rightarrow x$
J	$e^x \rightarrow x$
L	Used in conjunction with keys M, N, and O for inverse trigonometric functions
M	$\sin x \rightarrow x$
N	$\cos x \rightarrow x$
O	$\tan x \rightarrow x$
K, 4	Common logarithm of $x \rightarrow x$
K, 5	$10^x \rightarrow x$
K, CLX	Clears all numeric registers.

B. Alpha Numeric Mode

The alpha numeric mode is entered by using the FMT step twice and is exited by using FMT once. The mnemonics and their significances in this mode are shown below:

<u>Mnemonic</u>	<u>Character printed</u>
A through 0	A through 0, respectively.
π	P
b	Q
a	R
YTO	S
XTO	T
1/X	U
INT	V
IND	W
YE	X
XFR	Y
XSQ	Z
RUP	@
$\sqrt{\quad}$	$\sqrt{\quad}$
DIV	/
X	*
-	-
+	+
CHS	π
EEX	$\rightarrow$
0 through 9	0 through 9, respectively
CLX	,
SFL	.
LBL	=
IFL	\$
X<Y	?
PSE	(
X=Y	)
X>Y	%
GTO	"
CLR	#
CNT	This causes a carriage return
	This causes a space

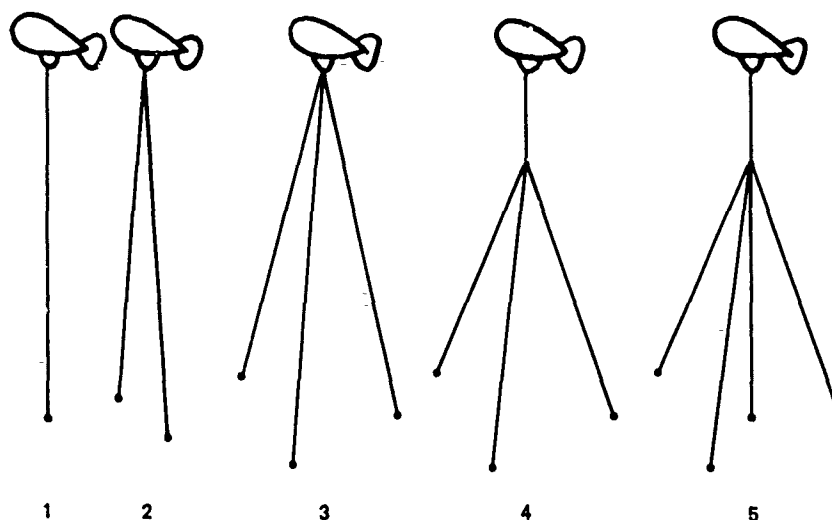
3. COMPUTER PROGRAMS

3.1 Program 76.001 — Tethered Balloon Basic Buoyancy, Ballonet Check, Multiple Tether Cable Configuration

3.1.1 GENERAL DESCRIPTION

This program was developed to assist in the rapid solution of many day-to-day problems involved in estimating which of several stock balloons might be acceptable for a given payload. It is also useful as the first step in the series of programs.

The approach was to permit any one of five typical tethered balloon cable configurations to be handled. These are single, dual, three, four, and five cable configurations as illustrated below.



The program is designed to simply compute the net lifting force at the surface that must be resisted by one or more winches or tie-down points on the ground by subtracting all of the various masses from the gross lift of the balloon. Since no aerodynamic forces are considered, this covers the zero wind case.

Since wind produces additional lift, particularly in the case of aerodynamically shaped balloons, this program is ideal for selecting a minimum balloon size for a given problem. That is, it represents the minimum lift that any configuration will experience.

Also included is a check that the balloon height above ground does not exceed that permitted by the fixed ballonnet volume. If it should exceed the allowable excursion, the user is permitted a choice of, (1) accepting the condition which entails a non-rigid balloon on the surface before reelup, (2) requesting the maximum permissible flight altitude for a tight balloon at the surface, or (3) selecting a new altitude.

In the tether cases 2 to 5, additional information on the geometry of the cable layout is also provided.

3.1.2 DEFINITIONS AND DEVELOPMENT: PROGRAM NO. 76.001

- A. Wind = 0. Most severe case, that is, minimum lift.
- B. Length of cable.

Config. 1: Single tether ($N = 1$), $l = Z_B - Z_S = \text{Vert. Height, } H$

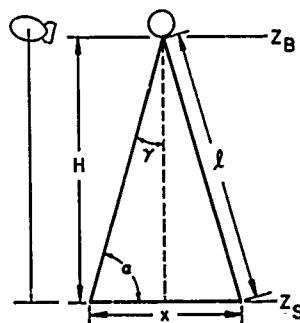
Config. 2: Two tether ($N = 2$)

Given x , Distance between two Anchor Points

$$\tan \gamma = \frac{x}{2H}$$

$$\alpha = 90 - \gamma$$

$$l = H / \sin \alpha$$



Config. 3, 4, and 5 have in common a 3-cable pyramid, all 3 equal in length, the apex lies vertically over the ground zero point, and the 3 anchor points form an equilateral triangle centered at ground zero.

Config. 3: Balloon attached at apex.

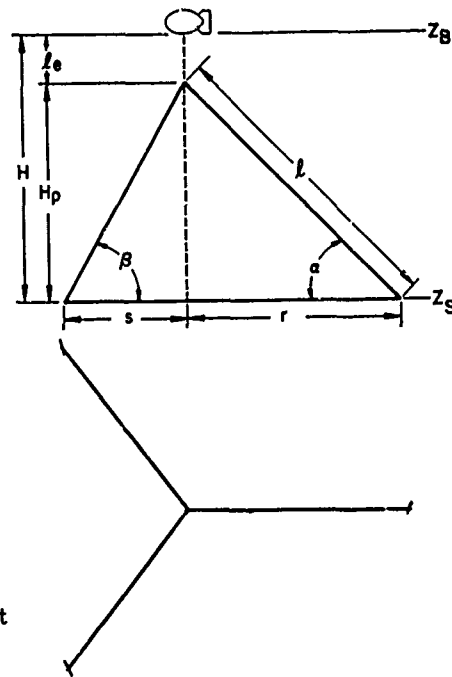
Config. 4: Balloon extended above apex by 4th cable, l_e , length of 4th cable, must be entered.

Config. 5: A 5th cable from apex to ground zero is added.

(Designated as 5 cables, $N = 5$, even if there is no 4th cable;

$l_e = 0$ as entry)

Given α , cable angle at surface
 $l = \frac{H_p}{\sin \alpha}$, lengths of pyr. cables
 $r = l \cos \alpha$, radius of ancor. pts.
 $s = r/2$
 $\beta = \arctan \frac{2 H_p}{r}$, pyr. plane
 angle at surface.



C. Cable weights:

Allow for each cable to be different
 size and weight.

Allow for entry of each cable weight
 after net lift at the balloon is calculated.

Weights entered in lb/1000 ft but these are reduced to lb/ft in
 program and stored so that the weight of each cable is $l \times (\text{lb/ft})$.

D. Basic calculations: V_B = Balloon volume, v = Ballonet volume.

sp. lift at Z_B = Sp Lift at $Z = 0$, MSL $\times \rho_{ZB}/\rho_0$

Gross lift, $L_G = V_B \times (\text{Sp. Lift at } Z_B)$

Net Balloon Lift, $L = L_G - W_B$

Net Balloon lift with Instrument Package = $L - W_I = L_G - W_B - W_I$

Net Balloon lift with Payload = $L - W_I - W_P = L_G - W_B - W_I - W_P$

Net lift on ground = $L_G - W_B - W_I - W_P$ - (sum of all cable weights)

E. Ballonet. Given ballonet volume, v , as entry

(1) By definition: $\rho_d/\rho_0 = \frac{V_B - v}{V_B}$, Designed into balloon

(2) Obtain ρ_B/ρ_0 from $\frac{\ln \rho/\rho_0}{Z_B} = a_0 + a_1 Z_B$

(3) Obtain ρ_S/ρ_0 from $\frac{\ln \rho_S/\rho_0}{Z_S} = a_0 + a_1 Z_S$

$$(4) \rho_B/\rho_S = \rho_B/\rho_o \times \rho_o/\rho_s$$

- a. If $\rho_B/\rho_S > \rho_d/\rho_S$, balloon flight altitude is lower than the max. it could be flown above Z_S
- b. If $\rho_B/\rho_S < \rho_d/\rho_S$, balloon flight altitude is above that permitted by ballonet design for flight starting at Z_S - that is, gas would be lost or must start with slack balloon on the surface to provide full balloon (ballonet empty) at Z_B .
- c. If $\rho_B/\rho_S = \rho_d/\rho_S$, exact design flight altitude above Z_S is being used.
- d. In program, user is allowed choice if condition b results from the altitude and ballonet size entered.

Choices are: 1. Keep Z_B and accept slack surface condition.

2. Let program compute max. Z_B so that condition c exists.

3. Pick a new Z

$$\text{For d-2: } \frac{\rho_B}{\rho_S} = \frac{\rho_d}{\rho_S}$$

$$\frac{\rho_d}{\rho_o} = \frac{\rho_d}{\rho_S} \times \frac{\rho_S}{\rho_o}$$

$$\text{Then } Z_B = Z_d = \frac{-a_o - \sqrt{a_o^2 - 4a_1 \ln \rho_d/\rho_o}}{2a_1}$$

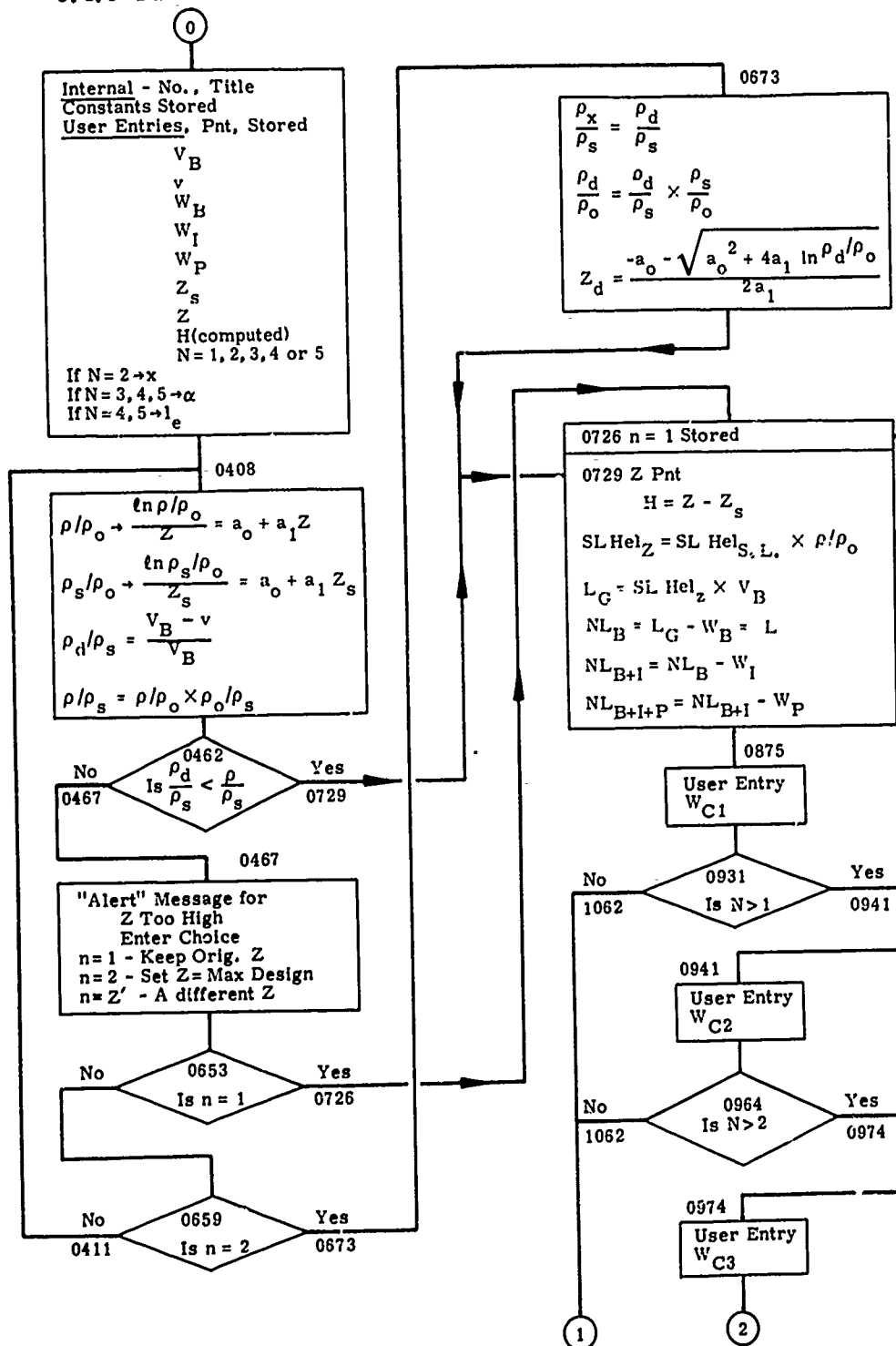
For d-1: Compute amount of inflation on surface

$$\frac{\rho_S}{\rho_B} = \frac{\text{Vol gas at } Z_B}{\text{Vol gas at } Z_S} = \frac{V_B}{\text{Vol gas at } Z_S}$$

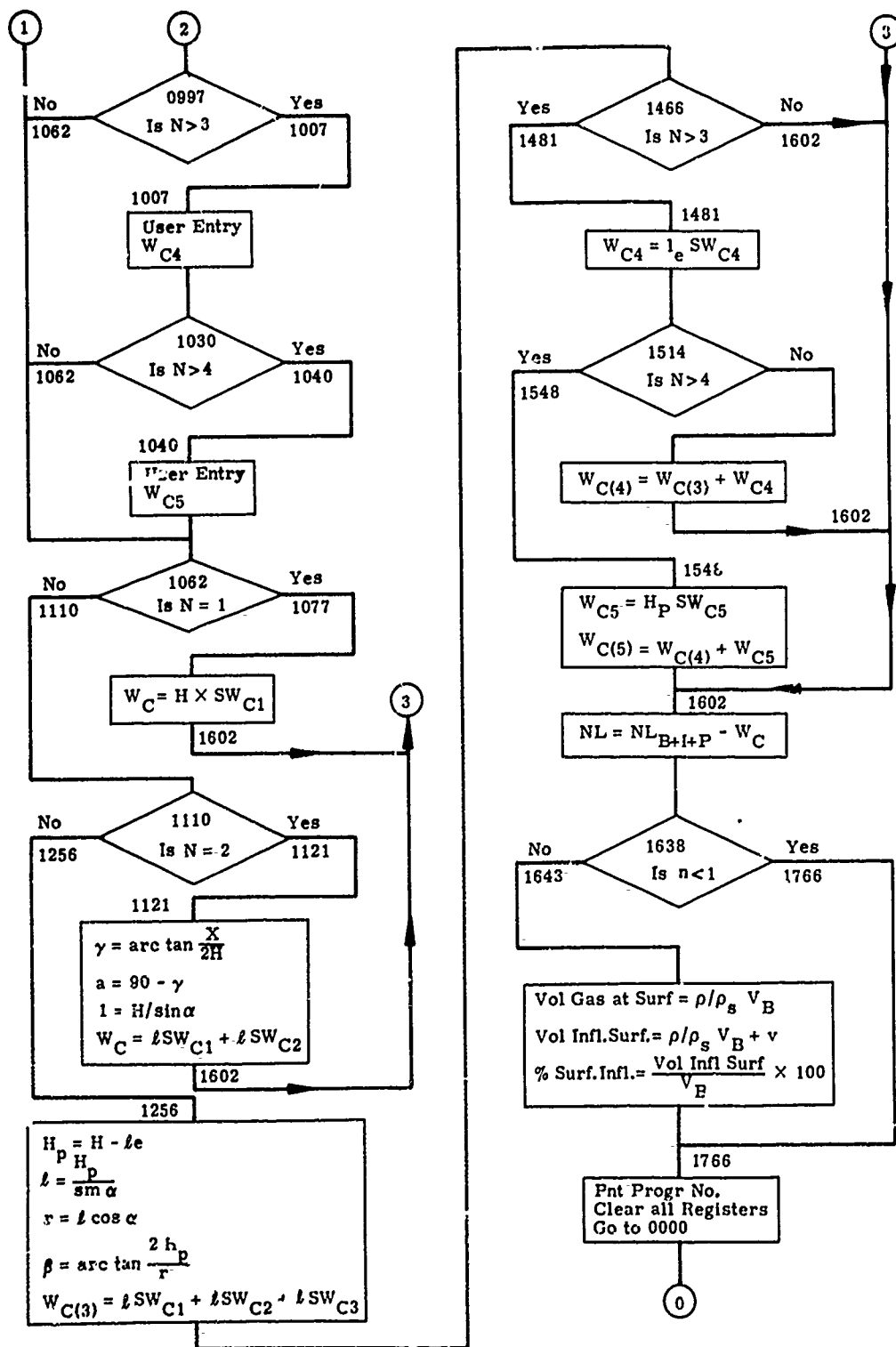
$$\text{Tot Vol at } Z_S = \text{Vol gas at } Z_S + v = V_B \frac{\rho_B}{\rho_S} + v$$

$$\% \text{ fullness at } Z_S = \left(\frac{V_B \rho_B/\rho_S + v}{V_B} \right) 100$$

3.1.3 FLOW CHART



Note: In flow chart, N indicates number of cables, n indicates altitude choice when original altitude entered is too high.



3.1.4 OPERATING INSTRUCTIONS

KEY STROKES

PRINTS

RUN

END

FIX 2, 3, ---

CONT

(No. of desired decimal places)

Program No. and Title

Enter in X,

BALLOON VOL. (V_B , CF)

Ent. V_B

CONT

V_B value

BALLOONET VOL. (v , CF)

Ent. v

CONT

v value

BALLOON WEIGHT (W_B , lb)

Ent. W_B

CONT

W_B value

WT. BAL. INSTR. PKG. (W_I , lb)

Ent. W_I

CONT

W_I value

WT. EXP. PAYLOAD (W_P , lb)

Ent. W_P

CONT

W_P value

SURFACE ALT. MSL (Z_S , ft)

Ent. Z_S

CONT

Z_S value

FLIGHT ALT. MSL (Z , ft)

Ent. Z

CONT

Z value

VERT. HEIGHT (H , ft)

H value

NUMBER OF CABLES ($N = 1, 2, 3, 4, \text{ or } 5$)

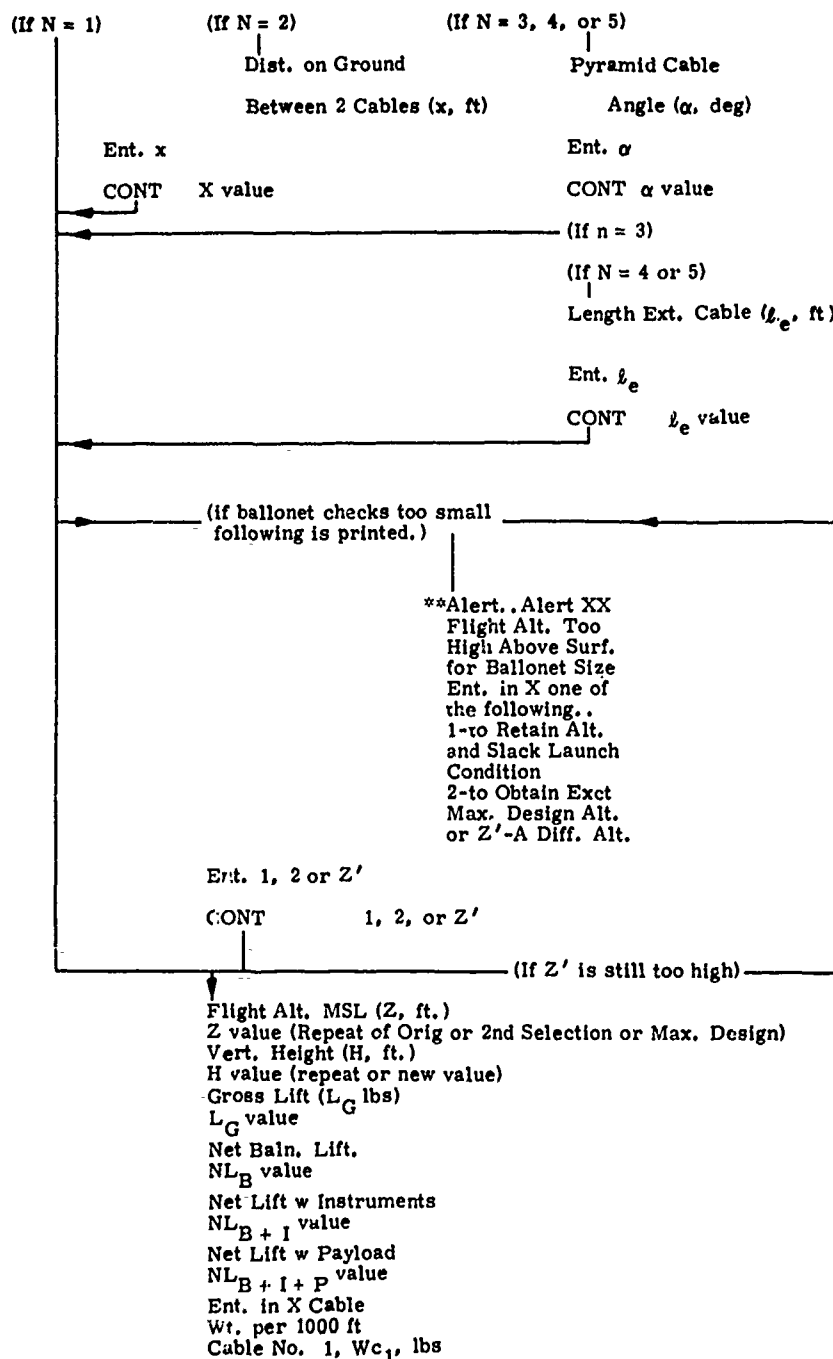
(If there is no extension cable between

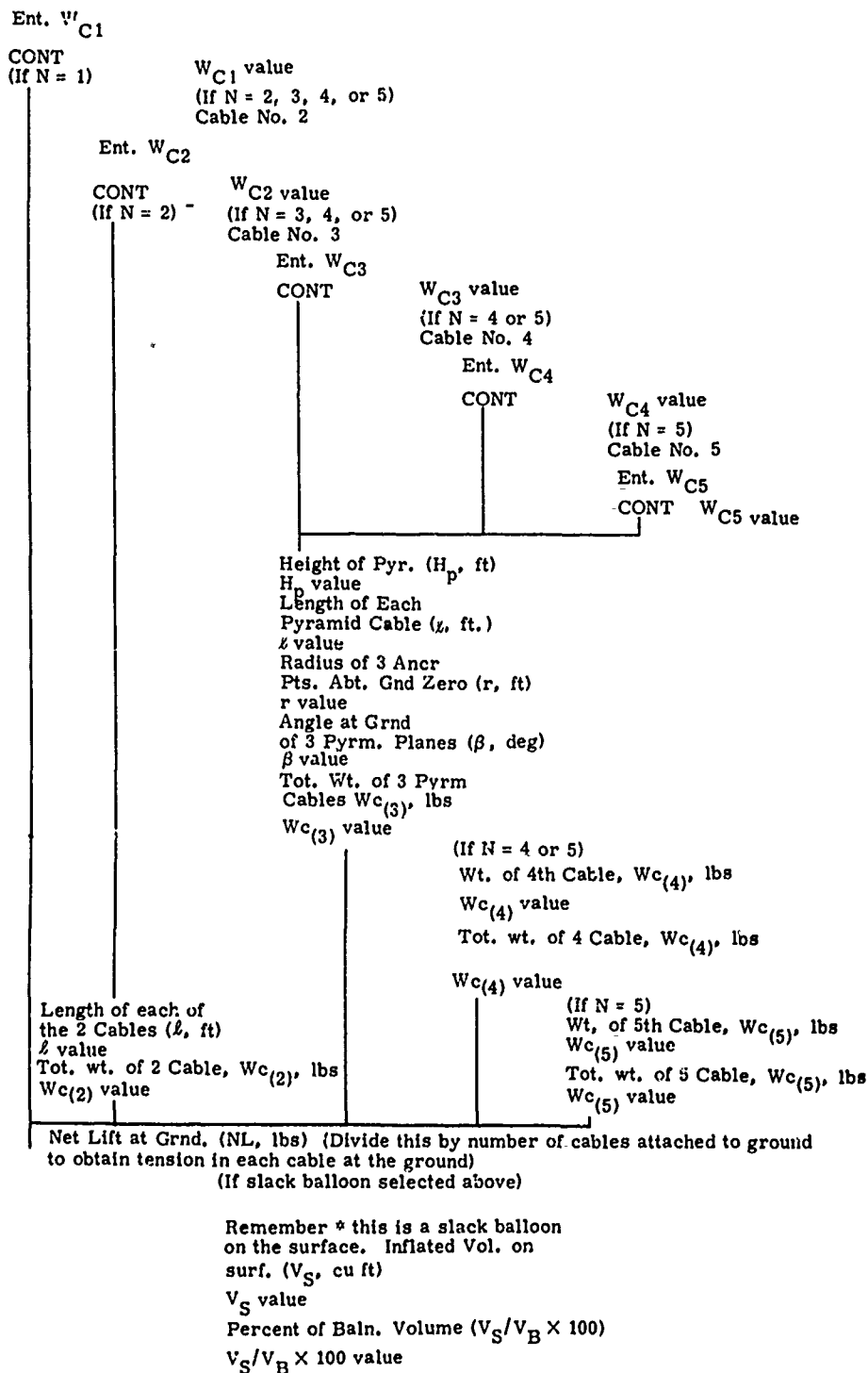
3 cable pyramid and balloon but there is a

cable from apex to ground zero, ENTER/(5).

Ent. N

CONT





3.1.5 SAMPLE INPUT DATA FORM

Input		76.001
Volume of Balloon	V_B	cu ft
Volume of Ballonet	v	cu ft
Weight of Balloon	W_B	lb
Weight of Instr. Pkg.	W_I	lb
Weight of Payload	W_P	lb
Altitude, Max. or Design	Z_{MAX}	ft, MSL
Altitude of Surface	Z_S	ft, MSL
Number of Cables	N	—
If 2, Distance on ground	X	ft
If 3, 4, or 5, Pyramid Cable Angle	α	deg
If 4 or 5, Length of Ext. Cable	l_e	ft
Cable #1 Weight per 1000 ft		lb
Cable #2 Weight per 1000 ft		lb
Cable #3 Weight per 1000 ft		lb
Cable #4 Weight per 1000 ft		lb
Cable #5 Weight per 1000 ft		lb

3.1.6 PROGRAM 76.001 - BASIC BUOYANCY

STORAGE					
b	a_0	007	Sp. Wt. C-2	018	NL
a	a_1	008	Sp. Wt. C-3	019	$\eta = 1$
000	1000	009	Sp. Wt. C-4	020	Sp. L. Hel. L.
001	V_B	010	Sp. Wt. C-5	021	Z_S
002	v	011	$X - 2 \text{ Cable}$	022	Z
003	W_B	012	$\alpha - 2 \text{ Cable}$	023	$H = Z - Z_S$
004	W_I	013	$\alpha - \text{Pyramid}$	024	P/P_r
005	W_P	014	$l_e - 4 \text{ H.C.}$	025	P_g/P_0
006	Sp. Wt. C-1	015	$N_c \text{ of C.}$	026	P_d/P_g
		016	$N \text{ CABLES}$	027	$H_r = H - l_e$
		017	NL B + I + P		

3.1.6 PROGRAM 76.001 - BASIC BUOYANCY

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
0000--CLP		0050-- 8		0100-- L		0150--XTO		0200--FMT		0250-- 3	
0001--FMT		0051-- 1		0101-- L		0151--FMT		0201--FMT		0251-- DN	
0002--FMT		0052-- 3		0102-- 0		0152--STP		0202--YTO		0252--FMT	
0003-- r		0053-- 6		0103-- 0		0153--PNT		0203--1/X		0253--FMT	
0004-- a		0054-- 0		0104-- H		0154--XTO		0204-- a		0254--INT	
0005-- 0		0055-- 6		0105--CNT		0155-- 3		0205-- F		0255-- E	
0006-- G		0056--CHS		0106--INT		0156--FMT		0206-- A		0256-- a	
0007-- a		0057--EEX		0107-- 0		0157--FMT		0207-- C		0257--XTO	
0008-- A		0058-- 5		0108-- L		0158--IND		0208-- E		0258-- .	
0009-- M		0059--CHS		0109-- .		0159--XTO		0209--CNT		0259-- H	
0010--CNT		0060--XTO		0110--FMT		0160-- .		0210-- A		0260-- E	
0011--GTO		0061-- b		0111--STP		0161-- B		0211-- L		0261-- I	
0012-- 7		0062-- 0		0112--PNT		0162-- A		0212--XTO		0262-- G	
0013-- 6		0063-- .		0113--XTO		0163-- L		0213-- .		0263-- H	
0014-- .		0064-- 0		0114-- 1		0164-- .		0214-- M		0264--XTO	
0015-- 0		0065-- 6		0115--FMT		0165-- I		0215--YTO		0265--FMT	
0016-- 0		0066-- 5		0116--FMT		0166-- H		0216-- L		0266--PNT	
0017-- 1		0067-- 9		0117-- B		0167--YTO		0217--FMT		0267--FMT	
0018--CLR		0068-- 8		0118-- A		0168--XTO		0218--STP		0268--FMT	
0019-- B		0069-- 8		0119-- L		0169-- a		0219--PNT		0269-- N	
0020-- A		0070--XTO		0120-- L		0170-- .		0220--XTO		0270--1/X	
0021--YTO		0071-- 0		0121-- 0		0171-- r		0221-- 2		0271-- M	
0022-- I		0072-- 2		0122-- H		0172-- K		0222-- 1		0272-- B	
0023-- C		0073-- 0		0123-- E		0173-- G		0223-- UP		0273-- E	
0024--CNT		0074-- 1		0124--XTO		0174--FMT		0224--FMT		0274-- a	
0025-- B		0075-- 0		0125--CNT		0175--STP		0225--FMT		0275--CNT	
0026--1/X		0076-- 0		0126--INT		0176--PNT		0226-- F		0276-- 0	
0027-- 0		0077-- 0		0127-- 0		0177--XTO		0227-- L		0277-- F	
0028--XFR		0078--XTO		0128-- L		0178-- 4		0228-- I		0278--CNT	
0029-- A		0079-- 0		0129-- .		0179--FMT		0229-- G		0279-- C	
0030-- H		0080--FMT		0130--FMT		0180--FMT		0230-- H		0280-- A	
0031-- C		0081--FMT		0131--STP		0181--IND		0231--XTO		0281-- B	
0032--XFR		0082-- E		0132--PNT		0182--XTO		0232--CNT		0282-- L	
0033--FMT		0083-- H		0133--XTO		0183-- .		0233-- A		0283-- E	
0034-- 1		0084--XTO		0134-- 2		0184-- E		0234-- L		0284--YTO	
0035-- .		0085-- E		0135--FMT		0185-- YE		0235--XTO		0285--FMT	
0036-- 7		0086-- a		0136--FMT		0186-- r		0236-- .		0286--STP	
0037-- 7		0087--CNT		0137-- B		0187-- .		0237-- M		0287--PNT	
0038-- 1		0088-- I		0138-- A		0188-- r		0238--YTO		0288--XTO	
0039-- 6		0089-- H		0139-- L		0189-- A		0239-- L		0289-- 1	
0040-- 7		0090--CNT		0140-- L		0190--XFR		0240--FMT		0290-- 5	
0041--CHS		0091-- YE		0141-- 0		0191-- L		0241--STP		0291-- UP	
0042--EEX		0092--CLX		0142-- 0		0192-- 0		0242--PNT		0292-- 2	
0043-- 1		0093-- -		0143-- H		0193-- A		0243--XTO		0293--X<Y	
0044-- 0		0094-- -		0144--CNT		0194-- D		0244-- 2		0294-- 0	
0045--CHS		0095-- -		0145--IND		0195--FMT		0245-- 2		0295-- 3	
0046--XTO		0096-- -		0146-- E		0196--STP		0246--XEY		0296-- 4	
0047-- a		0097--CLR		0147-- I		0197--PNT		0247-- -		0297-- 7	
0048-- 2		0098-- B		0148-- G		0198--XTO		0248--YTO		0298--X>Y	
0049-- .		0099-- A		0149-- H		0199-- 5		0249-- 2		0299-- 0	

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
0300--	4	0350--	XFR	0400--	L	0450--	1	0500--	A	0550--	IND
0301--	0	0351--	a	0401--	E	0451--	UP	0501--	B	0551--	I
0302--	8	0352--	A	0402--	FMT	0452--	XFR	0502--	0	0552--	N
0303--	FMT	0353--	M	0403--	STP	0453--	2	0503--	INT	0553--	G
0304--	FMT	0354--	I	0404--	XTC	0454--	-	0504--	E	0554--	.
0305--	D	0355--	D	0405--	1	0455--	XFR	0505--	CNT	0555--	.
0306--	I	0356--	CNT	0406--	4	0456--	1	0506--	YTO	0556--	.
0307--	YTO	0357--	C	0407--	PHT	0457--	DIV	0507--	1/X	0557--	CLR
0308--	XTO	0358--	A	0408--	XFR	0458--	DN	0508--	a	0558--	1
0309--	.	0359--	B	0409--	2	0459--	XTO	0509--	F	0559--	-
0310--	0	0360--	L	0410--	2	0460--	2	0510--	.	0560--	XTO
0311--	N	0361--	E	0411--	UP	0461--	7	0511--	F	0561--	0
0312--	CHT	0362--	CLR	0412--	UP	0462--	X<Y	0512--	0	0562--	CHT
0313--	G	0363--	A	0413--	a	0463--	0	0513--	a	0563--	a
0314--	a	0364--	N	0414--	X	0464--	7	0514--	CHT	0564--	E
0315--	0	0365--	G	0415--	b	0465--	2	0515--	B	0565--	XTO
0316--	1/X	0366--	L	0416--	+	0466--	9	0516--	A	0566--	A
0317--	N	0367--	E	0417--	DN	0467--	FMT	0517--	L	0567--	I
0318--	D	0368--	FMT	0418--	X	0468--	FMT	0518--	L	0568--	N
0319--	CLR	0369--	STP	0419--	DN	0469--	X	0519--	0	0569--	CHT
0320--	B	0370--	PNT	0420--	J	0470--	X	0520--	N	0570--	0
0321--	E	0371--	XTO	0421--	XTO	0471--	X	0521--	E	0571--	L
0322--	XTO	0372--	1	0422--	2	0472--	A	0522--	XTO	0572--	XTO
0323--	IND	0373--	3	0423--	4	0473--	L	0523--	CLR	0573--	.
0324--	E	0374--	XFR	0424--	XFR	0474--	E	0524--	YTO	0574--	A
0325--	E	0375--	1	0425--	2	0475--	a	0525--	I	0575--	N
0326--	N	0376--	5	0426--	1	0476--	XTO	0526--	XSQ	0576--	D
0327--	CNT	0377--	UP	0427--	UP	0477--	X	0527--	E	0577--	CNT
0328--	2	0378--	3	0428--	UP	0478--	X	0528--	CLR	0578--	YTO
0329--	CHT	0379--	X=Y	0429--	a	0479--	CLR	0529--	E	0579--	L
0330--	C	0380--	0	0430--	X	0480--	F	0530--	N	0580--	A
0331--	A	0381--	4	0431--	b	0481--	L	0531--	XTO	0581--	C
0332--	B	0382--	0	0432--	+	0482--	I	0532--	.	0582--	K
0333--	L	0383--	8	0433--	DN	0483--	G	0533--	I	0583--	CHT
0334--	E	0384--	FMT	0434--	X	0484--	H	0534--	H	0584--	I
0335--	YTO	0385--	FMT	0435--	DN	0485--	XTO	0535--	CHT	0585--	A
0336--	FMT	0386--	L	0436--	J	0486--	CHT	0536--	YE	0586--	1/X
0337--	STP	0387--	E	0437--	XTO	0487--	A	0537--	CHT	0587--	H
0338--	PNT	0388--	N	0438--	2	0488--	L	0538--	0	0588--	C
0339--	XTO	0389--	G	0439--	5	0489--	XTO	0539--	H	0589--	H
0340--	1	0390--	XTO	0440--	1/X	0490--	.	0540--	E	0590--	C
0341--	1	0391--	H	0441--	UP	0491--	XTO	0541--	CHT	0591--	0
0342--	GTO	0392--	CHT	0442--	XFR	0492--	0	0542--	0	0592--	H
0343--	0	0393--	E	0443--	2	0493--	0	0543--	F	0593--	D
0344--	4	0394--	YE	0444--	4	0494--	CLR	0544--	CLR	0594--	I
0345--	0	0395--	XTO	0445--	X	0495--	H	0545--	F	0595--	XTO
0346--	8	0396--	.	0446--	YTO	0496--	I	0546--	0	0596--	I
0347--	FMT	0397--	C	0447--	2	0497--	G	0547--	L	0597--	0
0348--	FMT	0398--	A	0448--	6	0498--	H	0548--	L	0598--	H
0349--	π	0399--	B	0449--	XFR	0499--	CHT	0549--	0	0599--	CLR

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
0600--	2	0650--	PHT	0700--	b	0750--	UP	0800--	UP	0850--	-
0601--	-	0651--	UP	0701--	CHS	0751--	XFR	0801--	XFR	0851--	DN
0602--	XTO	0652--	1	0702--	KEY	0752--	2	0802--	3	0852--	FMT
0603--	0	0653--	X=Y	0703--	-	0753--	1	0803--	-	0853--	FMT
0604--	CHT	0654--	0	0704--	a	0754--	-	0804--	DN	0854--	N
0605--	0	0655--	7	0705--	UP	0755--	DN	0805--	FMT	0855--	E
0606--	B	0656--	2	0706--	2	0756--	FMT	0806--	FMT	0856--	XTO
0607--	XTO	0657--	6	0707--	X	0757--	FMT	0807--	H	0857--	CNT
0608--	A	0658--	2	0708--	DN	0758--	INT	0808--	E	0858--	L
0609--	I	0659--	X=Y	0709--	DIV	0759--	E	0809--	XTO	0859--	I
0610--	H	0660--	0	0710--	YTO	0760--	a	0810--	CHT	0860--	F
0611--	CNT	0661--	6	0711--	2	0761--	XTO	0811--	B	0861--	XTO
0612--	E	0662--	7	0712--	2	0762--	-	0812--	A	0862--	CNT
0613--	YE	0663--	3	0713--	FMT	0763--	H	0813--	L	0863--	IND
0614--	C	0664--	DN	0714--	FMT	0764--	E	0814--	H	0864--	CNT
0615--	XTO	0665--	XTO	0715--	M	0765--	I	0815--	.	0865--	n
0616--	M	0666--	2	0716--	A	0766--	G	0816--	L	0866--	A
0617--	A	0667--	2	0717--	YE	0767--	H	0817--	I	0867--	XFR
0618--	YE	0668--	GTO	0718--	.	0768--	XTO	0818--	F	0868--	L
0619--	.	0669--	0	0719--	FMT	0769--	FMT	0819--	XTO	0869--	D
0620--	D	0670--	4	0720--	CNT	0770--	PHT	0820--	FMT	0870--	FMT
0621--	E	0671--	1	0721--	GTO	0771--	XTO	0821--	PNT	0871--	PNT
0622--	YTO	0672--	1	0722--	0	0772--	2	0822--	UP	0872--	XTO
0623--	I	0673--	XFR	0723--	7	0773--	3	0823--	XFR	0873--	1
0624--	G	0674--	2	0724--	2	0774--	XFR	0824--	4	0874--	7
0625--	H	0675--	7	0725--	9	0775--	2	0825--	-	0875--	FMT
0626--	CHT	0676--	UP	0726--	XTO	0776--	0	0826--	DN	0876--	FMT
0627--	A	0677--	YTO	0727--	1	0777--	UP	0827--	FMT	0877--	E
0628--	L	0678--	2	0728--	9	0778--	XFR	0828--	FMT	0878--	N
0629--	XTO	0679--	6	0729--	XFR	0779--	2	0829--	H	0879--	XTO
0630--	.	0680--	XFR	0730--	2	0780--	4	0830--	E	0880--	.
0631--	CLR	0681--	2	0731--	2	0781--	X	0831--	XTO	0881--	I
0632--	0	0682--	5	0732--	FMT	0782--	XFR	0832--	CNT	0882--	H
0633--	a	0683--	X	0733--	FMT	0783--	1	0833--	L	0883--	CNT
0634--	CNT	0684--	DN	0734--	F	0784--	X	0834--	I	0884--	YE
0635--	XSO	0685--	XTO	0735--	L	0785--	DN	0835--	F	0885--	CNT
0636--	-	0686--	2	0736--	I	0786--	FMT	0836--	XTO	0886--	C
0637--	A	0687--	4	0737--	G	0787--	FMT	0837--	CNT	0887--	A
0638--	CNT	0688--	I	0738--	H	0788--	G	0838--	IND	0888--	B
0639--	U	0689--	UP	0739--	XTO	0789--	a	0839--	CNT	0889--	L
0640--	I	0690--	4	0740--	CNT	0790--	0	0840--	I	0890--	E
0641--	F	0691--	X	0741--	A	0791--	YTO	0841--	H	0891--	CLR
0642--	F	0692--	a	0742--	L	0792--	YTO	0842--	YTO	0892--	IND
0643--	.	0693--	X	0743--	XTO	0793--	CNT	0843--	XTO	0893--	XTO
0644--	A	0694--	b	0744--	.	0794--	L	0844--	a	0894--	.
0645--	L	0695--	XSO	0745--	M	0795--	I	0845--	FMT	0895--	n
0646--	XTO	0696--	+	0746--	YTO	0796--	F	0846--	PHT	0896--	E
0647--	.	0697--	DN	0747--	L	0797--	XTO	0847--	UP	0897--	a
0648--	FMT	0698--	r	0748--	FMT	0798--	FMT	0848--	XFR	0898--	CNT
0649--	STP	0699--	UP	0749--	PHT	0799--	PHT	0849--	5	0899--	1

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
0900--	0	0950--	0	1000--	0	1050--	.	1100--	8	1150--	L
0901--	0	0951--	.	1001--	7	1051--	5	1101--	L	1151--	E
0902--	0	0952--	2	1002--	GTO	1052--	FMT	1102--	E	1152--	CHT
0903--	CHT	0953--	FMT	1003--	1	1053--	STP	1103--	FMT	1153--	0
0904--	F	0954--	STP	1004--	0	1054--	PHT	1104--	PHT	1154--	F
0905--	XTO	0955--	PHT	1005--	6	1055--	UP	1105--	GTO	1155--	CHT
0906--	CLR	0956--	UP	1006--	2	1056--	XFR	1106--	1	1156--	2
0907--	C	0957--	XFR	1007--	FMT	1057--	0	1107--	6	1157--	CHT
0908--	A	0958--	0	1008--	FMT	1058--	DIV	1108--	0	1158--	C
0909--	B	0959--	DIV	1009--	C	1059--	YTO	1109--	2	1159--	A
0910--	L	0960--	YTO	1010--	A	1060--	1	1110--	2	1160--	B
0911--	E	0961--	7	1011--	B	1061--	0	1111--	X=Y	1161--	L
0912--	CNT	0962--	DH	1012--	L	1062--	XFR	1112--	1	1162--	E
0913--	H	0963--	2	1013--	E	1063--	1	1113--	1	1163--	A
0914--	0	0964--	XCY	1014--	CNT	1064--	5	1114--	2	1164--	XTO
0915--	.	0965--	0	1015--	N	1065--	UP	1115--	1	1165--	CHT
0916--	1	0966--	9	1016--	0	1066--	1	1116--	GTO	1166--	G
0917--	FMT	0967--	7	1017--	.	1067--	X=Y	1117--	1	1167--	a
0918--	STP	0968--	4	1018--	4	1068--	1	1118--	2	1168--	0
0919--	PHT	0969--	GTO	1019--	FMT	1069--	0	1119--	5	1169--	1/X
0920--	UP	0970--	1	1020--	STP	1070--	7	1120--	6	1170--	N
0921--	XFR	0971--	0	1021--	PHT	1071--	7	1121--	XFR	1171--	D
0922--	0	0972--	6	1022--	UP	1072--	GTO	1122--	1	1172--	FMT
0923--	DIV	0973--	2	1023--	XFR	1073--	1	1123--	1	1173--	CHT
0924--	YTO	0974--	FMT	1024--	0	1074--	1	1124--	UP	1174--	PHT
0925--	6	0975--	FMT	1025--	DIV	1075--	1	1125--	XFR	1175--	M
0926--	XFR	0976--	C	1026--	YTO	1076--	0	1126--	2	1176--	UP
0927--	1	0977--	A	1027--	9	1077--	XFR	1127--	3	1177--	XFR
0928--	5	0978--	B	1028--	DH	1078--	2	1128--	UP	1178--	2
0929--	UP	0979--	L	1029--	4	1079--	3	1129--	2	1179--	3
0930--	1	0980--	E	1030--	XCY	1080--	UP	1130--	X	1180--	XEY
0931--	XCY	0981--	CHT	1031--	1	1081--	XFR	1131--	DH	1181--	DIV
0932--	0	0982--	H	1032--	0	1082--	6	1132--	DIV	1182--	DH
0933--	9	0983--	0	1033--	4	1083--	X	1133--	DH	1183--	FMT
0934--	4	0984--	.	1034--	0	1084--	YTO	1134--	L	1184--	FMT
0935--	1	0985--	3	1035--	GTO	1085--	1	1135--	0	1185--	L
0936--	GTO	0986--	FMT	1036--	1	1086--	6	1136--	UP	1186--	E
0937--	1	0987--	STP	1037--	0	1087--	DH	1137--	9	1187--	N
0938--	0	0988--	PHT	1038--	6	1088--	FMT	1138--	0	1188--	G
0939--	6	0989--	UP	1039--	2	1089--	FMT	1139--	XEY	1189--	XTO
0940--	2	0990--	XFR	1040--	FMT	1090--	IND	1140--	-	1190--	H
0941--	FMT	0991--	0	1041--	FMT	1091--	XTO	1141--	DH	1191--	CHT
0942--	FMT	0992--	DIV	1042--	C	1092--	.	1142--	XTO	1192--	0
0943--	C	0993--	YTO	1043--	A	1093--	0	1143--	1	1193--	F
0944--	A	0994--	8	1044--	B	1094--	F	1144--	2	1194--	CHT
0945--	B	0995--	DH	1045--	L	1095--	CHT	1145--	FMT	1195--	E
0946--	L	0996--	3	1046--	E	1096--	1	1146--	FMT	1196--	A
0947--	E	0997--	XCY	1047--	CHT	1097--	CNT	1147--	A	1197--	C
0948--	CNT	0998--	1	1048--	H	1098--	C	1148--	H	1198--	H
0949--	N	0999--	0	1049--	0	1099--	A	1149--	G	1199--	CLR

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
1200--	0	1250--	PNT	1300--	H	1350--	a	1400--	CHT	1450--	M
1201--	F	1251--	GTO	1301--	CNT	1351--	n	1401--	n	1451--	C
1202--	CHT	1252--	1	1302--	0	1352--	XTO	1402--	XFR	1452--	A
1203--	XTO	1253--	6	1303--	F	1353--	YTO	1403--	a	1453--	B
1204--	H	1254--	0	1304--	CHT	1354--	.	1404--	M	1454--	L
1205--	E	1255--	2	1305--	E	1355--	A	1405--	.	1455--	E
1206--	CNT	1256--	XFR	1306--	A	1356--	B	1406--	n	1456--	YTO
1207--	2	1257--	2	1307--	C	1357--	XTO	1407--	L	1457--	FMT
1208--	CHT	1258--	3	1308--	H	1358--	.	1408--	A	1458--	DH
1209--	C	1259--	JP	1309--	CLR	1359--	G	1409--	H	1459--	PNT
1210--	A	1260--	XFR	1310--	n	1360--	H	1410--	E	1460--	UP
1211--	B	1261--	1	1311--	XFR	1361--	D	1411--	YTO	1461--	XFR
1212--	L	1262--	4	1312--	a	1362--	.	1412--	FMT	1462--	1
1213--	E	1263--	-	1313--	A	1363--	XSQ	1413--	PNT	1463--	5
1214--	FMT	1264--	YTO	1314--	M	1364--	E	1414--	XFR	1464--	UP
1215--	PNT	1265--	2	1315--	I	1365--	a	1415--	6	1465--	3
1216--	UP	1266--	8	1316--	D	1366--	0	1416--	UP	1466--	XCY
1217--	UP	1267--	XFR	1317--	CHT	1367--	FMT	1417--	XFR	1467--	1
1218--	XFR	1268--	1	1318--	C	1368--	PNT	1418--	7	1468--	4
1219--	6	1269--	3	1319--	A	1369--	UP	1419--	RUP	1469--	8
1220--	X	1270--	M	1320--	B	1370--	XFR	1420--	X	1470--	1
1221--	XFR	1271--	XEY	1321--	L	1371--	2	1421--	RUP	1471--	DH
1222--	7	1272--	FMT	1322--	E	1372--	8	1422--	XEY	1472--	YTO
1223--	RUP	1273--	FMT	1323--	FMT	1373--	XFY	1423--	X	1473--	1
1224--	X	1274--	H	1324--	PNT	1374--	DIV	1424--	RUP	1474--	6
1225--	DH	1275--	E	1325--	UP	1375--	2	1425--	RUP	1475--	DH
1226--	+	1276--	I	1326--	XFR	1376--	X	1426--	+	1476--	GTO
1227--	DH	1277--	G	1327--	1	1377--	DH	1427--	XFR	1477--	1
1228--	XTO	1278--	H	1328--	3	1378--	L	1428--	8	1478--	6
1229--	1	1279--	XTO	1329--	N	1379--	0	1429--	RUP	1479--	0
1230--	6	1280--	CHT	1330--	XEY	1380--	FMT	1430--	X	1480--	2
1231--	FMT	1281--	0	1331--	X	1381--	FMT	1431--	DH	1481--	XFR
1232--	FMT	1282--	F	1332--	XEY	1382--	A	1432--	+	1482--	1
1233--	XTO	1283--	CHT	1333--	FMT	1383--	H	1433--	FMT	1483--	4
1234--	0	1284--	n	1334--	FMT	1384--	G	1434--	FMT	1484--	XEY
1235--	XTO	1285--	XFR	1335--	a	1385--	L	1435--	XTO	1485--	XFR
1236--	.	1286--	a	1336--	A	1386--	E	1436--	0	1486--	9
1237--	IND	1287--	.	1337--	D	1387--	CHT	1437--	XTO	1487--	X
1238--	XTO	1288--	FMT	1338--	I	1388--	A	1438--	.	1488--	DH
1239--	.	1289--	PNT	1339--	1/X	1389--	XTO	1439--	IND	1489--	FMT
1240--	0	1290--	XEY	1340--	YTO	1390--	CNT	1440--	XTO	1490--	FMT
1241--	F	1291--	DIV	1341--	CHT	1391--	G	1441--	.	1491--	IND
1242--	CHT	1292--	DH	1342--	0	1392--	a	1442--	0	1492--	XTO
1243--	2	1293--	FMT	1343--	F	1393--	H	1443--	F	1493--	.
1244--	CHT	1294--	FMT	1344--	CHT	1394--	D	1444--	CHT	1494--	0
1245--	C	1295--	L	1345--	3	1395--	CLR	1445--	3	1495--	F
1246--	A	1296--	E	1346--	CHT	1396--	0	1446--	CHT	1496--	CLT
1247--	B	1297--	H	1347--	A	1397--	F	1447--	n	1497--	4
1248--	L	1298--	G	1348--	H	1398--	CNT	1448--	XFR	1498--	XTO
1249--	FMT	1299--	XTO	1349--	C	1399--	3	1449--	a	1499--	H

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
1500--	CNT	1550--	8	1600--	FMT	1650--	UP	1700--	0	1750--	F
1501--	C	1551--	XKEY	1601--	PNT	1651--	XFR	1701--	H	1751--	CNT
1502--	A	1552--	CNT	1602--	UP	1652--	2	1702--	CNT	1752--	B
1503--	B	1553--	XFR	1603--	XFR	1653--	RUP	1703--	XTO	1753--	A
1504--	L	1554--	1	1604--	1	1654--	+	1704--	H	1754--	L
1505--	E	1555--	0	1605--	7	1655--	DN	1705--	E	1755--	H
1506--	FMT	1556--	X	1606--	XKEY	1656--	XKEY	1706--	CNT	1756--	.
1507--	PNT	1557--	DN	1607--	-	1657--	UP	1707--	YTO	1757--	INT
1508--	+	1558--	FMT	1608--	DN	1658--	DN	1708--	1/X	1758--	0
1509--	XFR	1559--	FMT	1609--	XTO	1659--	DIV	1709--	a	1759--	L
1510--	1	1560--	IND	1610--	1	1660--	1	1710--	F	1760--	1/X
1511--	5	1561--	XTO	1611--	8	1661--	0	1711--	A	1761--	M
1512--	UP	1562--	.	1612--	FMT	1662--	0	1712--	C	1762--	E
1513--	4	1563--	0	1613--	FMT	1663--	X	1713--	E	1763--	FMT
1514--	XKY	1564--	F	1614--	H	1664--	DN	1714--	CLR	1764--	PNT
1515--	1	1565--	CNT	1615--	E	1665--	XKEY	1715--	I	1765--	PNT
1516--	5	1566--	5	1616--	XTO	1666--	FMT	1716--	H	1766--	FMT
1517--	4	1567--	XTO	1617--	CNT	1667--	FMT	1717--	F	1767--	FMT
1518--	8	1568--	H	1618--	L	1668--	a	1718--	L	1768--	J
1519--	RUP	1569--	CNT	1619--	I	1669--	E	1719--	A	1769--	.
1520--	FMT	1570--	C	1620--	F	1670--	M	1720--	XTO	1770--	B
1521--	FMT	1571--	A	1621--	XTO	1671--	E	1721--	E	1771--	.
1522--	XTO	1572--	B	1622--	CNT	1672--	M	1722--	D	1772--	IND
1523--	0	1573--	L	1623--	-	1673--	B	1723--	CNT	1773--	.
1524--	XTO	1574--	E	1624--	G	1674--	E	1724--	INT	1774--	CNT
1525--	.	1575--	FMT	1625--	a	1675--	a	1725--	0	1775--	CNT
1526--	IND	1576--	PNT	1626--	H	1676--	X	1726--	L	1776--	7
1527--	XTO	1577--	+	1627--	D	1677--	XTO	1727--	.	1777--	6
1528--	.	1578--	DN	1628--	.	1678--	H	1728--	0	1778--	.
1529--	0	1579--	XTO	1629--	-	1679--	I	1729--	N	1779--	0
1530--	F	1580--	1	1630--	FMT	1680--	YTO	1730--	CLR	1780--	0
1531--	CNT	1581--	6	1631--	PNT	1681--	CNT	1731--	YTO	1781--	1
1532--	4	1582--	FMT	1632--	PNT	1682--	I	1732--	1/X	1782--	CLR
1533--	CNT	1583--	FMT	1633--	XFR	1683--	YTO	1733--	a	1783--	CLR
1534--	C	1584--	XTO	1634--	1	1684--	A	1734--	F	1784--	CLR
1535--	A	1585--	0	1635--	9	1685--	CNT	1735--	.	1785--	CLR
1536--	B	1586--	XTO	1636--	UP	1686--	YTO	1736--	FMT	1786--	CLR
1537--	L	1587--	.	1637--	1	1687--	L	1737--	PNT	1787--	CLR
1538--	FMT	1588--	IND	1638--	XKY	1688--	A	1738--	DN	1788--	FMT
1539--	PNT	1589--	XTO	1639--	1	1689--	C	1739--	FMT	1789--	K
1540--	XTO	1590--	.	1640--	7	1690--	K	1740--	FMT	1790--	CLX
1541--	1	1591--	0	1641--	6	1691--	CNT	1741--	#	1791--	GTO
1542--	6	1592--	F	1642--	6	1692--	B	1742--	E	1792--	0
1543--	GTO	1593--	CNT	1643--	XFR	1693--	A	1743--	a	1793--	0
1544--	1	1594--	5	1644--	2	1694--	L	1744--	C	1794--	0
1545--	6	1595--	CNT	1645--	6	1695--	L	1745--	E	1795--	0
1546--	0	1596--	C	1646--	UP	1696--	0.	1746--	N	1796--	END
1547--	2	1597--	A	1647--	XFR	1697--	0	1747--	XTO		
1548--	XFR	1598--	B	1648--	1	1698--	N	1748--	CNT		
1549--	2	1599--	L	1649--	X	1699--	CNT	1749--	0		

3.1.7 SAMPLE INPUT/OUTPUT PRINT

The following copy of the HP Printed Tape shows a typical problem and solution.
For a discussion of the particulars of this problem, see Section 4.

PROBLEM #76.001	MAX.
BASIC BUOYANCY	FLIGHT ALT.MSL
ENTER IN N:----	13906.417
BALLOON VOL.	VERT.HEIGHT
30000.000*	9906.417
BALLOONET VOL.	GROSS LIFT
8000.000*	1293.538
BALLOON WEIGHT	NET BALN.LIFT
725.000*	568.538
WT.BAL.INSTR.PKG	NET LIFT W INSTR
100.000*	468.538
WT.EXP.PAYLOAD	NET LIFT W PAYLD
100.000*	368.538
SURFACE ALT.MSL	ENT.IN % CABLE
4000.000*	WT.PER 1000 FT
FLIGHT ALT.MSL	CABLE NO.1
18000.000*	25.000*
VERT.HEIGHT	WT.OF 1 CABLE
14000.000	247.680
NUMBER OF CABLES	NET LIFT -GRND.-
1.000*	120.878
***ALERT**	J.B.W. 76.001
FLIGHT ALT.TOO	
HIGH ABOVE SURF.	
FOR BALLOONET	
SIZE	
ENT.IN % ONE OF	
FOLLOWING...	
1-TO RETAIN ALT.	
AND SLACK LAUNCH	
CONDITION	
2-TO OBTAIN EXCT	
MAX.DESIGN ALT.	
OR 2-A DIFF.ALT.	
2.000*	

PROGRAM #76.001
 BASIC BUOYANCY
 ENTER IN X,----
 BALLOON VOL.
 45000.000*
 BALLONET VOL.
 13522.000*
 BALLOON WEIGHT
 970.000*
 WT.BAL.INSTR.PKG
 150.000*
 WT.EXP.PAYLOAD
 100.000*
 SURFACE ALT.NSL
 4000.000*
 FLIGHT ALT.NSL
 18000.000*
 VERT.HEIGHT
 14000.000
 NUMBER OF CABLES
 1.000*
 ***ALERT**
 FLIGHT ALT.TOO
 HIGH ABOVE SURF.
 FOR BALLONET
 SIZE
 ENT.IN X ONE OF
 FOLLOWING...
 1-TO RETAIN ALT.
 AND SLACK LAUNCH
 CONDITION
 2-TO OBTAIN EXCT
 MAX.DESIGN ALT.
 OR 2-A DIFF.ALT.
 2.000-

MAX.
 FLIGHT ALT.NSL
 15323.770
 VERT.HEIGHT
 11323.770
 GROSS LIFT
 1850.818
 NET BALN.LIFT
 880.818
 NET LIFT W INSTR
 730.818
 NET LIFT W PAYLD
 630.818
 ENT.IN X CABLE
 WT.PER 1000 FT
 CABLE NO.1
 25.000*
 WT.OF 1 CABLE
 283.094
 NET LIFT -GRND.-
 347.724

J.B.W. 76.001

PROGRAM #76.001
 BASIC BUOYANCY
 ENTER IN X,----
 BALLOON VOL.
 45000.000*
 BALLONET VOL.
 13522.000*
 BALLOON WEIGHT
 970.000*
 WT.BAL.INSTR.PKG
 150.000*
 WT.EXP.PAYLOAD
 100.000*
 SURFACE ALT.NSL
 4000.000*
 FLIGHT ALT.NSL
 14000.000*
 VERT.HEIGHT
 10000.000
 NUMBER OF CABLES
 1.000*
 FLIGHT ALT.NSL
 14000.000
 VERT.HEIGHT
 10000.000
 GROSS LIFT
 1934.310
 NET BALN.LIFT
 964.310
 NET LIFT W INSTR
 814.310
 NET LIFT W PAYLD
 714.310
 ENT.IN X CABLE
 WT.PER 1000 FT
 CABLE NO.1
 25.000*
 WT.OF 1 CABLE
 250.000
 NET LIFT -GRND.-
 464.310

J.B.W. 76.001

**3.2 Program No. 76.002 — General Tethered Balloons, Trim,
Single Altitude, Zero Wind, Optional Matrix**

3.2.1 GENERAL DESCRIPTION

The trim of a tethered balloon is associated with the magnitude of several types of forces and their effective points of application relative to the point to which the tether-line is attached. This point of tether-line attachment is called the confluence-point due to its being the confluence of a number of smaller flying-lines leading to attaching points along the balloon's skin.

The forces, (see Figure in Section 3.2.2) acting on a tethered balloon, under zero wind conditions are the gross lift and the weight of the balloon and its hardware; their net effect being opposed by tension in the tether cable.

In Section 3.2.2, the derivation of an equation adaptable to use in a simple computer is shown. It essentially states that the net rotational moment about the confluence-point must be zero. The program will compute the lift force from the volume and altitude entered and then solve a simple equation for the trim angle-of-attack.

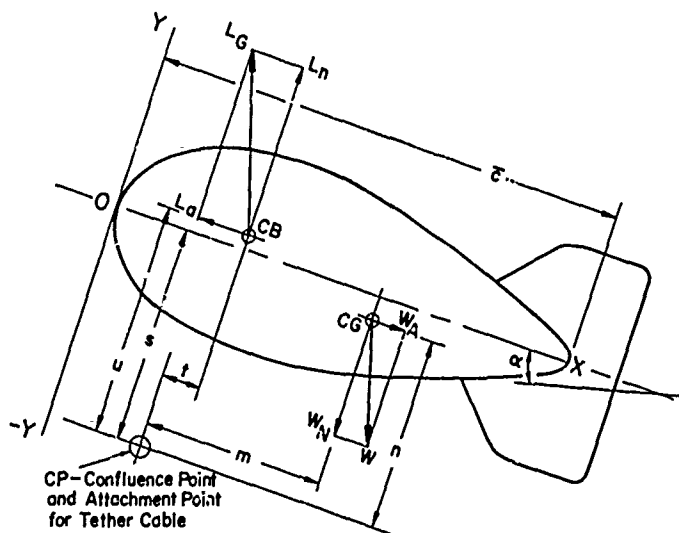
An optional feature is a matrix whereby four dimensions relating the center-of-gravity and center-of-buoyancy positions are made to vary automatically with a trim angle solution for every combination of the four variables.

3.2.2 DEVELOPMENT OF PROGRAM AND EQUATIONS

This case is concerned with any tethered balloon under zero wind conditions.

A. The object of the program is to determine the trim angle of the balloon. The tether cable is connected to the system at the confluence point of the multiple flying-lines attached to the balloon's skin. Hence at trim:

$$\Sigma \text{ Moments at Confluence Point} = 0$$



Consider Positive Moment Clockwise

$$\begin{aligned} \text{If } L_a &= L_G \sin \alpha \\ L_n &= L_G \cos \alpha \\ W_A &= W \sin \alpha \\ W_N &= W \cos \alpha \end{aligned}$$

Sum of the moments:

- (1) $m W_N + n W_A - u L_a - t L_n = 0$
- (2) $m W \cos \alpha + n W \sin \alpha - u L_G \sin \alpha - t L_G \cos \alpha = 0$
- (3) $m W - t L_G + n W \tan \alpha - u L_G \cos \alpha = 0$
- (4) $m W - t L_G = \tan \alpha (u L_G - n W)$
- (5) $\alpha = \arctan \frac{m W - t L_G}{u L_G - n W}$

B. Dimensions, m, n, t, and u are needed within program but are included by providing the locations of the C. P., C. G., and C. B. on the x-y grid defined above, that is,

$$\begin{array}{ll} X_{CP} - \text{Pos. Value} & Y_{CG} - \text{Neg. Value} \\ Y_{CP} - \text{Neg. Value} & X_{CB} - \text{Pos. Value} \\ X_{CG} - \text{Pos. Value} & Y_{CB} - \text{Pos. Value} \end{array}$$

Then,

$$\begin{array}{ll} m = X_{CG} - X_{CP} & t = X_{CB} - X_{CP} \\ n = Y_{CG} - Y_{CP} & u = Y_{CB} - Y_{CP} \end{array}$$

C. To provide an optional matrix of variations in m, n, t, and u to indicate an optimum combination in design problem, the program is set up so that after first computation each in turn will be incremented to a larger value by a desired amount, say 0.1 ft, any number of times up to a limit. To handle this, inputs are:

$$\begin{array}{ll} \Delta m - m \text{ Increment} & \Delta t - t \text{ Increment} \\ n\Delta m - \text{Number of } m \text{ Increments} & N\Delta t - \text{Number of } t \text{ Increments} \\ \Delta n - n \text{ Increment} & \Delta u - u \text{ Increment} \\ N\Delta n - \text{Number of } n \text{ Increments} & N\Delta u - \text{Number of } u \text{ Increments} \end{array}$$

This suggests that when running the matrix, values of CG, CB, and CP locations should be entered to produce the smallest reasonable starting values for m, n, t, and u in order to bracket useable conditions.

D. To calculate lift for a given volume of balloon at any altitude, using helium. The density ratio may be obtained by use of the relationship

$$\frac{\ln \rho/\rho_0}{Z} = a_0 + a_1 Z$$

where

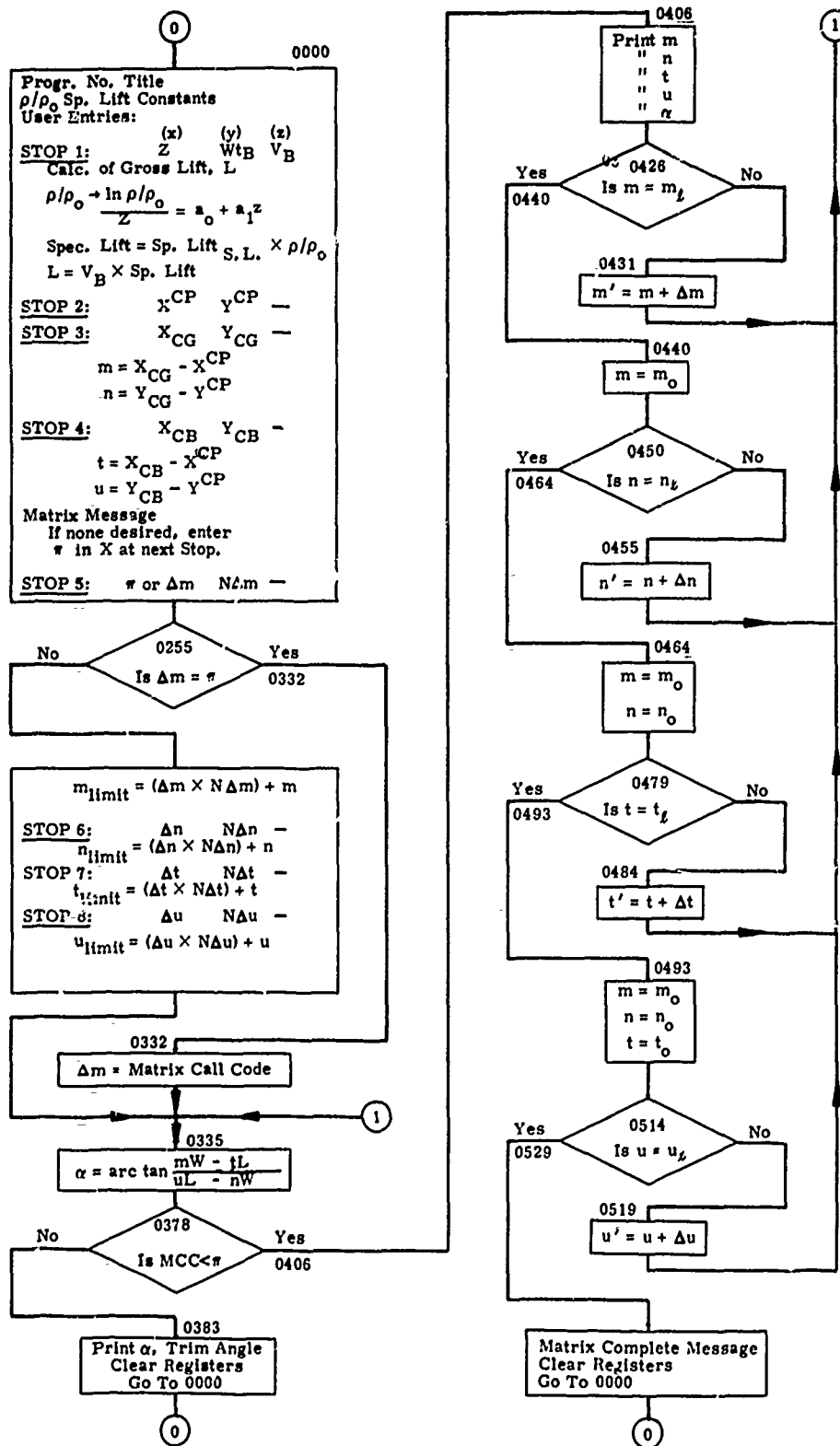
$$\begin{array}{l} Z = \text{altitude, Ft. MSL} \\ a_1 = -1.7772 \times 10^{-10} \\ a_0 = -2.81361 \times 10^{-5} \end{array}$$

The specific lift of helium, standard conditions at sea level .06599 lbs/ft².

Specific lift at altitude = .06599 ρ/ρ_0

Gross lift, $L_G = V_B \times (\text{Specific lift})$

3.2.3 FLOW CHART



3.2.4 OPERATING INSTRUCTIONS

<u>KEY STROKES</u>	<u>ENTRIES</u>			<u>PRINTS</u>
RUN				
END				
FIX, 2, 3, ----				(No. of decimal places desired)
CONT	(X)	(Y)	(Z)	Program No. & Title
Stop 1, Enter:	Z	W_B	V_B	
CONT				V_B , Balloon Volume CF W_B , Balloon Weight, lb Z, Altitude, ft MSL L_G , Gross Lift, lb
Stop 2, Enter:	X^{CP}	Y^{CP}	-	
CONT				X^{CP} , Confl. Point X, ft Y^{CP} , Confl. Point Y, ft
Stop 3, Enter:	X_{CG}	Y_{CG}	-	
CONT				X_{CG} , Center of Gravity X, ft Y_{CG} , Center of Gravity Y, ft
Stop 4, Enter:	X_{CB}	Y_{CB}	-	
CONT				X_{CB} , Center of Buoyancy X, ft Y_{CB} , Center of Buoyancy Y, ft m, ft n, ft t, ft u, ft Ent. Π in X if no matrix calculations are desired.
Stop 5, Enter:	Π	-	-	(If no matrix requested.) Trim angle, α Value of trim angle
or				
Stop 5, Enter:	Δm	$N\Delta m$	-	
CONT				Δm , Increments of Δm , ft $N\Delta m$, No. of Increments m_l , Limiting Value of t_m , ft

Stop 6, Enter:	Δn	$N\Delta n$	-	Δn Increments of Δn ft $N\Delta n$ No. of Increments n_l Limiting values of n, ft
CONT				
Stop 7, Enter:	Δt	$N\Delta t$	-	Δt , Increments of Δt , ft $N\Delta t$, No. of Increments t_l Limiting value of t, ft
CONT				
Stop 8, Enter:	Δu	$N\Delta u$	-	Δu , Increments of Δu , ft $N\Delta u$, No. of Increments u_l Limiting value of u, ft
CONT				

Program then proceeds to calculate all combinations of m, n, t and u in matrix beginning with initial values obtained from entries at Stop Nos. 2, 3, and 4.

	m, ft n, ft t, ft u, ft α , deg trim angle $m' = m + \Delta m$ n t u α $m'' = m + 2\Delta m$ n t u α etc, until $m_l = m$ then, m $n' = n + \Delta n$ t u α
etc, until final m_l n_l t_l u_l α	

1

38

3.2.6 PROGRAM 76.002 - TRIM, GENERAL BALLOON, WIND = 0

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
0000--CLR		0050--XTO		0100-- 6		0150-- 9		0200--PHT		0250-- UP	
0001--FMT		0051-- 0		0101--RUP		0151-- -		0201-- DH		0251--STP	
0002--FMT		0052-- 1		0102--KEY		0152--YTO		0202--PHT		0252-- UP	
0003-- #		0053-- 3		0103-- X		0153-- 1		0203-- DH		0253-- #	
0004-- a		0054-- 2		0104-- UP		0154--YTO		0204--PHT		0254--X=Y	
0005-- 0		0055-- .		0105--XFR		0155-- 3		0205--PHT		0255-- 0	
0006-- G		0056-- 8		0106-- 1		0156-- 1		0206--FMT		0256-- 3	
0007-- .		0057-- 1		0107-- 3		0157--XFR		0207--FMT		0257-- 3	
0008--GTO		0058-- 3		0108--RUP		0158-- 8		0208-- E		0258-- 2	
0009-- 7		0059-- 6		0109-- +		0159--RUP		0209-- H		0259-- DH	
0010-- 6		0060-- 1		0110-- DH		0160--KEY		0210--XTO		0260--PHT	
0011-- .		0061--CHS		0111--KEY		0161-- -		0211-- .		0261--XTO	
0012-- 0		0062--EEX		0112-- X		0162--YTO		0212--CHS		0262-- 4	
0013-- 0		0063-- 5		0113-- DH		0163-- 0		0213--CHT		0263--KEY	
0014-- 2		0064--CHS		0114-- J		0164--YTO		0214-- I		0264--PHT	
0015--CLR		0065--XTO		0115-- UP		0165-- 0		0215-- H		0265-- X	
0016--XTO		0066-- 0		0116--XFR		0166-- 3		0216--CHT		0266--XFR	
0017-- a		0067-- 1		0117-- 1		0167-- 0		0217-- YE		0267-- 0	
0018-- I		0068-- 2		0118-- 4		0168-- 4		0218--CHT		0268-- +	
0019-- M		0069-- .		0119-- X		0169-- UP		0219-- I		0269--YTO	
0020--CLX		0070-- 0		0120--XFR		0170-- UP		0220-- F		0270-- 5	
0021-- G		0071-- 6		0121-- 1		0171--STP		0221--CHT		0271-- DH	
0022-- E		0072-- 5		0122-- 5		0172--PHT		0222-- H		0272--PHT	
0023-- H		0073-- 9		0123-- X		0173--KEY		0223-- 0		0273-- 6	
0024-- .		0074-- 9		0124--YTO		0174--PHT		0224-- M		0274-- UP	
0025-- B		0075--XTO		0125-- 6		0175--PHT		0225-- A		0275-- UP	
0026-- A		0076-- 0		0126-- DH		0176-- UP		0226--XTO		0276--STP	
0027-- L		0077-- 1		0127--PHT		0177--XFR		0227-- a		0277--PHT	
0028-- L		0078-- 4		0128--PHT		0178-- 9		0228-- I		0278--XTO	
0029-- 0		0079-- 1		0129--PHT		0179-- -		0229-- YE		0279-- 6	
0030-- 0		0080-- UP		0130-- 2		0180--YTO		0230--CHT		0280--KEY	
0031-- H		0081-- UP		0131-- UP		0181-- 3		0231-- C		0281--PHT	
0032--IND		0082--STP		0132-- UP		0182--YTO		0232-- A		0282-- X	
0033-- I		0083--RUP		0133--STP		0183-- 3		0233-- L		0283--XFR	
0034-- H		0084--PHT		0134--YTO		0184-- 3		0234-- C		0284-- 1	
0035-- D		0085--XTO		0135-- 9		0185--XFR		0235-- .		0285-- +	
0036--SFL		0086-- 1		0136--PHT		0186-- 8		0236-- A		0286--YTO	
0037-- 0		0087-- 5		0137--XTO		0187--RUP		0237-- a		0287-- 7	
0038--FMT		0088--RUP		0138-- 8		0188--KEY		0238-- E		0288-- DH	
0039-- 1		0089--PHT		0139--KEY		0189-- -		0239--CLR		0289--PHT	
0040-- .		0090--XTO		0140--PHT		0190--YTO		0240-- D		0290-- 7	
0041-- 7		0091-- a		0141-- 3		0191-- 2		0241-- E		0291-- UP	
0042-- 7		0092--XFR		0142-- UP		0192--YTO		0242--YTO		0292-- UP	
0043-- 7		0093-- 1		0143-- UP		0193-- 3		0243-- I		0293--STP	
0044-- 2		0094-- 3		0144--STP		0194-- 2		0244-- a		0294--PHT	
0045--CHS		0095--KEY		0145--PHT		0195--XFR		0245-- E		0295--XTO	
0046--EEX		0096--RUP		0146--KEY		0196-- 0		0246-- D		0296-- 8	
0047-- 1		0097--PHT		0147--PHT		0197--PHT		0247--FMT		0297--KEY	
0048-- 0		0098--XTO		0148-- UP		0198--XFR		0248-- 5		0298--PHT	
0049--CHS		0099-- 1		0149--XFR		0199-- 1		0249-- UP		0299-- X	

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
0300--XFR		0350-- 2		0400--CLX		0450--X=Y		0500-- 1		0550-- 0	
0301-- 2		0351-- X		0401--GTO		0451-- 0		0501--XTO		0551-- 0	
0302-- -		0352--XFR		0402-- 0		0452-- 4		0502-- 1		0552-- 0	
0303--YTO		0353-- 3		0403-- 0		0453-- 6		0503--XFR		0553-- 0	
0304-- 9		0354--RUP		0404-- 0		0454-- 4		0504-- 3		0554--END	
0305-- DH		0355--RUP		0405-- 0		0455--XFR		0505-- 2			
0306--PNT		0356-- -		0406--XFR		0456-- 6		0506--XTO			
0307-- 6		0357-- 6		0407-- 0		0457-- +		0507-- 2			
0308-- UP		0358--RUP		0408--PNT		0458--YTO		0508--XFR			
0309-- UP		0359-- X		0409-- UP		0459-- 1		0509-- 3			
0310--STP		0360--XFR		0410--XFR		0460--GTO		0510-- UP			
0311--PNT		0361-- 3		0411-- 1		0461-- 3		0511--XFR			
0312--XTO		0362-- 4		0412--PNT		0462-- 3		0512-- 1			
0313-- 1		0363-- -		0413--XFR		0463-- 5		0513-- 1			
0314-- 0		0364-- DH		0414-- 2		0464--XFR		0514--X=Y			
0315--XEY		0365--DIV		0415--PNT		0465-- 3		0515-- 0			
0316--PNT		0366-- DH		0416--XFR		0466-- 0		0516-- 5			
0317-- X		0367-- L		0417-- 3		0467--XTO		0517-- 2			
0318--XFR		0368-- 0		0418--PNT		0468-- 0		0518-- 9			
0319-- 3		0369--XTO		0419--XFR		0469--XFR		0519--XFR			
0320-- +		0370-- 1		0420-- 1		0470-- 3		0520-- 1			
0321--YTO		0371-- 7		0421-- 7		0471-- 1		0521-- 0			
0322-- 1		0372-- UP		0422--PNT		0472--XTO		0522-- +			
0323-- 1		0373--XFR		0423--PNT		0473-- 1		0523--YTO			
0324-- DH		0374-- 2		0424--XFR		0474--XFR		0524-- 3			
0325--PNT		0375-- 9		0425-- 5		0475-- 2		0525--GTO			
0326--PNT		0376-- UP		0426--X=Y		0476-- UP		0526-- 3			
0327--PNT		0377-- π		0427-- 0		0477--XFR		0527-- 3			
0328--GTO		0378--X>Y		0428-- 4		0478-- 9		0528-- 3			
0329-- 3		0379-- 0		0429-- 4		0479--X=Y		0529--FMT			
0330-- 3		0380-- 4		0430-- 0		0480-- 0		0530--FMT			
0331-- 5		0381-- 0		0431--XFR		0481-- 4		0531-- M			
0332--XTO		0382-- 6		0432-- 4		0482-- 9		0532-- R			
0333-- 2		0383--RUP		0433-- +		0483-- 3		0533--XTO			
0334-- 9		0384--FMT		0434--YTO		0484--XFR		0534-- a			
0335--XFR		0385--FMT		0435-- 0		0485-- 8		0535-- I			
0336-- 0		0386--XTO		0436--GTO		0486-- +		0536-- YE			
0337-- UP		0387-- a		0437-- 3		0487--YTO		0537--CNT			
0338-- a		0388-- I		0438-- 3		0488-- 2		0538-- C			
0339-- X		0389-- M		0439-- 5		0489--GTO		0539-- 0			
0340-- UP		0390--CNT		0440--XFR		0490-- 3		0540-- M			
0341--XFR		0391-- R		0441-- 3		0491-- 3		0541-- π			
0342-- 1		0392-- H		0442-- 0		0492-- 5		0542-- L			
0343-- X		0393-- G		0443--XTO		0493--XFR		0543-- E			
0344--YTO		0394-- L		0444-- 0		0494-- 3		0544--XTO			
0345-- 3		0395-- E		0445--XFR		0495-- 0		0545-- E			
0346-- 4		0396--FMT		0446-- 1		0496--XTO		0546--FMT			
0347-- 6		0397--PNT		0447-- UP		0497-- 0		0547-- K			
0348--XEY		0398--PNT		0448--XFR		0498--XFR		0548--CLX			
0349--XFR		0399-- K		0449-- 7		0499-- 3		0549--GTO			

STORAGE	
b	Le
a	W ₀
000	m
001	n
002	t
003	u
004	Δm
005	M limit
006	Δn
007	n limit
008	Δt
009	t limit
010	Δu
011	u limit
012	Δc
013	Δ ₁
014	Sp. Lift 2nd
015	V ₀
016	Z
017	cc
018	X ^{CP}
019	Y ^{CP}
020	
021	
022	
023	
024	
025	
026	
027	
028	
029	π MATRIX
030	M _{1c}
031	M _c
032	E ₀
033	U ₀
034	TEMP.
035	
036	
037	
038	
039	

040	
041	
042	
043	
044	
045	
046	
047	
048	
049	
050	
051	
052	
053	
054	
055	
056	
057	
058	
059	
060	
061	
062	
063	
064	
065	
066	
067	
068	
069	
070	
071	
072	
073	
074	
075	
076	
077	
078	
079	

080	
081	
082	
083	
084	
085	
086	
087	
088	
089	
090	
091	
092	
093	
094	
095	
096	
097	
098	
099	
100	
101	
102	
103	
104	
105	
106	
107	
108	

3.2.7 SAMPLE INPUT/OUTPUT PRINT

The following copy of the HP Printed Tape shows a typical problem and solution. The left column shows input and output printouts without the matrix solution. The center and right columns show, for the same starting input figures, the first few and last few of the matrix solutions called for by the initial definitions of matrix size, Δm , $N\Delta m$, etc.

PROG.#76.002	PROG.#76.002	
TRIM,GEN.BALLOON	TRIM,GEN.BALLOON	
WIND=0	WIND=0	38.40
45000.00	45000.00	23.90
1000.00	1000.00	3.40
5000.00	5000.00	32.10
2568.41	2568.41	28.99
		28.40
		29.90
26.60	26.60	3.40
-31.90	-31.90	32.10
55.00*	55.00*	20.52
-3.00	-3.00	
30.00*	30.00*	33.40
0.20	0.20	29.90
		3.40
28.40	28.40	32.10
28.90	28.90	25.15
3.40	3.40	
32.10	32.10	38.40
		29.90
ENT.# IN X IF NO	ENT.# IN X IF NO	3.40
MATRIX CALC.ARE	MATRIX CALC.ARE	32.10
DESIRED	DESIRED	29.45
TRIM ANGLE		
20.17	5.00	
	2.00	28.40
	38.40	30.90
	1.00*	3.40
	2.00	32.10
	30.90	20.88
	7.50*	
	2.00	
	18.40	33.40
	0.25*	30.90
	2.00	18.40
	32.60	32.60
		-14.70
	28.40	38.40
	28.90	30.90
	3.40	18.40
	32.10	32.60
	20.17	-9.52
	33.40	
	28.90	
	3.40	
	32.10	
	24.73	
		MATRIX COMPLETE
		PROG.#76.002
		TRIM,GEN.BALLOON
		WIND=0

3.3 Program No. 76.003 — General Tethered Balloon, Trim, Variable Altitude and Wind

3.3.1 GENERAL DESCRIPTION

The trim of a tethered balloon is associated with the magnitude of several types of forces and their effective points of application relative to the point to which the tether-line is attached. This point of tether-line attachment is called the confluence-point due to its being the confluence of a number of smaller flying-lines leading to attaching points along the balloon's skin.

The forces acting on a tethered balloon, (Figure in Section 3.3.2) are the gross lift, the weight of the balloon and its hardware, and those aerodynamic forces and moments generated by the action of the wind. Since trim in the vertical sense is of principal interest in loading or in early design of a tethered system, the lift, drag, and pitching-moment were the only aerodynamic parameters considered.

In Section 3.3.2, the derivation of an equation adaptable to use in a simple computer is shown. It essentially states that the net rotational moment about the confluence-point must be zero. Program 76.002 is for the condition of a single altitude where the wind is zero and therefore considers only the lift due to helium buoyancy and the weight of the balloon. Program 76.003 considers all parameters, including a zero-wind input, and in addition permits application of any extra masses at any location on the balloon. It calculates the gross-lift at any maximum altitude selected assuming that the balloon is completely filled with helium. At incrementally decreasing altitudes, this lift remains constant. Since a wind-profile from the maximum altitude to the surface altitude, is part of the user entries, the aerodynamic parameters vary with the wind magnitude and atmospheric density.

Unlike Program Nos. 76.004 and 76.005, the parameters completely defining the aerodynamics and the possible movement of the centers of buoyancy or gravity with trim-angle or ballonnet condition of most balloon designs are not completely known. Accordingly, all defining parameters are left as user inputs and the reference centers left fixed for all flight conditions. For example, a fixed aerodynamic-reference-center for application of a pitching-moment coefficient is utilized here (In 76.004 and 5, the more convenient concept of a variable center-of-pressure eliminating pitching-moment was possible.)

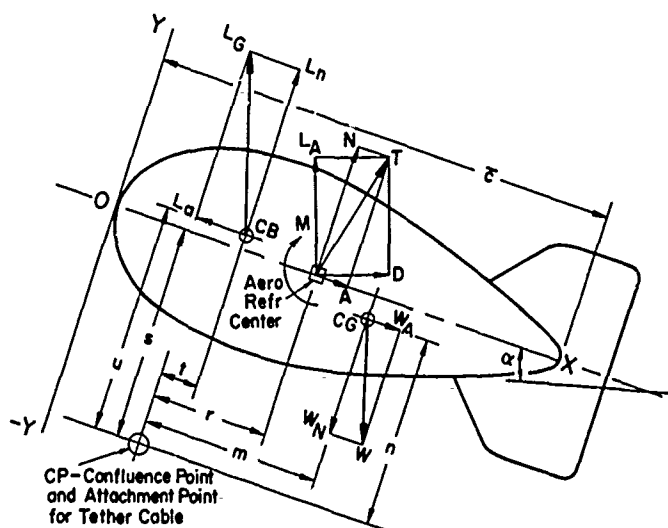
The ballonnet fullness, which depends on relationships between maximum and surface altitudes, was not needed or considered here. Use of Program No. 76.001 is recommended to first check that the capacity of the balloon's ballonnet is not exceeded by any proposed altitude excursion.

3.3.2 DEVELOPMENT OF PROGRAM AND EQUATIONS

This case is concerned with any tethered balloon at any altitude or wind condition. Knowledge of aerodynamic coefficients, C_L - C_D - C_M , are presumed.

A. The object of the program is to determine the trim conditions of the balloon and the total force and its angle which must be resisted by the tether-cable. The tether cable is connected to the system at the confluence-point of the multiple flying-lines attached to the balloon's skin. Hence at trim:

$$\Sigma \text{ Moments at Confluence Point} = 0$$



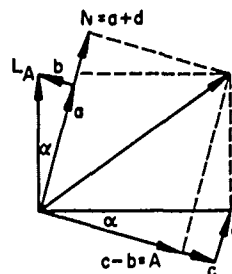
Positive Moments are Clockwise

$$(1) 0 = mW_N + nW_A - tL_n - uL_a - rN + sA + M$$

Resolve Aero L_A & D into N and A by:

$$\cos \alpha = \frac{a}{L_A} \text{ and } \frac{c}{D}$$

$$\sin \alpha = \frac{b}{L_A} \text{ and } \frac{d}{D}$$



$$\begin{aligned}
 a &= L_A \cos \alpha & N &= L_A \cos \alpha + D \sin \alpha \\
 b &= L_A \sin \alpha & A &= D \cos \alpha - L_A \sin \alpha \\
 c &= D \cos \alpha \\
 d &= D \sin \alpha
 \end{aligned}$$

$$(2) \quad 0 = mW_N + nW_A - tL_n - uL_a - rL_A \cos \alpha - rD \sin \alpha + sD \cos \alpha - sL_A \sin \alpha + M$$

$$\begin{aligned}
 L_a &= L_G \sin \alpha & W_A &= W \sin \alpha \\
 L_n &= L_G \cos \alpha & W_N &= W \cos \alpha
 \end{aligned}$$

$$(3) \quad 0 = mW \cos \alpha + nW \sin \alpha - tL_G \cos \alpha - uL_G \sin \alpha - rL_A \cos \alpha - rD \sin \alpha + sD \cos \alpha - sL_A \sin \alpha + M$$

$$(4) \quad 0 = mW + nW \tan \alpha - tL_G - uL_G \tan \alpha - rL_A - rD \tan \alpha + sD - sL_A \tan \alpha + M/\cos \alpha$$

$$(5) \quad 0 = mW - tL_G + \tan \alpha (nW - uL_G) - rL_A - rD \tan \alpha + sD - sL_A \tan \alpha + M/\cos \alpha$$

$$\text{Let } a = dC_L/d\alpha, C_{L_O} = 0, \text{ then: } L_A = a\alpha q V_B^{2/3}$$

$$b = C_{D_O} \text{ and } c = dC_D/d\alpha^2$$

$$\text{then: } C_D = b + \alpha^2 \text{ and: } D = (b + \alpha^2) q V_B^{2/3}$$

$$(6) \quad 0 = mW - tL_G + \tan \alpha (nW - uL_G) - ra\alpha q V_B^{2/3} - r(b + \alpha^2) q V_B^{2/3} \tan \alpha + s(b + \alpha^2) q V_B^{2/3} - sa\alpha q V_B^{2/3} \tan \alpha + \frac{C_M q V_B^{2/3}}{\cos \alpha}$$

$$\text{Let } K = q V_B^{2/3}$$

$$(7) \quad 0 = mW - tL_G + \tan \alpha (nW - uL_G) - K[ra\alpha + r(b + \alpha^2) \tan \alpha - s(b + \alpha^2) + sa\alpha \tan \alpha] + \frac{C_M \bar{c} K}{\cos \alpha}$$

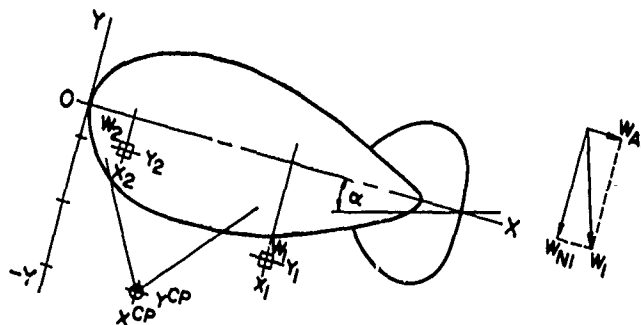
$$(8) \quad 0 = mW - tL_G + \tan \alpha (nW - uL_G) - K[ra\alpha - sb - s\alpha^2 + \tan \alpha (sa\alpha + rb + r\alpha^2)] + \frac{C_M \bar{c} K}{\cos \alpha}$$

To allow for adding extra loads (equipment, counter-weights, etc.) at any position on the balloon, consider the following two weights:

$$M_1, \text{ Moment about Conf Point} = W_{N1}(x_1 - x^{CP}) + W_{A1}(y_1 - y^{CP})$$

$$M_1 = W_1 \cos \alpha (x_1 - x^{CP}) + W_1 \sin \alpha (y_1 - y^{CP})$$

$$M_2 = W_2 \cos \alpha (x_2 - x^{CP}) + W_2 \sin \alpha (y_2 - y^{CP})$$



$$\tau M \text{ extra} = M_1 + M_2$$

$$\frac{\tau M \text{ extra}}{\cos \alpha} = W_1 (x_1 - x^{CP}) + W_2 (x_2 - x^{CP}) + \tan \alpha [W_1 (y_1 - y^{CP}) + W_2 (y_2 - y^{CP})]$$

$$(9) \quad \frac{\Sigma M \text{ extra}}{\cos \alpha} = \Sigma W_e (x - x^{CP}) + \tan \alpha \Sigma W_e (y - y^{CP})$$

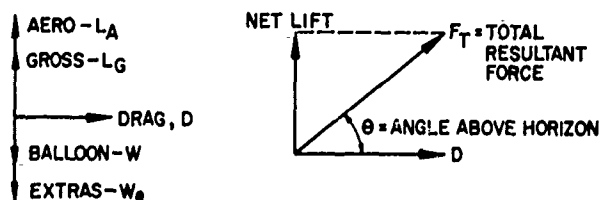
Letting $L = L_G$ for clarity and adding the provision for extra weights,

Eq. (8) expands to

$$(10) \quad \left. \begin{aligned} 0 = mW - tL + \tan \alpha (nW - uL) & \quad (\text{Mech. Mom.}) \\ - K[ra \alpha - sb - sc\alpha^2 + \tan \alpha (sa \alpha + rb + rc\alpha^2)] & \\ + \frac{C_M \bar{c} K}{\cos \alpha} & \quad (\text{Aero Mom.}) \\ + \cos \alpha [\Sigma W_e (x - x^{CP}) + \tan \alpha \Sigma W_e (y - y^{CP})] & \quad (\text{Extras Mom.}) \end{aligned} \right\}$$

B. After solving Eq. (10) for α_{trim} , the coefficients C_L , C_D , C_M , as well as L_A , D , M_O , can be calculated.

Then solution for the total force and its angle at the confluence point are known.



C. A 2 constant form for density ratio is utilized in this and other programs.

$$\frac{\ln \rho/\rho_0}{z} = a_0 + a_1 z$$

where

$$a_1 = -1.7772 \cdot 10^{-10}$$

$$a_0 = -2.81361 \cdot 10^{-5}$$

D. Dimensions m, n, r, s, t and u are calculated by program after user entries of

- x^{CP} and y^{CP} - Confluence Point
- x^{CG} and y^{CG} - Center Gravity
- x^{CB} and y^{CB} - Center of Buoyancy
- x^{ARC} - Aero Ref. Center ($y^{ARC} = 0$ assumed)

E. Aerodynamic coefficients in this general program are handled as inputs also. However, options at the end of program allow repeated passes without re-entry of these coefficients, balloon dimensions, or other parameters.

$$\frac{dC_L}{d\alpha} = a \text{ in Moment Equation - Slope of the lift coefficient curve}$$

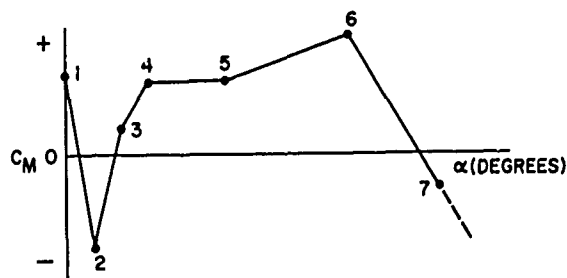
where $C_L = 0$ at $\alpha = 0$

$$C_{D0} = b \text{ in Moment Equation - Drag coefficient at } \alpha = 0$$

$$\frac{dC_D}{d\alpha^2} = c \text{ in Moment Equation - Second constant in drag coefficient}$$

$$\text{form } C_D + \frac{dC_D}{d\alpha^2} \alpha^2$$

Pitching Moment Coefficient, C_M , was found, with at least one balloon to have a variation with α that could be defined by a series of straight lines.

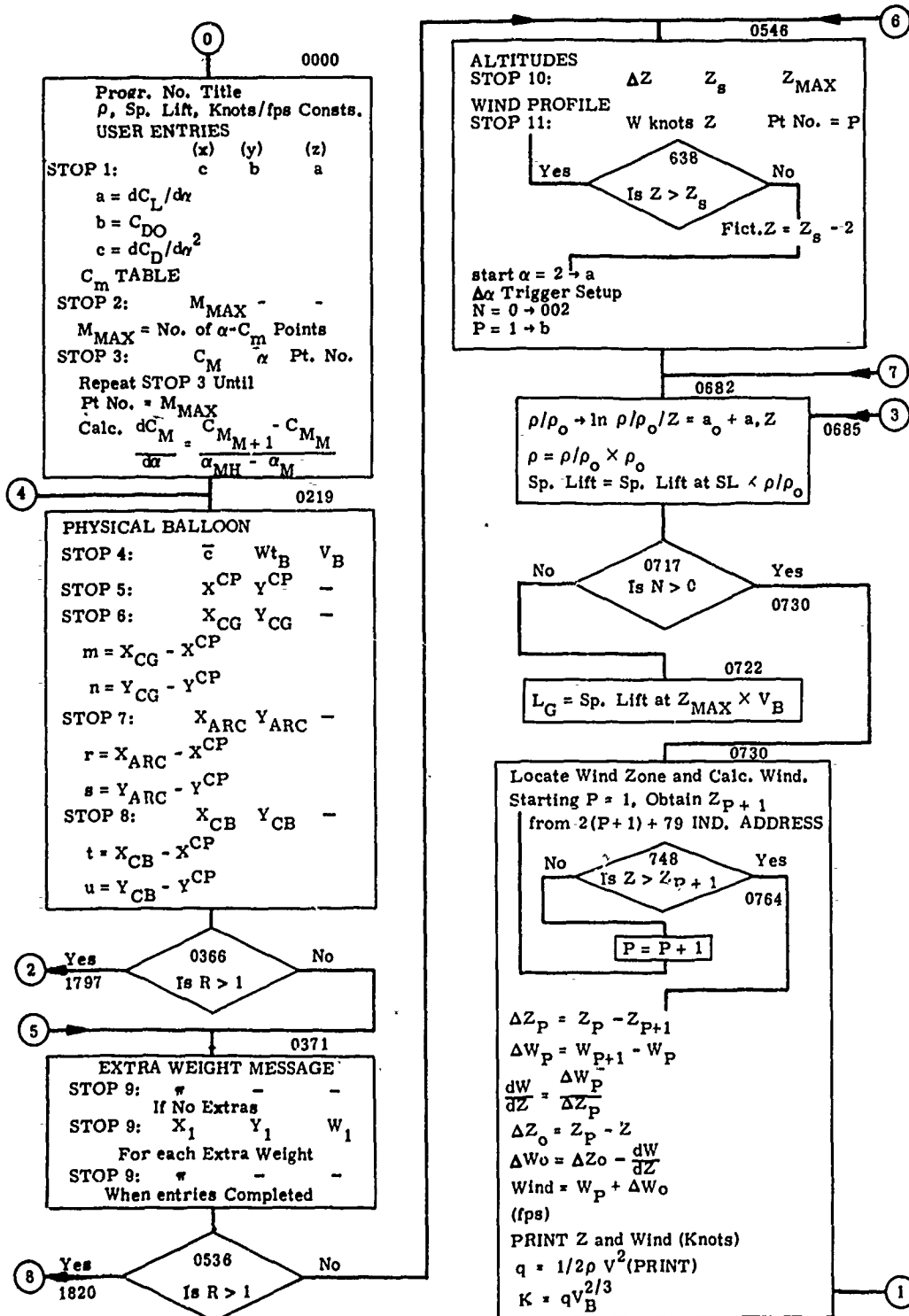


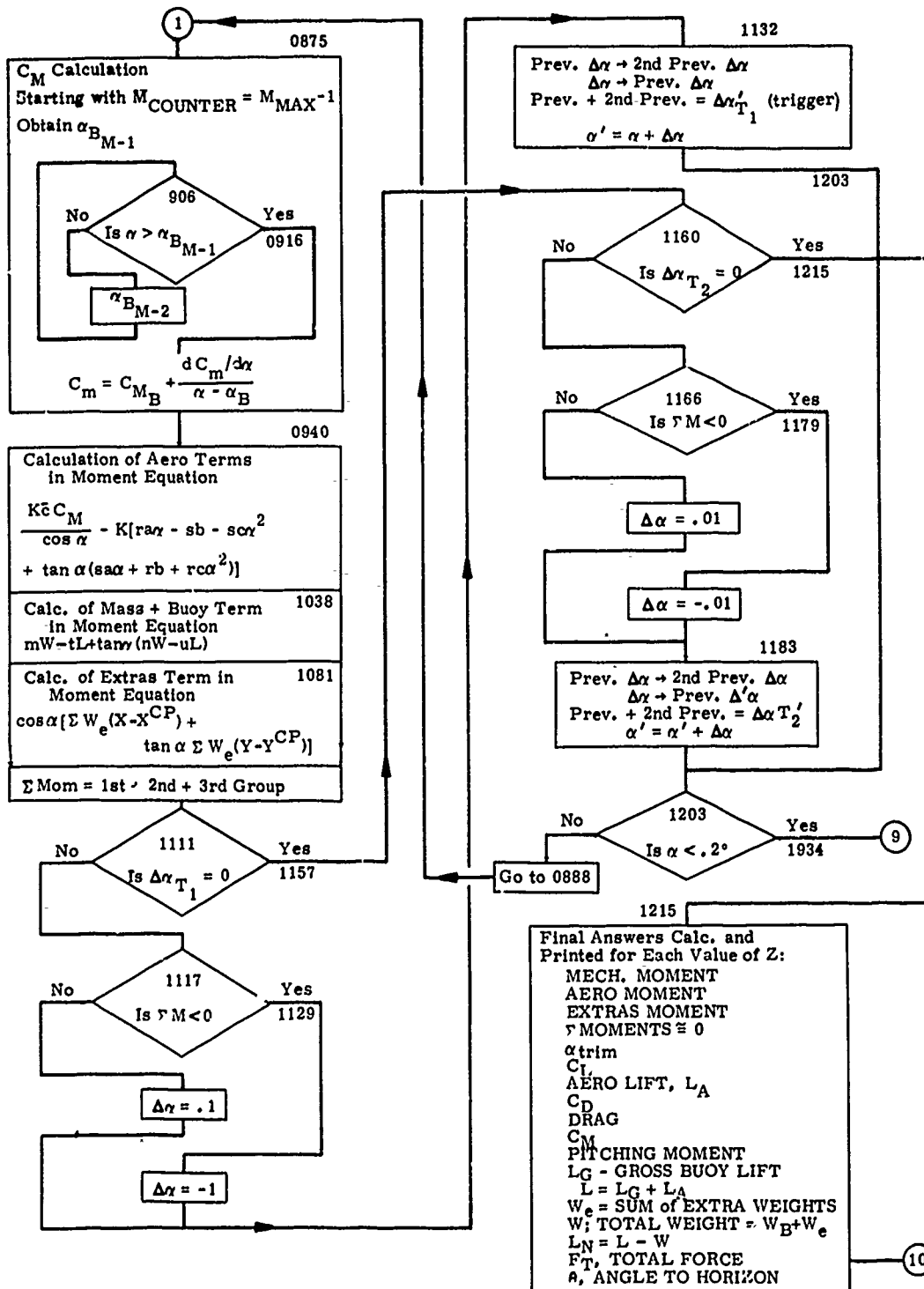
This requires entries (up to a maximum of 7 sets of entries) of significant points in the following manner which are stored and retrieved by use of region number codes. $dC_M/d\alpha$ values of each region are computed and stored at time of entry. Subscript B used here to indicate base value of a region, that is, the values at point number 1 are the base values for the region between points 1 and 2.

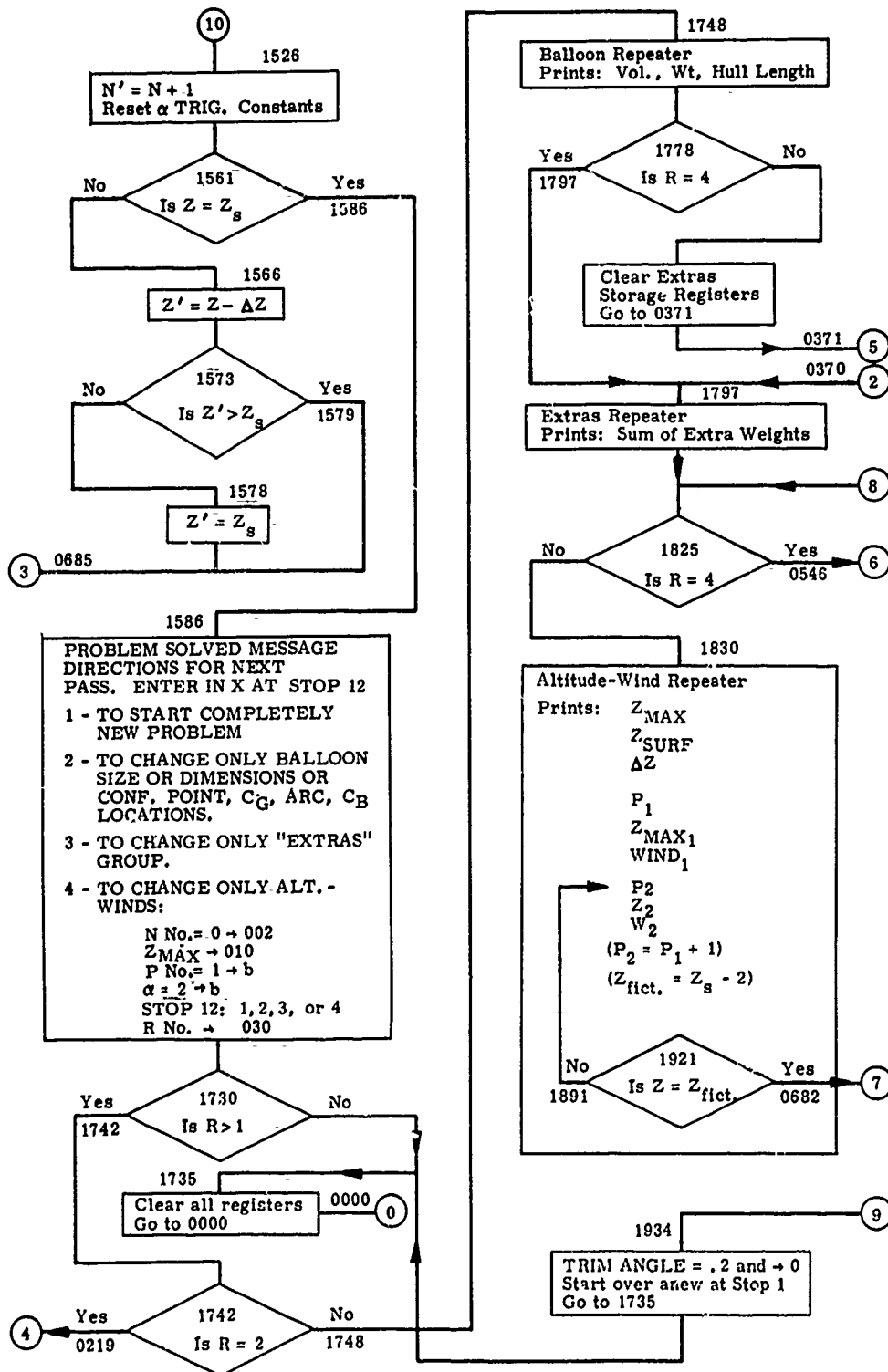
Register	(Z)	(Y)	(X)
	<u>Point No.</u>	<u>α_B</u>	<u>C_{M_B}</u>
Entry	1		
Entry	2		
Entry	3		
Entry	4		
Entry	5		
Entry	6		
Entry	7		

To calculate: $C_M = C_{M_B} + \frac{dC_M}{d\alpha} (\alpha - \alpha_B)$

3.3.3 FLOW CHART







Note: In flow chart, N is altitude point counter, P is wind profile point number and is repeater code for starting new problem.

3.3.4 OPERATING INSTRUCTIONS

<u>KEY STROKES</u>	<u>ENTRIES</u>			<u>PRINTS</u>
RUN				
END				
FIX, 2, 3, ----				(No. of desired decimal places)
CONT	(X)	(Y)	(Z)	Program No. and Title
Stop 1-1-1, Enter:	$c = \frac{dC_D}{d\alpha^2}$	$b = C_{Do}$	$a = \frac{dC_L}{d\alpha}$	
CONT				a b c
Stop 2-2-2, Enter:	M = No. of C_M Pts	-	-	
CONT				C_M Table
Stop 3-3-, Enter:	C_M	α	Pt. No. (start #1)	
CONT				Pt. No. α C_M Repeats until all points entered at succ. Stops No. 3
Stop 4-4-4, Enter:	$\bar{c}$	W_B	V_B	
CONT				V_B , Balloon Volume CF W_B , Balloon Volume lb $\bar{c}$, Length, Hull, ft
Stop 5-5-5, Enter:	X^{CP}	Y^{CP}	-	
CONT				X^{CP} , Confl. Point X, ft Y^{CP} , Confl. Point Y, ft
Stop 6-6-6, Enter:	X_{CG}	Y_{CG}	-	
CONT				X_{CG} , Center of gravity X, ft Y_{CG} , Center of gravity Y, ft m, ft n, ft
Stop 7-7-7, Enter:	X_{ARC}	Y_{ARC}	-	
CONT				X_{ARC} , ft Y_{ARC} , ft r, ft s, ft

Stop 8-8-8, Enter: X_{CB} Y_{CB} -

CONT

X_{CB} , Center of Buoyancy X, ft

Y_{CB} , Center of Buoyancy Y, ft

t, ft
u, ft

Directions for "Extra" weights;

Ent. Π in X if none.

Ent. Wt. in Z, y in Y, x in X.

Ent. Π in X when entries made complete

Stop 9-9-9, Enter: Π - -
(If no Extras")

Stop 9-9-9, Enter: X_1 Y_1 W_1

(For each "extra" weight)

Stop 9-9-9, Enter: π

(After all weights entered)

CONT

W_1 For each extra if
 X_1 any are
 Y_1 entered

ALTITUDES

Stop 10-10-10, Enter: ΔZ Z_S Z_{MAX}

CONT

Z_{MAX}

Z_{max} , ft MSL

Z_S , ft, MSL

ΔZ , ft

WIND PROFILE

Stop 11-11-11, Enter: Wind Z Pt. No.
(Start No. 1)

CONT

Pt. No. Z, 1st point
Alt. Ft must be
Wind, Knots Z max.
Repeats
for each
point
entered
until last
point must
be Z_S .

Program now takes over and computes and prints following group of parameters starting at $Z = Z_{\max}$, then at decreasing altitudes $Z = Z_M - \Delta Z$, $Z = Z_M - 2\Delta Z$, etc. to and including $Z = Z_S$. Values of parameters appear on tape on next line below the word.

ALT. ft
WIND, Knots
DYN. PRES. lb/ft²
MECH. MOM., ft-lb
AERO MOM., ft-lb
EXTRAS MOM. ft-lb
SUM OF MOM.,
ft-lbs, (~ 0)
Trim Angle Atck.
 C_L
AERO LIFT, L_A , lb
 C_D
DRAG, D, lb
 C_M
AERO P. MOM.
(about the ARC)
GROSS BUOYANT
LIFT, L_G , lb
TOTAL LIFT,
 $L = L_G + L_A$, lb
SUM "EXTRA" WTS,
 W_e , lb
TOT. WEIGHT,
 $W = W_B + W_e$, lb
NET LIFT,
 $L = L - W$, lb
TOTAL FORCE
 F_T , lb
ANGLE TO HORIZON,
 θ , deg

After $Z = Z_S$ condition is printed:

Prob. Solved
J. B. W. 76.003
Enter in X
1. To Start Anew
2. To Change Baln.
Dim.
3. To Change Extras
4. To Change Alts
and Wind Profile

Stop 1? Enter:

1, 2, 3, or 4

CONT

If Entry is:

1

Goes to Start.
Reprints Title.
User Reenters.
Complete Input.

2

PNTS: Physical
Balm. Stops 4, 5,
6, 7, 8 repeated
for reentry. Then
auto pnts. Sum of
extra wts, alts.
max. surf, Δ ,
wind profile.
Continues into
computations.

3

PNTS: Vol, Wt,
Length Hull extra
wt message Stops
9 repeated for
reentry then auto
pnts alts, max,
surf, Δ , wind
profile. Con-
tinues into
computations.

4

PNTS: Vol,
Wt, Length
hull, sum
of extra
wts, alts,
max, surf,
 Δ , wind
profile.
Continues
into com-
putations.

3.3.5. SAMPLE INPUT DATA FORM

INPUT			76.002, 76.003, 76.004, and 76.005			
			76.003, 76.004, 76.005 EXTRA WEIGHT TABLE		76.003 and 76.005 WIND PROFILE*	
Balloon Volume	V_B	cu ft	W_1	lb	No. 1	1
Ballonet Volume	v	cu ft	Y_1	ft	Z_{M1}	Z_L
Balloon Weight	W_B	lb	X_1	ft	Wind, knots	
Hull Length	$\bar{L}$	ft	W_2		No. 2	2
① Location of Confluence Pt.	Y_{CP}	ft	Y_2		Z_2	
	X_{CP}	ft	X_2		Wind ₂	
① Location of Center of Gravity	Y_{CG}	ft	W_3		No. 3	3
	X_{CG}	ft	Y_3		Z_3	
② Location of Center of Buoyancy	Y_{CB}	ft	X_3		Wind ₃	
	X_{CB}	ft	W_4		No. 4	4
③ Location of Aero Reference Center	Y_{ARC}	ft	Y_4		Z_4	
	X_{ARC}	ft	X_4		Wind ₄	
Altitude, Max	Z_{M1}	ft	W_5		No. 5	5
Altitude, Surf	Z_S	ft	Y_5		Z_5	
Increment of Alt	ΔZ	ft	X_5		Wind ₅	
④ dC_L/da	a		W_6		No. 6	6
④ C_{D0}	b		Y_6		Z_6	
④ $dC_D/d\alpha^2$	c		X_6		Wind ₆	
④ C_M TABLE*			W_7		No. 7	7
	NO. 1	1	Y_7		Z_7	
	α_1	0 deg	X_7		Wind ₇	
	C_{M1}		W_8		No. 8	8
	NO. 2	2	Y_8		Z_8	
	α_2	deg	X_8		Wind ₈	
	C_{M2}		W_9		No. 9	9
	NO. 3	3	Y_9		Z_9	
	α_3	deg	X_9		Wind ₉	
	C_{M3}		W_{10}		No. 10	10
	NO. 4	4	Y_{10}		Z_{10}	
	α_4	deg	X_{10}		Wind ₁₀	
	C_{M4}		W_{11}		No. 11	11
	NO. 5	5	Y_{11}		Z_{11}	
	α_5	deg	X_{11}		Wind ₁₁	
	C_{M5}		W_{12}		No. 12	12
	NO. 6	6	Y_{12}		Z_{12}	
	α_6	deg	X_{12}		Wind ₁₂	
	C_{M6}		W_{13}		No. 13	13
	NO. 7	7	Y_{13}		Z_{13}	
	α_7	deg	X_{13}		Wind ₁₃	
	C_{M7}					
① See Note 76.003 ② Req. 1 for 76.002 and 76.003 ③ Req. 1 for 76.003 only. * A series of two points may be used, a maximum of seven points may be used. First point must be for 0°.			Any number of extra weights may be used. One entry may be Instrument Package and Payloads. If these are at Confluence Point see $X = Y_{CP}$ $X = X_{CP}$		A series of 2 points may be used and a maximum of 11 may be used. First must be Z_{M1} and last must be Z_{11} . 76.005 requires one value of wind.	

3.3.6 PROGRAM 76.003 - TRIM, GENERAL BALLOON

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
0000--CLR		0050-- 8		0100--XTO		0150--RUP		0200-- DH		0250--PNT	
0001--FNT		0051-- 1		0101-- 5		0151--PNT		0201--DIV		0251-- 2	
0002--FNT		0052-- 3		0102-- 5		0152--PNT		0202-- 2		0252--RUP	
0003-- #		0053-- 6		0103--RUP		0153--RUP		0203--XTO		0253--PNT	
0004-- a		0054-- 1		0104--PNT		0154--XTO		0204-- +		0254-- 3	
0005-- 0		0055--CHS		0105--XTO		0155-- 0		0205-- 0		0255--DIV	
0006-- G		0056--EEX		0106-- 5		0156--YTO		0206--YTO		0256-- DH	
0007-- .		0057-- 5		0107-- 6		0157--IND		0207--IND		0257--KEY	
0008--GTO		0058--CHS		0108--RUP		0158-- 0		0208-- 0		0258-- H	
0009-- 7		0059--XTO		0109--XTO		0159-- a		0209-- b		0259--XTO	
0010-- 6		0060-- 0		0110-- 5		0160--RUP		0210-- UP		0260-- 0	
0011-- .		0061-- 3		0111-- 7		0161--XTO		0211--XFR		0261-- 4	
0012-- 0		0062-- 8		0112--PNT		0162-- -		0212-- 2		0262-- 1	
0013-- 0		0063-- .		0113--FNT		0163-- 0		0213-- 5		0263-- 5	
0014-- 3		0064-- 0		0114--FMT		0164--YTO		0214--X>Y		0264-- UP	
0015--CLR		0065-- 6		0115-- C		0165--IND		0215-- 0		0265-- UP	
0016--XTO		0066-- 5		0116-- M		0166-- 0		0216-- 1		0266--STP	
0017-- a		0067-- 9		0117--CHT		0167--KEY		0217-- 3		0267--XTO	
0018-- I		0068-- 9		0118--XTO		0168-- b		0218-- 2		0268-- 3	
0019-- H		0069--XTO		0119-- A		0169--X=Y		0219--FMT		0269-- 6	
0020--CLX		0070-- 0		0120-- B		0170-- 0		0220--FMT		0270--PNT	
0021-- G		0071-- 3		0121-- L		0171-- 1		0221-- #		0271--YTO	
0022-- E		0072-- 5		0122-- E		0172-- 3		0222-- H		0272-- 3	
0023-- H		0073-- .		0123--FMT		0173-- 2		0223--XFR		0273-- 7	
0024-- .		0074-- 0		0124-- 2		0174--KEY		0224--YTO		0274--KEY	
0025-- B		0075-- 0		0125-- UP		0175-- -		0225-- I		0275--PNT	
0026-- A		0076-- 2		0126-- UP		0176-- 3		0226-- C		0276--PNT	
0027-- L		0077-- 3		0127--STP		0177-- X		0227-- A		0277-- 6	
0028-- L		0078-- 7		0128--XTO		0178-- 5		0228-- L		0278-- UP	
0029-- 0		0079-- 8		0129-- 0		0179-- 8		0229--CHT		0279-- UP	
0030-- 0		0080--XTO		0130-- 2		0180-- +		0230-- B		0280--STP	
0031-- H		0081-- 0		0131-- 5		0181--YTO		0231-- A		0281--PNT	
0032--FNT		0082-- 3		0132-- 3		0182-- 0		0232-- L		0282--KEY	
0033-- 1		0083-- 4		0133-- UP		0183--XFR		0233-- H		0283--PNT	
0034-- .		0084-- 1		0134-- UP		0184--IND		0234-- .		0284-- UP	
0035-- 7		0085-- .		0135--STP		0185-- 0		0235--FMT		0285--XFR	
0036-- 7		0086-- 6		0136--RUP		0186--RUP		0236-- 4		0286-- 3	
0037-- 7		0087-- 8		0137--PNT		0187--KEY		0237-- UP		0287-- 6	
0038-- 2		0088-- 7		0138--RUP		0188-- -		0238-- UP		0288--RUP	
0039--CHS		0089-- 8		0139--YTO		0189-- 1		0239--STP		0289--KEY	
0040--EEX		0090--XTO		0140-- b		0190--XTO		0240--YTO		0290-- -	
0041-- 1		0091-- 0		0141--XTO		0191-- -		0241-- 1		0291--XFR	
0042-- 0		0092-- 3		0142-- a		0192-- 0		0242--XTO		0292-- 3	
0043--CHS		0093-- 2		0143--PNT		0193--XFR		0243-- 9		0293-- 7	
0044--XTO		0094-- 1		0144-- 3		0194--IND		0244--RUP		0294--KEY	
0045-- 0		0095-- UP		0145-- X		0195-- 0		0245--PNT		0295--XTO	
0046-- 3		0096-- UP		0146-- 5		0196-- UP		0246--XTO		0296-- 3	
0047-- 9		0097--STP		0147-- 8		0197-- a		0247-- 4		0297--PNT	
0048-- 2		0098--RUP		0148-- +		0198--KEY		0248-- 2		0298-- DH	
0049-- .		0099--FNT		0149-- 1		0199-- -		0249--RUP		0299-- -	

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
0300--YTO		0350-- 3		0400-- N		0450-- IND		0500--PNT		0550--XTO	
0301-- 4		0351-- 7		0401-- E		0451--XTO		0501--KEY		0551--YTO	
0302-- DH		0352--XKEY		0402--CLR		0452--YTO		0502-- -		0552-- .	
0303--PNT		0353--PNT		0403-- E		0453-- .		0503--XFR		0553--FMT	
0304--PNT		0354-- DH		0404-- H		0454-- E		0504-- 3		0554-- 1	
0305-- 7		0355-- -		0405--XTO		0455-- H		0505-- 1		0555-- 0	
0306-- UP		0356--YTO		0406-- .		0456--XTO		0506-- X		0556-- UP	
0307-- UP		0357-- 0		0407-- IND		0457-- E		0507--YTO		0557-- UP	
0308--STP		0358-- DH		0408--XTO		0458-- a		0508-- +		0558--STP	
0309--PNT		0359--PNT		0409-- .		0459-- E		0509-- 5		0559--RUP	
0310--KEY		0360--PNT		0410-- I		0460-- D		0510-- 2		0560--PNT	
0311--PNT		0361--XFR		0411-- H		0461--FMT		0511--RUP		0561--XTO	
0312-- UP		0362-- 3		0412--CHT		0462-- 9		0512-- X		0562-- 1	
0313--XFR		0363-- 0		0413--XSQ		0463-- UP		0513--YTO		0563-- 0	
0314-- 3		0364-- UP		0414--CLR		0464-- UP		0514-- +		0564--XTO	
0315-- 6		0365-- 1		0415--XFR		0465--STP		0515-- 0		0565-- 2	
0316--RUP		0366--XKY		0416--CHT		0466--YTO		0516-- 5		0566-- 9	
0317--KEY		0367-- 1		0417-- I		0467-- 3		0517-- 1		0567--YTO	
0318-- -		0368-- 7		0418-- H		0468-- 1		0518-- 9		0568-- 1	
0319--XFR		0369-- 9		0419--CHT		0469--KEY		0519-- UP		0569-- 2	
0320-- 3		0370-- 7		0420--XFR		0470-- n		0520-- UP		0570--RUP	
0321-- 7		0371--FMT		0421--CLX		0471--X=Y		0521--STP		0571--PNT	
0322--KEY		0372--FMT		0422--CHT		0472-- 0		0522--YTO		0572--XTO	
0323--PNT		0373-- E		0423-- YE		0473-- 5		0523-- 3		0573-- 1	
0324--XTO		0374-- YE		0424--CHT		0474-- 3		0524-- 1		0574-- 1	
0325-- 5		0375--XTO		0425-- I		0475-- 6		0525--KEY		0575--RUP	
0326-- DH		0376-- a		0426-- H		0476--XFR		0526-- n		0576--PNT	
0327-- -		0377-- A		0427--CHT		0477-- 3		0527--X=Y		0577--FMT	
0328--YTO		0378--CHT		0428-- YE		0478-- 1		0528-- 0		0578--FMT	
0329-- 6		0379--IND		0429--CLR		0479--RUP		0529-- 5		0579--IND	
0330-- DH		0380--XTO		0430-- E		0480--PNT		0530-- 3		0580-- 1	
0331--PNT		0381--YTO		0431-- H		0481--XTO		0531-- 6		0581-- H	
0332--PNT		0382-- .		0432--XTO		0482-- +		0532--GTO		0582-- D	
0333-- 8		0383--CLR		0433-- .		0483-- 5		0533-- 4		0583--CHT	
0334-- UP		0384-- E		0434--CHS		0484-- 0		0534-- 7		0584-- n	
0335-- UP		0385-- N		0435--CHT		0485--XTO		0535-- 6		0585-- a	
0336--STP		0386--XTO		0436-- I		0486-- 3		0536--XFR		0586-- 0	
0337--PNT		0387-- .		0437-- H		0487-- 1		0537-- 3		0587-- F	
0338--KEY		0388--CHS		0438--CHT		0488--XFR		0538-- 0		0588-- 1	
0339--PNT		0389--CHT		0439-- YE		0489-- 3		0539-- UP		0589-- L	
0340-- UP		0390-- I		0440--CHT		0490-- 6		0540-- 1		0590-- E	
0341--XFR		0391-- H		0441-- A		0491--RUP		0541--XKY		0591--FMT	
0342-- 3		0392--CNT		0442-- F		0492--PNT		0542-- 1		0592-- 1	
0343-- 6		0393-- YE		0443--XTO		0493--KEY		0543-- 8		0593-- 1	
0344--RUP		0394--CHT		0444-- E		0494-- -		0544-- 2		0594-- UP	
0345--KEY		0395-- 1		0445-- a		0495--XFR		0545-- 0		0595-- UP	
0346-- -		0396-- F		0446-- A		0496-- 3		0546--FMT		0596--STP	
0347--YTO		0397--CLR		0447-- L		0497-- 7		0547--FMT		0597--RUP	
0348-- 7		0398-- H		0448-- L		0498--RUP		0548-- A		0598--PNT	
0349--XFR		0399-- 0		0449--CHT		0499--PNT		0549-- L		0599--RUP	

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
0600--PNT		0650-- 0		0700-- UP		0750-- 7		0800--XFR		0850--IND	
0601--RUP		0651--XTO		0701--XFR		0751-- 6		0801-- 1		0851-- 1	
0602--YTO		0652-- a		0702-- 3		0752-- 4		0802-- 0		0852-- H	
0603-- 3		0653-- 1		0703-- 4		0753-- 1		0803-- -		0853-- D	
0604-- 1		0654-- 1		0704-- X		0754-- UP		0804-- DN		0854--FMT	
0605--PNT		0655--XTO		0705--YTO		0755-- b		0805-- X		0855--PNT	
0606--PNT		0656-- 4		0706-- 1		0756-- +		0806-- 2		0856--XFR	
0607--KEY		0657-- 3		0707-- 3		0757--YTO		0807--XTO		0857-- 1	
0608-- 2		0658--XTO		0708-- DN		0758-- b		0808-- -		0858-- 5	
0609--RUP		0659-- 4		0709--XFR		0759--GTO		0809-- 0		0859--XSO	
0610-- X		0660-- 5		0710-- 3		0760-- 0		0810--XFR		0860-- UP	
0611-- 8		0661--XTO		0711-- 5		0761-- 7		0811--IND		0861--XFR	
0612-- 0		0662-- 4		0712-- X		0762-- 3		0812-- 0		0862-- 1	
0613-- +		0663-- 6		0713--XFR		0763-- 0		0813-- +		0863-- 3	
0614--YTO		0664--XTO		0714-- 2		0764-- 2		0814--XFR		0864-- X	
0615-- 0		0665-- 0		0715-- UP		0765--XTO		0815-- 3		0865-- 2	
0616--XFR		0666-- 4		0716-- 0		0766-- -		0816-- 2		0866--DIV	
0617-- 3		0667-- 8		0717--XKY		0767-- 0		0817--YTO		0867--XFR	
0618-- 2		0668-- 0		0718-- 0		0768--XFR		0818-- 1		0868-- 4	
0619--RUP		0669--XTO		0719-- 7		0769--IND		0819-- 5		0869-- 1	
0620-- X		0670-- 4		0720-- 3		0770-- 0		0820--DIV		0870--KEY	
0621-- 1		0671-- 4		0721-- 0		0771--XTO		0821--XFR		0871-- X	
0622--YTO		0672--XTO		0722--XFR		0772-- 5		0822-- 1		0872--YTO	
0623--IND		0673-- 4		0723-- 4		0773-- 8		0823-- 0		0873-- 1	
0624-- 0		0674-- 7		0724-- 2		0774--KEY		0824--FMT		0874-- 6	
0625--XTO		0675--XTO		0725--RUP		0775-- -		0825--FMT		0875--FMT	
0626-- -		0676-- 0		0726-- X		0776-- 1		0826-- A		0876--FMT	
0627-- 0		0677-- 0		0727--YTO		0777--XTO		0827-- L		0877-- D	
0628--XFR		0678-- 2		0728-- 1		0778-- +		0828--XTO		0878--XFR	
0629-- 3		0679-- 1		0729-- 4		0779-- 0		0829--FMT		0879-- H	
0630-- 1		0680--XTO		0730-- b		0780--XFR		0830--PNT		0880-- .	
0631--XTO		0681-- b		0731-- UP		0781--IND		0831-- UP		0881-- a	
0632--IND		0682--XFR		0732-- 1		0782-- 0		0832--XFR		0882-- a	
0633-- 0		0683-- 1		0733-- +		0783-- UP		0833-- 1		0883-- E	
0634-- UP		0684-- 0		0734-- 2		0784-- 2		0834-- 1		0884--YTO	
0635--XFR		0685-- UP		0735-- X		0785--XTO		0835-- -		0885-- .	
0636-- 1		0686-- UP		0736-- 7		0786-- +		0836-- DN		0886--FMT	
0637-- 1		0687--XFR		0737-- 9		0787-- 0		0837--FMT		0887--PNT	
0638--XKY		0688-- 3		0738-- +		0788--XFR		0838--FMT		0888--XFR	
0639-- 0		0689-- 9		0739--YTO		0789--IND		0839-- H		0889-- 2	
0640-- 5		0690-- X		0740-- 0		0790-- 0		0840-- E		0890-- 5	
0641-- 9		0691--XFR		0741--XFR		0791--KEY		0841-- 1		0891-- UP	
0642-- 2		0692-- 3		0742--IND		0792-- -		0842-- C		0892-- 1	
0643-- 2		0693-- 8		0743-- 0		0793-- DN		0843-- H		0893-- -	
0644--XTO		0694-- +		0744-- UP		0794--KEY		0844--XTO		0894-- 3	
0645-- +		0695-- DN		0745--XFR		0795--DIV		0845--FMT		0895-- X	
0646-- 0		0696-- X		0746-- 1		0796--FP		0846--PNT		0896-- 5	
0647-- -		0697-- DN		0747-- 0		0797-- 5		0847-- DN		0897-- 7	
0648--YTO		0698-- J		0748--XKY		0798-- 8		0848--FMT		0898-- +	
0649--IND		0699-- UP		0749-- 0		0799-- UP		0849--FMT		0899--YTO	

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
0900--	0	0950--	YTO	1000--	XFR	1050--	X	1100--	0	1150--	YTO
0901--	XFR	0951--	1	1001--	5	1051--	DN	1101--	+	1151--	a
0902--	IND	0952--	8	1002--	6	1052--	-	1102--	XFR	1152--	GTO
0903--	0	0953--	a	1003--	X	1053--	YTO	1103--	1	1153--	1
0904--	UP	0954--	UP	1004--	DN	1054--	3	1104--	9	1154--	2
0905--	a	0955--	XSQ	1005--	+	1055--	1	1105--	+	1155--	0
0906--	X>Y	0956--	UP	1006--	a	1056--	XFR	1106--	0	1156--	3
0907--	0	0957--	XFR	1007--	UP	1057--	1	1107--	UP	1157--	XFR
0908--	9	0958--	6	1008--	XFR	1058--	UP	1108--	XFR	1158--	4
0909--	1	0959--	X	1009--	6	1059--	XFR	1109--	4	1159--	6
0910--	9	0960--	XFR	1010--	X	1060--	4	1110--	3	1160--	X=Y
0911--	3	0961--	5	1011--	XFR	1061--	X	1111--	X=Y	1161--	1
0912--	XTO	0962--	7	1012--	5	1062--	XFR	1112--	1	1162--	2
0913--	-	0963--	X	1013--	5	1063--	1	1113--	1	1163--	1
0914--	0	0964--	XFR	1014--	X	1064--	4	1114--	5	1164--	5
0915--	GTO	0965--	5	1015--	DN	1065--	UP	1115--	7	1165--	DN
0916--	9	0966--	5	1016--	XEY	1066--	XFR	1116--	DN	1166--	X>Y
0917--	0	0967--	RUP	1017--	+	1067--	8	1117--	X>Y	1167--	1
0918--	1	0968--	X	1018--	a	1068--	X	1118--	1	1168--	1
0919--	XEY	0969--	XFR	1019--	0	1069--	DN	1119--	1	1169--	7
0920--	-	0970--	5	1020--	X	1070--	-	1120--	2	1170--	9
0921--	2	0971--	X	1021--	XFR	1071--	a	1121--	9	1171--	.
0922--	XTO	0972--	XFR	1022--	3	1072--	0	1122--	.	1172--	0
0923--	+	0973--	5	1023--	1	1073--	X	1123--	1	1173--	1
0924--	0	0974--	6	1024--	XEY	1074--	XFR	1124--	GTO	1174--	GTO
0925--	XFR	0975--	RUP	1025--	+	1075--	3	1125--	1	1175--	1
0926--	IND	0976--	RUP	1026--	XFR	1076--	1	1126--	1	1176--	1
0927--	0	0977--	XEY	1027--	1	1077--	+	1127--	3	1177--	8
0928--	X	0978--	-	1028--	6	1078--	YTO	1128--	2	1178--	3
0929--	1	0979--	XFR	1029--	X	1079--	2	1129--	.	1179--	.
0930--	XTO	0980--	6	1030--	XFR	1080--	0	1130--	1	1180--	0
0931--	-	0981--	RUP	1031--	1	1081--	XFR	1131--	CHS	1181--	1
0932--	0	0982--	X	1032--	8	1082--	5	1132--	UP	1182--	CHS
0933--	XFR	0983--	DN	1033--	XEY	1083--	2	1133--	XFR	1183--	UP
0934--	IND	0984--	-	1034--	-	1084--	UP	1134--	4	1184--	XFR
0935--	0	0985--	YTO	1035--	YTO	1085--	a	1135--	4	1185--	4
0936--	+	0986--	3	1036--	1	1086--	0	1136--	XTO	1186--	7
0937--	YTO	0987--	1	1037--	9	1087--	X	1137--	4	1187--	XTO
0938--	1	0988--	a	1038--	XFR	1088--	XFR	1138--	5	1188--	4
0939--	7	0989--	UP	1039--	1	1089--	5	1139--	YTO	1189--	8
0940--	XFR	0990--	XSQ	1040--	UP	1090--	1	1140--	4	1190--	YTO
0941--	9	0991--	UP	1041--	XFR	1091--	+	1141--	4	1191--	4
0942--	X	0992--	XFR	1042--	3	1092--	a	1142--	XEY	1192--	7
0943--	XFR	0993--	5	1043--	X	1093--	H	1143--	+	1193--	XEY
0944--	1	0994--	7	1044--	XFR	1094--	X	1144--	YTO	1194--	+
0945--	6	0995--	X	1045--	1	1095--	YTO	1145--	4	1195--	YTO
0946--	X	0996--	XFR	1046--	4	1096--	2	1146--	3	1196--	4
0947--	a	0997--	5	1047--	UP	1097--	1	1147--	XEY	1197--	6
0948--	H	0998--	X	1048--	XFR	1098--	XFR	1148--	a	1198--	XEY
0949--	DIV	0999--	RUP	1049--	7	1099--	2	1149--	+	1199--	a

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
1200--	+	1250--	2	1300--	FMT	1350--	D	1400--	0	1450--	FMT
1201--	YTO	1251--	1	1301--	C	1351--	FMT	1401--	YTO	1451--	PNT
1202--	a	1252--	+	1302--	L	1352--	PNT	1402--	YTO	1452--	+
1203--	.	1253--	FMT	1303--	FMT	1353--	DN	1403--	CHT	1453--	DN
1204--	2	1254--	FMT	1304--	UP	1354--	FMT	1404--	L	1454--	FMT
1205--	X>Y	1255--	E	1305--	XSO	1355--	FMT	1405--	I	1455--	FMT
1206--	1	1256--	YE	1306--	XEY	1356--	D	1406--	F	1456--	XTO
1207--	9	1257--	XTO	1307--	UP	1357--	a	1407--	XTO	1457--	0
1208--	3	1258--	a	1308--	XFR	1358--	A	1408--	FMT	1458--	XTO
1209--	4	1259--	A	1309--	5	1359--	G	1409--	PNT	1459--	.
1210--	PSE	1260--	YTO	1310--	5	1360--	FMT	1410--	UP	1460--	IND
1211--	GTO	1261--	CHT	1311--	X	1361--	PNT	1411--	XFR	1461--	E
1212--	8	1262--	M	1312--	DN	1362--	XTO	1412--	2	1462--	I
1213--	8	1263--	0	1313--	PNT	1363--	2	1413--	2	1463--	G
1214--	8	1264--	M	1314--	UP	1364--	3	1414--	+	1464--	H
1215--	FMT	1265--	.	1315--	XFR	1365--	XFR	1415--	DN	1465--	XTO
1216--	FMT	1266--	FMT	1316--	1	1366--	9	1416--	FMT	1466--	FMT
1217--	M	1267--	PNT	1317--	6	1367--	X	1417--	FMT	1467--	PNT
1218--	E	1268--	DN	1318--	X	1368--	XFR	1418--	XTO	1468--	-
1219--	C	1269--	FMT	1319--	XEY	1369--	1	1419--	0	1469--	XFR
1220--	H	1270--	FMT	1320--	FMT	1370--	7	1420--	XTO	1470--	2
1221--	.	1271--	YTO	1321--	FMT	1371--	X	1421--	.	1471--	3
1222--	M	1272--	1/X	1322--	A	1372--	FMT	1422--	L	1472--	XEY
1223--	0	1273--	M	1323--	E	1373--	FMT	1423--	I	1473--	FMT
1224--	M	1274--	CHT	1324--	a	1374--	C	1424--	F	1474--	FMT
1225--	.	1275--	0	1325--	0	1375--	M	1425--	XTO	1475--	H
1226--	FMT	1276--	F	1326--	CHT	1376--	FMT	1426--	FMT	1476--	E
1227--	XFR	1277--	CHT	1327--	L	1377--	PNT	1427--	PNT	1477--	XTO
1228--	2	1278--	H	1328--	I	1378--	DN	1428--	UP	1478--	CHT
1229--	0	1279--	0	1329--	F	1379--	FMT	1429--	XFR	1479--	L
1230--	PNT	1280--	M	1330--	XTO	1380--	FMT	1430--	1	1480--	I
1231--	UP	1281--	.	1331--	FMT	1381--	A	1431--	UP	1481--	F
1232--	XFR	1282--	FMT	1332--	PNT	1382--	E	1432--	XFR	1482--	XTO
1233--	1	1283--	PNT	1333--	XTO	1383--	a	1433--	5	1483--	FMT
1234--	9	1284--	a	1334--	2	1384--	0	1434--	0	1484--	PNT
1235--	+	1285--	FMT	1335--	2	1385--	CHT	1435--	FMT	1485--	XEY
1236--	FMT	1286--	FMT	1336--	XFR	1386--	π	1436--	FMT	1486--	A
1237--	FMT	1287--	XTO	1337--	5	1387--	.	1437--	YTO	1487--	FMT
1238--	A	1288--	a	1338--	7	1388--	M	1438--	1/X	1488--	FMT
1239--	E	1289--	I	1339--	RUP	1389--	0	1439--	M	1489--	XTO
1240--	a	1290--	M	1340--	X	1390--	M	1440--	X>Y	1490--	0
1241--	0	1291--	CHT	1341--	XFR	1391--	FMT	1441--	E	1491--	XTO
1242--	CHT	1292--	A	1342--	5	1392--	PNT	1442--	YE	1492--	6
1243--	M	1293--	H	1343--	6	1393--	XFR	1443--	XTO	1493--	L
1244--	0	1294--	G	1344--	+	1394--	1	1444--	a	1494--	CHT
1245--	M	1295--	L	1345--	DN	1395--	4	1445--	A	1495--	F
1246--	.	1296--	E	1346--	X	1396--	FMT	1446--	X>Y	1496--	0
1247--	FMT	1297--	FMT	1347--	FMT	1397--	FMT	1447--	IND	1497--	a
1248--	PNT	1298--	PNT	1348--	FMT	1398--	G	1448--	XTO	1498--	C
1249--	XFR	1299--	FMT	1349--	C	1399--	a	1449--	YTO	1499--	E

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
1500--FMT		1550-- 4		1600-- J		1650-- N		1700-- D		1750--INT	
1501--PHT		1551--XTO		1601-- .		1651-- C		1701--YTO		1751-- 0	
1502--KEY		1552-- 4		1602-- B		1652-- E		1702--FMT		1752-- L	
1503--FMT		1553-- 7		1603-- .		1653--CHT		1703-- 0		1753--CLX	
1504--FMT		1554--XFR		1604--IND		1654-- B		1704--XTO		1754--IND	
1505-- A		1555-- 1		1605-- .		1655-- A		1705-- 2		1755--XTO	
1506-- H		1556-- 0		1606--CHT		1656-- L		1706--XFR		1756--CLX	
1507-- G		1557-- UP		1607--CHT		1657-- H		1707-- 2		1757-- L	
1508-- L		1558--XFR		1608-- 7		1658-- D		1708-- 9		1758-- H	
1509-- E		1559-- 1		1609-- 6		1659-- I		1709--XTO		1759-- G	
1510--CHT		1560-- 1		1610-- .		1660-- H		1710-- 0		1760--XTO	
1511--XTO		1561--X=Y		1611-- 0		1661-- .		1711-- 1		1761-- .	
1512-- 0		1562-- 1		1612-- 0		1662--CLR		1712-- 0		1762-- H	
1513--CHT		1563-- 5		1613-- 3		1663-- 3		1713-- 1		1763--1/X	
1514-- H		1564-- 8		1614--CLR		1664--CHT		1714--XTO		1764-- L	
1515-- 0		1565-- 6		1615--CLR		1665--XTO		1715-- 6		1765-- L	
1516-- a		1566--KEY		1616--CLR		1666-- 0		1716-- 2		1766--FMT	
1517-- I		1567-- UP		1617-- E		1667--CHT		1717--XTO		1767--XFR	
1518--XSO		1568--XFR		1618-- H		1668-- C		1718-- a		1768-- 4	
1519-- 0		1569-- 1		1619--XTO		1669-- H		1719-- 1		1769-- 2	
1520-- H		1570-- 2		1620-- .		1670-- G		1720-- 2		1770--PHT	
1521--FMT		1571-- -		1621-- I		1671-- .		1721-- UP		1771--XFR	
1522--PHT		1572-- DH		1622-- H		1672-- E		1722-- UP		1772-- 1	
1523--PHT		1573--X>Y		1623--CHT		1673-- YE		1723--STP		1773--PHT	
1524--PHT		1574-- 1		1624-- YE		1674--XTO		1724--PHT		1774--XFR	
1525--PHT		1575-- 5		1625--CLR		1675-- a		1725-- UP		1775-- 9	
1526-- 1		1576-- 7		1626-- 1		1676-- A		1726-- 1		1776--PHT	
1527--XTO		1577-- 9		1627--CHT		1677--YTO		1727--YTO		1777-- 4	
1528-- +		1578-- DH		1628--XTO		1678--CLR		1728-- 3		1778--X=Y	
1529-- 0		1579--XTO		1629-- 0		1679-- 4		1729-- 0		1779-- 1	
1530-- 0		1580-- 1		1630--CHT		1680--CHT		1730--X<Y		1780-- 7	
1531-- 2		1581-- 0		1631--YTO		1681--XTO		1731-- 1		1781-- 9	
1532-- 1		1582--GTO		1632--XTO		1682-- 0		1732-- 7		1782-- 7	
1533-- 1		1583-- 6		1633-- A		1683--CHT		1733-- 4		1783-- 0	
1534--XTO		1584-- 8		1634-- a		1684-- C		1734-- 2		1784--XTO	
1535-- 4		1585-- 5		1635--XTO		1685-- H		1735-- K		1785-- 5	
1536-- 3		1586--FMT		1636--CHT		1686-- G		1736--CLX		1786-- 0	
1537--XTO		1587--FMT		1637-- A		1687-- .		1737--GTO		1787--XTO	
1538-- 4		1588-- 4		1638-- H		1688-- A		1738-- 0		1788-- 5	
1539-- 5		1589-- a		1639-- E		1689-- L		1739-- 0		1789-- 1	
1540--XTO		1590-- 0		1640--IND		1690--XTO		1740-- 0		1790--XTO	
1541-- 4		1591-- B		1641--CLR		1691--YTO		1741-- 0		1791-- 5	
1542-- 6		1592-- .		1642-- 2		1692-- .		1742-- 2		1792-- 2	
1543--XTO		1593--YTO		1643--CHT		1693--CLR		1743--X=Y		1793--GTO	
1544-- 0		1594-- 0		1644--XTO		1694-- 0		1744-- 0		1794-- 3	
1545-- 4		1595-- L		1645-- 0		1695-- a		1745-- 2		1795-- 7	
1546-- 8		1596--INT		1646--CHT		1696--CHT		1746-- 1		1796-- 1	
1547-- 0		1597-- E		1647-- C		1697--IND		1747-- 9		1797--FMT	
1548--XTO		1598-- D		1648-- H		1698-- I		1748--FMT		1798--FMT	
1549-- 4		1599--CLR		1649-- A		1699-- N		1749--FMT		1799--YTO	

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
1800--1/X		1850-- L		1900--XFR		1950--CLR		2000-- 5			
1801-- M		1851--XTO		1901-- 3		1951-- A		2001--END			
1802--CHT		1852-- A		1902-- 2		1952-- H					
1803-- 0		1853--FMT		1903--DIV		1953-- D					
1804-- F		1854--XFR		1904-- DN		1954--CHT					
1805--CHT		1855-- 1		1905--PNT		1955--EEK					
1806-- E		1856-- 0		1906--PNT		1956-- 0					
1807-- YE		1857--PNT		1907-- 1		1957--CHT					
1808--XTO		1858--XFR		1908-- +		1958--CHT					
1809-- a		1859-- 1		1909--XTO		1959--CLX					
1810-- A		1860-- 1		1910-- +		1960--YTO					
1811--CHT		1861--PNT		1911-- 0		1961-- 0					
1812--IND		1862--XFR		1912--XFR		1962-- a					
1813--XTO		1863-- 1		1913-- 1		1963-- a					
1814--YTO		1864-- 2		1914-- 1		1964--XFR					
1815--FMT		1865--PNT		1915-- UP		1965--CLR					
1816--XFR		1866--FMT		1916-- 2		1966--XFR					
1817-- 5		1867--FMT		1917-- -		1967-- 0					
1818-- 0		1868--IND		1918--XFR		1968--1/X					
1819--PNT		1869-- I		1919--IND		1969--CHT					
1820--XFR		1870-- H		1920-- 0		1970-- M					
1821-- 3		1871-- D		1921--X=Y		1971--1/X					
1822-- 0		1872--CHT		1922-- 0		1972--YTO					
1823-- UP		1873-- a		1923-- 6		1973--XTO					
1824-- 4		1874-- a		1924-- 8		1974--CHT					
1825--X=Y		1875-- 0		1925-- 2		1975--YTO					
1826-- 0		1876-- F		1926--RUP		1976--XTO					
1827-- 5		1877-- I		1927--PNT		1977-- A					
1828-- 4		1878-- L		1928--KEY		1978-- a					
1829-- 6		1879-- E		1929--GTO		1979--XTO					
1830--FMT		1880--FMT		1930-- 1		1980--CLR					
1831--FMT		1881-- 1		1931-- 8		1981-- A					
1832-- A		1882--PNT		1932-- 9		1982-- H					
1833-- L		1883-- UP		1933-- 1		1983-- E					
1834--XTO		1884-- 8		1934--FMT		1984--IND					
1835--YTO		1885-- 1		1935--FMT		1985--CHT					
1836-- .		1886--XTO		1936--XTO		1986-- A					
1837--CLX		1887-- 0		1937-- a		1987--XTO					
1838-- M		1888--XFR		1938-- I		1988--CHT					
1839-- A		1889--IND		1939-- M		1989--YTO					
1840-- YE		1890-- 0		1940--CHT		1990--XTO					
1841--CLX		1891--PNT		1941-- A		1991-- 0					
1842--YTO		1892-- 1		1942-- N		1992-- a					
1843--1/X		1893--XTO		1943-- G		1993--CHT					
1844-- a		1894-- +		1944-- L		1994-- 1					
1845-- F		1895-- 0		1945-- E		1995--FMT					
1846--CLX		1896--XFR		1946--CNT		1996--GTO					
1847--CLR		1897--IND		1947--SFL		1997-- 1					
1848-- D		1898-- 0		1948-- .		1998-- 7					
1849-- E		1899-- UP		1949-- 2		1999-- 3					

STORAGE REGISTERS

STORAGE	
b	Temp/P Count
a	α
000	IND. Use
001	Wt_a
002	N Count
003	m
004	n
005	r
006	s
007	t
008	u
009	v
010	Zmax/start
011	Zsure
012	ΔZ
013	p
014	L_c
015	Wind: fms
016	$K = q \cdot V_a^{2/3}$
017	C_m
018	$KECm/cos\alpha$
019	Aero. Mom.
020	Mech. Mom.
021	Extras Mom.
022	L_A
023	D
024	
025	Mmax COUNT.
026	
027	
028	
029	Z MAX
030	R-Repeat
031	Temp.
032	1.6878
033	
034	$P_0 \text{ slug/ft}^2$
035	Sp. Life S.L.
036	$X^{CP} \text{ Conf}$
037	$Y^{CP} \text{ Permit}$
038	α_0
039	α_1

040	
041	$V_a^{2/3}$
042	V_b
043	sol Trigger
044	Prev sol
045	2nd Prev sol
046	sol Trigger
047	Prev sol
048	2nd Prev sol
049	
050	ΣW_{EXTRA}
051	$E_{WE}(X-X^P)$
052	$E_{WE}(Y-Y^P)$
053	
054	
055	$a = dC_L/d\alpha$
056	$b = C_{D0}$
057	$c = dC_D/d\alpha^2$
058	Temp
059	
060	$\alpha(=0)$
061	$C_m \#1$
062	$dC_m/d\alpha$
063	α
064	$C_m \#2$
065	$dC_m/d\alpha$
066	α
067	$C_m \#3$
068	$dC_m/d\alpha$
069	α
070	$C_m \#4$
071	$dC_m/d\alpha$
072	α
073	$C_m \#5$
074	$dC_m/d\alpha$
075	α
076	$C_m \#6$
077	$dC_m/d\alpha$
078	α
079	$C_m \#7$

080	
081	Z ₁
082	Wind ₁
083	Z ₂
084	Wind ₂
085	Z ₃
086	Wind ₃
087	Z ₄
088	Wind ₄
089	Z ₅
090	Wind ₅
091	Z ₆
092	Wind ₆
093	Z ₇
094	Wind ₇
095	Z ₈
096	Wind ₈
097	Z ₉
098	Wind ₉
099	Z ₁₀
100	Wind ₁₀
101	Z ₁₁
102	Wind ₁₁
103	Z ₁₂
104	Wind ₁₂
105	Z ₁₃
106	Wind ₁₃
107	Reserv. Z ₁₄
108	

3.3.7 SAMPLE INPUT/OUTPUT PRINT

The following copy of the HP Printed Tape shows a typical problem and solution.

The balloon, 45,000 CF, was assumed to have an aerodynamic pitching-moment variation with angle-of-attack which could be defined with only 3 points (2 straight lines). No "Extra Weights" were added. A 3-point wind profile from the max altitude, 5500 ft, to the surface, 4000, was also part of the input.

Solutions provided trim angle, total balloon force and angle, and other parameters at 5500, 5000, 4500, and 4000 ft. Option 3 was then exercised to add 275 lb at the confluence point and similar solutions then followed. Note that only the extra weight and its location had to be entered; the other format inputs were printed automatically.

PROG.#76.003
 TRIM, GEN. BALLOON
 0.04900
 0.10600
 0.00071

CM TABLE
 1.00000
 0.00000
 0.00000
 2.00000
 6.00000
 0.01000
 3.00000
 14.00000
 0.00000

PH. SICAL BALN.
 45000.00
 1000.00
 83.70
 26.60
 -31.90

57.30*
 -2.50
 30.70
 29.40

52.20*
 0.00
 25.60
 31.90

35.10*
 0.30
 8.50
 32.20

EXTRA WTS.
 ENT. IN X IF
 NONE
 ENT. WT. IN Z
 Y IN Y, X IN X
 ENT. IN X AFTER
 ALL WTS. ENTERED
 ALTS.

5500.00
 4000.00
 500.00
 WIND PROFILE
 1.00
 5500.00
 50.00

2.00
 5000.00
 25.00
 3.00
 4000.00
 15.00

ALT
 5500.00
 HEIGHT
 1500.00

WIND
 50.00
 DYH. PRES.
 7.21

MECH. MOM.
 6081.72

AERO MOM.
 -6025.60

EXTRAS MOM.
 0.00

SUM OF MOM.
 56.12

TRIM ANGLE
 3.42

CL
 0.17

AERO LIFT
 1529.63

CD
 0.11
 DRAG
 1043.34
 CM
 0.01
 AERO P. MOM
 4354.76
 GROSS LIFT
 2530.17
 TOT. LIFT
 4059.80
 SUM "EXTRA" WTS
 0.00
 TOT. WEIGHT
 1000.00
 NET LIFT
 3059.80
 TOTAL FORCE
 3232.79
 ANGLE TO HORIZON
 71.17

ALT
 5000.00
 HEIGHT
 1000.00

WIND
 25.00
 DYH. PRES.
 1.83

MECH. MOM.
 4967.41

AERO MOM.
 -4963.24

EXTRAS MOM.
 0.00

SUM OF MOM.
 4.18

TRIM ANGLE
 4.64

CL
 0.23

AERO LIFT
 526.66

~~~~~//~~~~~

ALT 4000.00  
 HEIGHT 0.00  
 WIND 15.00  
 DYN.PRES. 0.68  
 MECH.MOM. 3546.00  
 AERO MOM. -3533.28  
 EXTRAS MOM. 0.00  
 SUM OF MOM. 12.72  
 TRIM ANGLE 6.19  
 CL 0.30  
 AERO LIFT 260.57  
 CD 0.13  
 DRAG 114.43  
 CM 0.01  
 AERO P.MOM 701.98  
 GROSS LIFT 2530.17  
 TOT.LIFT 2790.74  
 SUM"EXTRA"MTS 0.00  
 TOT.WEIGHT 1000.00  
 NET LIFT 1790.74  
 TOTAL FORCE 1794.39  
 ANGLE TO HORIZON 86.34

PROP.SOLVED  
 J.B.W. 76.003

ENT.IN X  
 1 TO START ANEW  
 2 TO CHANGE BALN  
 DIM.  
 3 TO CHG.EXTRAS  
 4 TO CHG.ALTS.  
 OR WINDS

3.00\*  
 VOL,WT,LNHT,HULL  
 45000.00  
 1000.00  
 83.70

EXTRA WTS.  
 ENT.π IN X IF  
 NONE  
 ENT.WT.IN Z  
 Y IN Y, X IN X  
 ENT.π IN X AFTER  
 ALL WTS. ENTERED  
 275.00  
 26.60  
 -31.90

ALTS., MAX, SURF,  
 DELTA

5500.00  
 4000.00  
 500.00  
 WIND PROFILE  
 1.00\*  
 5500.00  
 50.00

2.00  
 5000.00  
 25.00  
 3.00  
 4000.00  
 15.00

ALT 5500.00  
 HEIGHT 1500.00  
 WIND 50.00

DYN.PRES. 7.21  
 MECH.MOM. 6081.72  
 AERO MOM. -6025.60  
 EXTRAS MOM. 0.00  
 SUM OF MOM. 56.12  
 TRIM ANGLE 3.42  
 CL 0.17  
 AERO LIFT 1529.63  
 CD 0.11  
 DRAG 1043.34  
 CM 0.01  
 AERO P.MOM 4354.76  
 GROSS LIFT 2530.17  
 TOT.LIFT 4059.80  
 SUM"EXTRA"MTS 275.00  
 TOT.WEIGHT 1275.00  
 NET LIFT 2784.80  
 TOTAL FORCE 2973.83  
 ANGLE TO HORIZON 69.46

ALT 5000.00  
 HEIGHT 1000.00  
 WIND 25.00  
 DYN.PRES. 1.83  
 MECH.MOM. 4967.41

### 3.3.8 NOTES

A. If incorrect data is entered, do not press STOP END to restart program. For proper restart, clearing all registers, press the following

STOP  
GO TO  
1  
7  
6  
9  
CONT

B. Pitching-moment coefficient,  $C_M$  table, STOPS 2, 3. See also section on development

1. STOP 2 requires entry of the total number of points used to define the  $C_M/\alpha$  curve.
2. STOP 3 requires entry of Point Nos. which should start with 1 for first point where  $\alpha = 0$  and proceed to 2, 3, etc, with larger values of  $\alpha$ . Last Point No. must equal number entered in STOP 2.
3. Up to a total 7 points may be used to define the  $C_m/\alpha$  curve.
4. If for example, 6 points are used to define the curve, 5 slopes,  $dC_m/d\alpha$  are thereby available for calculation of  $C_m$  at any  $\alpha$ . The slope between Point Nos. 5 and 6 is assumed to extend beyond Point No. 6

C. Extra Weight Entries, STOP 9

1. The payload weight can be included here if desired as will not affect the trim angle if located at the confluence point:

|            | (X)      | (Y)      | (z)    |
|------------|----------|----------|--------|
| STOP 9-9-9 | $X^{CP}$ | $Y^{CP}$ | $Wt_p$ |

It will affect the net lift and hence the total force and its angle.

2. Other extra weights locations will also affect the trim. Due to the make up of the program do not make the X location of any weight equal to  $\pi$ . X locations can carry a negative sign if ahead of the nose of the balloon. A negative-Y indicates a position below the centerline of the balloon.

D. Wind Profile Entries, STOP 11

1. First entry must be Point No. 1, with  $Z = Z_{max}$  (Ballonet empty condition).

2. Up to 12 more altitude-wind points may be entered to define the wind profile from  $Z_{\text{max}}$  to  $Z_{\text{surf}}$ .
3. The last entry must be for  $Z_{\text{surf}}$ .

**3.4 Program 76.004 - FAMILY-2 Tethered Balloon Trim, Single Altitude,  
Design Condition: Ballonet Empty**

**3.4.1 GENERAL DESCRIPTION**

A type of tethered balloon, called the FAMILY-2 has an aerodynamic shaped hull and two vertical and two horizontal fins. During its development, model wind-tunnel and full-scale static and flight tests were made in extensive detail. References 1 and 2 provide a sufficient amount of information on a 200,000 CF system to write a trim equation with more exact constants than any other balloon now available.

Program Nos. 76.004 (and 76.005) were approached with the idea of providing a quick solution to trim problems as well as inputs to the tether-cable program. They were tailored for a 45,000 CF balloon which the AFGL will receive in 1976. However, they can be easily converted into a completely general program as explained in Section 3.4.8. Program No. 76.004 is concerned with the condition where the balloon is completely filled with gas, that is, its ballonet is empty. It will be called the design condition. Program No. 76.005 was designed to accommodate both the design condition as well as other conditions at lower altitudes where the ballonet is in various stages of air inflation.

Due to the extensive measurements made with the 200,000 CF FAMILY-2 balloon by the Range Measurements Lab of the Air Force Eastern Test Range, it was possible to obtain data which allowed use of the balloon aerodynamic center-of-pressure. Like the neutral-point, it is defined as the point where the pitching-moment is zero. This permits elimination of one term in the moment equation developed under Program No. 76.003 where a fixed aerodynamic center was utilized. The longitudinal variation of CP with trim angle was computed in non-dimensional form.

Since the RML balloon features a large windscreen to cover its payload and the more general balloon being obtained does not have a windscreen, the differences in aerodynamic characteristics had to be obtained from wind-tunnel tests of the two designs. Since flight data differed significantly from wind-tunnel data, the delta windscreen effects were applied to the flight data to obtain the full-scale aerodynamic characteristics of a FAMILY-2 balloon without windscreen.

The center of buoyancy locations were non-dimensionalized from flight measurements of the RML balloon assuming that the windscreen has no effect. The vertical location is a straight-line function of true angle-of-attack. However, the longitudinal location is a function of both trim angle and ballonet fullness. For

1. Yon, T. H. (1974) Design Verification of the IID-7A Balloon, Test Program Report TR No. 74-058, RCA Service Co. for Range Measurements Laboratory, Air Force Eastern Test Range, Patrick AFB, Florida, 2 Volumes.
2. Schjeldahl, G. T. Co. (1971) Wind Tunnel Test Results Family IID Aerodynamically Shaped Balloon, 5 Volumes.

this case, of an empty ballonnet, a curve-fit with a correlation of 0.99 was possible. This fit is used in Program No. 76.004, the design condition.

### 3.4.2 DEVELOPMENT OF PROGRAM AND EQUATIONS

This case covers a specific tethered balloon type wherein:

a. The location of the aerodynamic center of pressure ( $C_M = 0$ ) is known and can be utilized rather than an arbitrary fixed aerodynamic reference center ( $C_M \neq 0$ ).

b. The fore and aft location of the center of pressure varies with angle of attack.

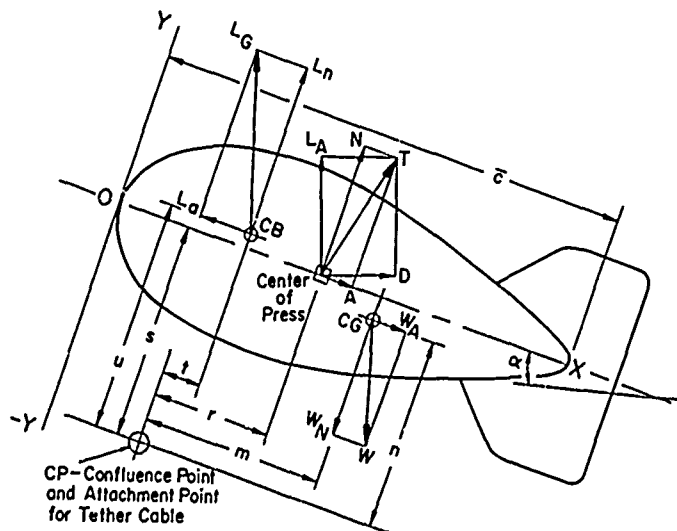
c. The location of the center of buoyancy varies with  $\alpha$ .

d. The balloon will be flown only at its design altitude condition (ballonet empty).

A. The object of the program is to determine the trim conditions of the balloon and the total force and its angle which must be resisted by the tether-cable. The tether-cable is attached at the confluence point of the multiple flying-lines attached to the balloon's skin. Hence at trim:

$$\Sigma \text{ Moments at Confluence Point} = 0$$

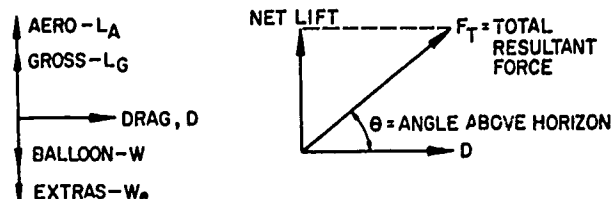
Positive moments are clockwise



The moment Eq. (10) developed for Program 76.003 in Section 3.3.2 is applicable here provided the aerodynamic pitching-moment is removed. The equation then becomes:

$$\begin{aligned}
 0 &= mW - tL + \tan \alpha (nW - uL) && \text{(Mech. Mom.)} \\
 &- K [ra \alpha - sb - sc\alpha^2 + \tan \alpha (sa \alpha + rb + rc\alpha^2)] && \text{(Aero Mom.)} \\
 &+ \cos \alpha [\Sigma W_e (x - x^{CP}) + \tan \alpha \Sigma W_e (y - y^{CP})] && \text{(Extras Mom.)}
 \end{aligned}$$

B. After solving for  $\alpha_{\text{trim}}$  the Aero Lift ( $L_A$ ) and Drag, can be calculated and used with buoyancy and Mass terms to obtain total Resultant Force ( $F_T$ ) and ( $\theta$ ) at the Confluence Point



C. Use 2 constant form for density ratio (same in all programs)

$$\frac{\ln \rho / \rho_0}{Z} = a_0 + a_1 Z$$

where

$$\begin{aligned}
 a_1 &= -1.7772^{-10} \\
 a_0 &= -2.81361^{-5}
 \end{aligned}$$

D. For 45,000 CF Balloon, let

$$\begin{aligned}
 X_{CG} &= 57.3 \text{ ft} \\
 Y_{CG} &= -2.5 \\
 X^{CP} &= 26.6 \\
 Y^{CP} &= -31.9 \\
 s &= 31.9 \\
 \bar{c} &= 83.7
 \end{aligned}$$

Built into program.  
See Notes to change to  
entry quantities or to  
change values

CG Location assumed unchanged with  $\alpha$  variation. RML tests for CG were made with empty ballonet and therefore best for design condition.

E. Center of Buoyancy - Empty Ballonet

$$Y_{CB} \text{ for 200,000 CF balloon} = 0.5$$

$$\text{Hull length, } \bar{c} \text{ for 200,000 CF balloon} = 137.58$$

$$Y_{CB}/\bar{c} = .003634$$

From fit of data in Reference 1 for empty ballonet case

$$X_{CB}/\bar{c} = a_0 + a_1 \alpha + a_2 \alpha^2$$

where

$$a_0 = .426185$$

$$a_1 = -.00110645$$

$$a_2 = .0000438942$$

F. Aero Coefficients - Flight data corrected for no windscreen by difference in wind-tunnel data with and without windscreen

$$a. C_L = .049 \alpha \text{ or } dC_L/d\alpha = .049$$

$$b. C_D = .106 + .00071 \alpha^2 = C_{D0} + \frac{dC_D}{d\alpha^2} \alpha^2$$

$$C_{D0} = .106 = \text{minimum drag at } \alpha = 0$$

$$dC_D/d\alpha^2 = .00071$$

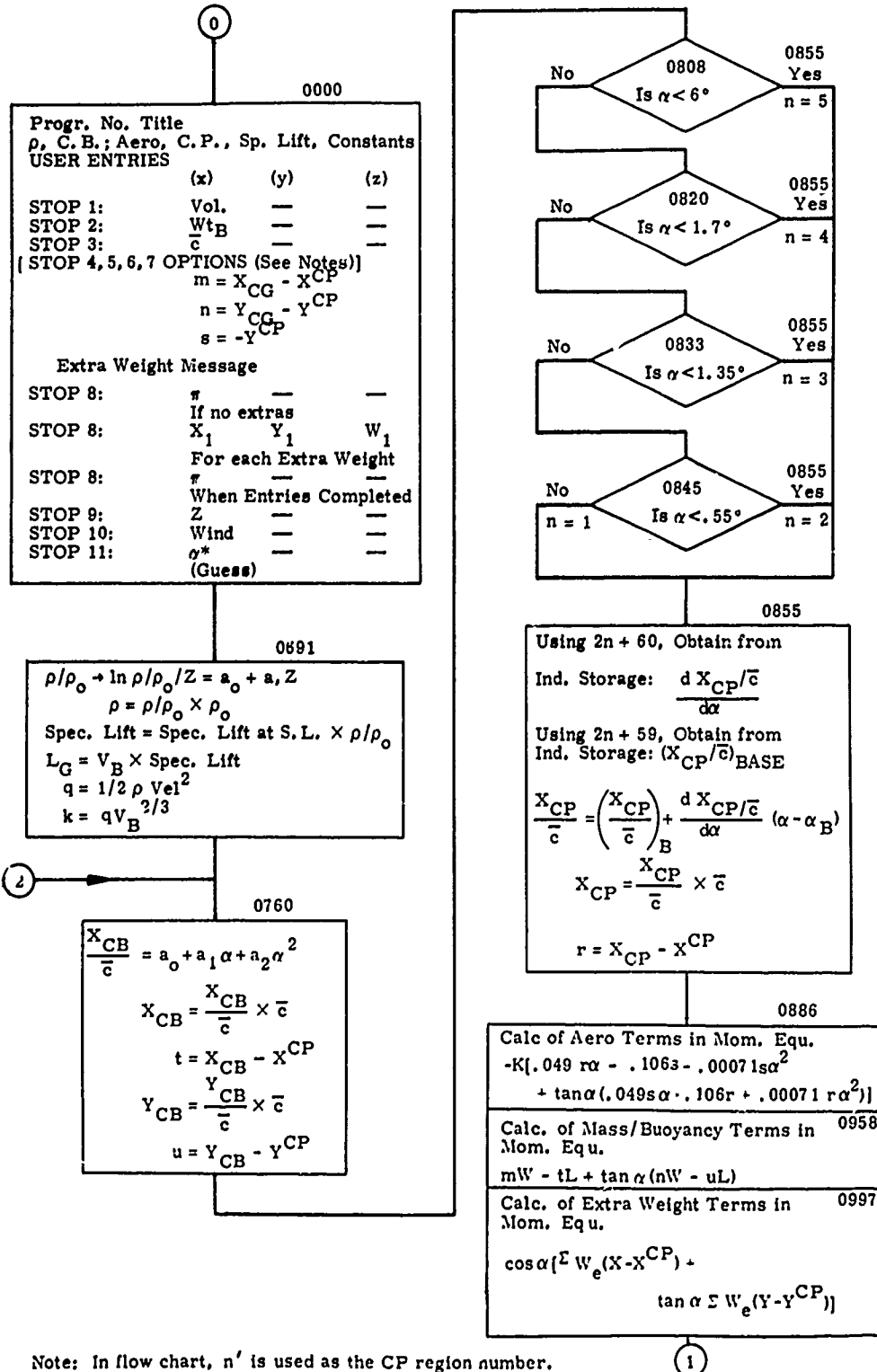
$$c. \frac{Y_{CP}}{\bar{c}} = 0$$

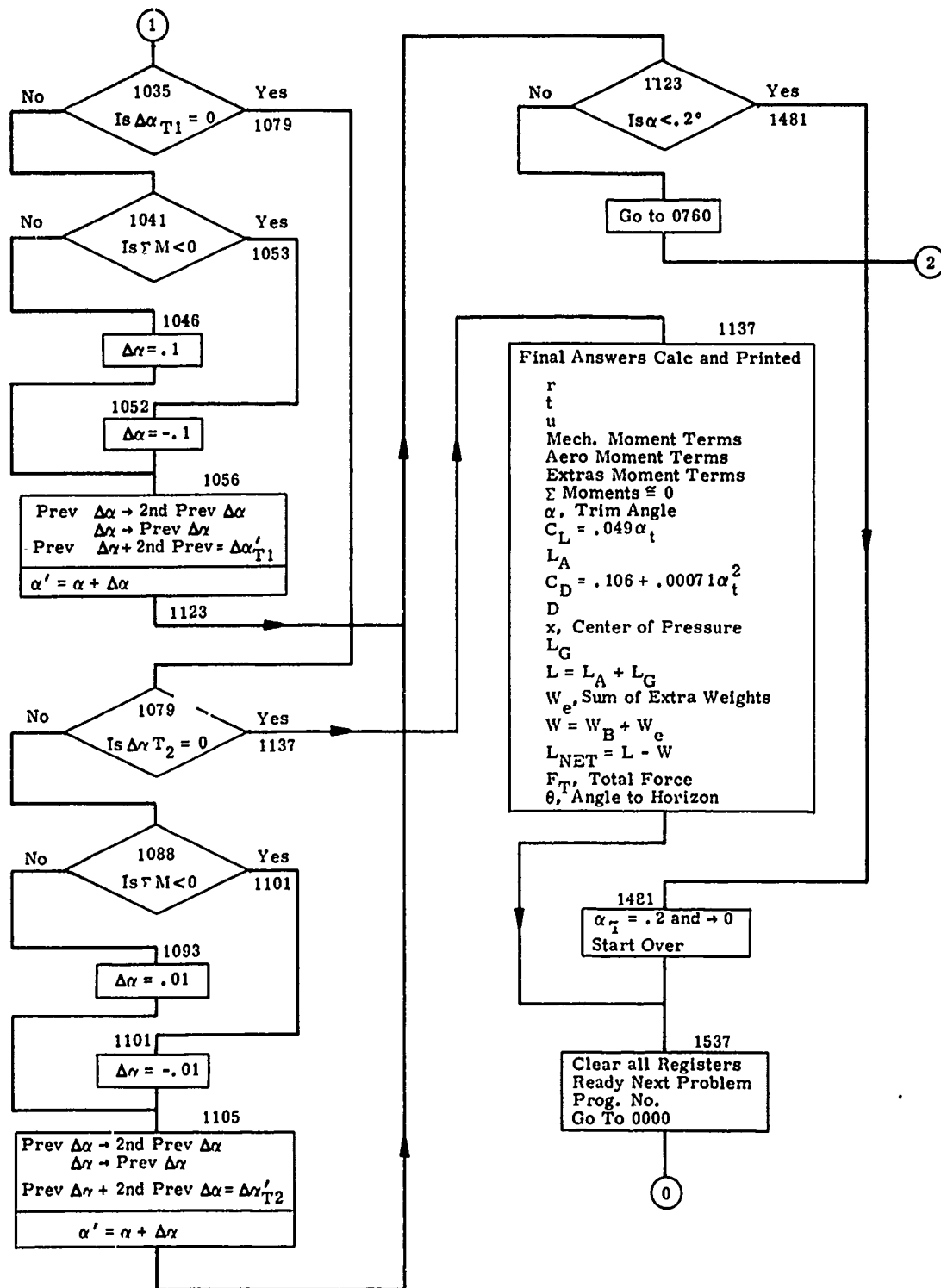
d.  $\frac{X_{CP}}{\bar{c}}$  from W. T. tests w/o windscreen. A series of straight lines is used to define the variation of  $X_{CP}/\bar{c}$  with

| Region | $\alpha$ Base | $\left(\frac{X_{CP}}{\bar{c}}\right)_{\text{Base}}$ | $\frac{d\frac{X_{CP}}{\bar{c}}}{d\alpha}$ | $\alpha$ Range |
|--------|---------------|-----------------------------------------------------|-------------------------------------------|----------------|
| 1      | 0             | .657                                                | .2091                                     | 0 - .55        |
| 2      | .55           | .805                                                | -.4350                                    | .55 - 1.35     |
| 3      | 1.35          | .457                                                | .1229                                     | 1.35 - 1.7     |
| 4      | 1.7           | .50                                                 | .01395                                    | 1.7 - 6.0      |
| 5      | 6.0<br>26.0   | .56<br>.634                                         | .00370                                    | 6.0            |

$$\frac{X_{CP}}{\bar{c}} = \left(\frac{X_{CP}}{\bar{c}}\right)_{\text{Base}} + \frac{d\frac{X_{CP}}{\bar{c}}}{d\alpha} (\alpha - \alpha_{\text{Base}})$$

### 3.4.3. FLOW CHART





### 3.4.4 OPERATING INSTRUCTIONS

| <u>KEY STROKES</u>                                                                                                                       |           | <u>ENTRIES</u> |       | <u>PRINTS</u>                    |
|------------------------------------------------------------------------------------------------------------------------------------------|-----------|----------------|-------|----------------------------------|
| RUN                                                                                                                                      |           |                |       |                                  |
| END                                                                                                                                      |           |                |       |                                  |
| FIX, 2,3----                                                                                                                             |           |                |       | (No. of desired decimal places)  |
| CONT                                                                                                                                     | (X)       | (Y)            | (Z)   | Program No. and Title            |
| Stop 1, Enter:                                                                                                                           | $V_B$     | -              | -     |                                  |
| CONT                                                                                                                                     |           |                |       | $V_B$ , Balloon Volume, CF       |
| Stop 2, Enter:                                                                                                                           | $W_B$     | -              | -     |                                  |
| CONT                                                                                                                                     |           |                |       | $W_B$ , Balloon Weight, lb       |
| Stop 3, Enter:                                                                                                                           | $\bar{c}$ | -              | -     |                                  |
| CONT                                                                                                                                     |           |                |       | $\bar{c}$ , Length, Hull, ft     |
| (Stops 4, 5, 6, and 7 not in program as written. See notes for optional use of these for $X_{CP}$ , $Y_{CP}$ , $X_{CG}$ , AND $Y_{CG}$ ) |           |                |       |                                  |
| X - CONF. PT.<br>$X_{CP}$                                                                                                                |           |                |       |                                  |
| Y - CONF. PT.<br>$Y_{CP}$                                                                                                                |           |                |       |                                  |
| X, Y CG-M, N, S<br>$X_{CG}$<br>$Y_{CG}$<br>m<br>n<br>s                                                                                   |           |                |       |                                  |
| Directions for "Extra" weights:<br>Ent $\Pi$ in X, if None.<br>Ent Wt in Z, y in Y, x in X.<br>Ent $\Pi$ in X when all entries made.     |           |                |       |                                  |
| Stop 8, Enter $\Pi$ or:                                                                                                                  | $X_1$     | $Y_1$          | $W_1$ |                                  |
| CONT                                                                                                                                     |           |                |       | $W_1$ (if entered)               |
| (Stop 8 repeats until closing $\Pi$ is entered)                                                                                          |           |                |       | $Y_1$ (if entered)               |
|                                                                                                                                          |           |                |       | $X_1$ (if entered)               |
| Stop 9, Enter:                                                                                                                           | Z         | -              | -     |                                  |
| CONT                                                                                                                                     |           |                |       | Z, Alt, ft                       |
| Stop 10, Enter:                                                                                                                          | W         | -              | -     |                                  |
| CONT                                                                                                                                     |           |                |       | W, Wind, Knots                   |
| Stop 11, Enter:                                                                                                                          | $\alpha$  | -              | -     |                                  |
| CONT                                                                                                                                     |           |                |       | $\alpha$ , Guess trim angle, deg |

(Program begins computations)

DYN PRES  
q, lb/ft<sup>2</sup>

In  $\alpha$ -trim loop, a pause at Step 1125, displays  $\alpha$  in X reg., and Moments in Z reg. as search is made for  $\alpha$ -trim where  $\sum$  Moments = 0. When found, printouts then occur as follows:

R  
r, ft  
T  
t, ft  
U  
u, ft  
MECH. MOM.  
Values of Mech  
Moment, ft-lb  
AERO MOM.  
Value of Aero  
Moment, ft-lb  
EXTRAS MOM.  
Value of Extras  
Moment, ft-lb  
SUM of MOM.  
 $\sum$  Moments  $\approx$  0  
TRIM ANGLE ATCK  
 $\alpha$ , deg  
CL  
 $C_L$   
AERO LIFT  
 $L_A$ , lb  
CD  
 $C_D$   
DRAG  
D, lb  
X-CENTER PRESS  
 $X_{CP}$ , ft  
GROSS BUOY. LIFT  
 $L_G$ , lb  
TOT. LIFT  
 $L = L_A + L_G$ , lb  
SUM "EXTRA" WTS  
 $\sum W_{extra}$ , lb  
TOT. WEIGHT  
 $W = W_B +$   
 $\sum W_{extra}$ , lb  
NET LIFT  
 $L_N = L - W$ , lb  
TOTAL FORCE  
 $F_T = \sqrt{L_N^2 + D^2}$ , lb  
ANGLE TO HORIZON  
 $\theta = \arctan$   
 $L_N/D$ , deg  
READY NEXT PROB.  
J. B. W. 76.004

A new set of data can now be entered at first stop in program after repeat of Title and Number.

### 3.4.5. SAMPLE INPUT DATA FORM

| INPUT                                                                                                                                                                                                      |            |       | 76.002, 76.003, 76.004, and 76.005                                                                                                                                |    |                                                                                                                                                               |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|----|---------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                                                                                                                                            |            |       | 76.003, 76.004, 76.005<br>EXTRA WEIGHT TABLE                                                                                                                      |    | 76.003 and 76.005<br>WIND PROFILE*                                                                                                                            |
| Ballon Volume                                                                                                                                                                                              | $V_B$      | cu ft | $W_1$                                                                                                                                                             | lb | No. 1                                                                                                                                                         |
| Ballonet Volume                                                                                                                                                                                            | $v$        | cu ft | $Y_1$                                                                                                                                                             | ft | $Z_{MAX}$ , ft ASSL                                                                                                                                           |
| Ballonet Weight                                                                                                                                                                                            | $W_B$      | lb    | $X_1$                                                                                                                                                             | ft | Wind, knots                                                                                                                                                   |
| Hull Length                                                                                                                                                                                                | $L$        | ft    | $W_2$                                                                                                                                                             |    | No. 2                                                                                                                                                         |
| ① Location of Confluence Pt.                                                                                                                                                                               | $Y_{CP}$   | ft    | $Y_2$                                                                                                                                                             |    | $Z_2$                                                                                                                                                         |
|                                                                                                                                                                                                            | $X_{CP}$   | ft    | $X_2$                                                                                                                                                             |    | Wind <sub>2</sub>                                                                                                                                             |
| ① Location of Center of Gravity                                                                                                                                                                            | $Y_{CG}$   | ft    | $W_3$                                                                                                                                                             |    | No. 3                                                                                                                                                         |
|                                                                                                                                                                                                            | $X_{CG}$   | ft    | $Y_3$                                                                                                                                                             |    | $Z_3$                                                                                                                                                         |
| ② Location of Center of Buoyancy                                                                                                                                                                           | $Y_{CB}$   | ft    | $X_3$                                                                                                                                                             |    | Wind <sub>3</sub>                                                                                                                                             |
|                                                                                                                                                                                                            | $X_{CB}$   | ft    | $W_4$                                                                                                                                                             |    | No. 4                                                                                                                                                         |
| ③ Location of Aero Reference Center                                                                                                                                                                        | $Y_{ARC}$  | ft    | $Y_4$                                                                                                                                                             |    | $Z_4$                                                                                                                                                         |
|                                                                                                                                                                                                            | $X_{ARC}$  | ft    | $X_4$                                                                                                                                                             |    | Wind <sub>4</sub>                                                                                                                                             |
| Altitude, Max                                                                                                                                                                                              | $Z_M$      | ft    | $W_5$                                                                                                                                                             |    | No. 5                                                                                                                                                         |
| Altitude, Surf                                                                                                                                                                                             | $Z_S$      | ft    | $Y_5$                                                                                                                                                             |    | $Z_5$                                                                                                                                                         |
| Increment of Alt                                                                                                                                                                                           | $\Delta Z$ | ft    | $X_5$                                                                                                                                                             |    | Wind <sub>5</sub>                                                                                                                                             |
| ③ $dC_L/d\alpha$                                                                                                                                                                                           | a          |       | $W_6$                                                                                                                                                             |    | No. 6                                                                                                                                                         |
| ③ $C_{D0}$                                                                                                                                                                                                 | b          |       | $Y_6$                                                                                                                                                             |    | $Z_6$                                                                                                                                                         |
| ③ $dC_D/d\alpha^2$                                                                                                                                                                                         | c          |       | $X_6$                                                                                                                                                             |    | Wind <sub>6</sub>                                                                                                                                             |
| ③ $C_M$ TABLE*                                                                                                                                                                                             |            |       | $W_7$                                                                                                                                                             |    | No. 7                                                                                                                                                         |
| NO. 1                                                                                                                                                                                                      | 1          |       | $Y_7$                                                                                                                                                             |    | $Z_7$                                                                                                                                                         |
| $\alpha_1$                                                                                                                                                                                                 | 0          | deg   | $X_7$                                                                                                                                                             |    | Wind <sub>7</sub>                                                                                                                                             |
| $C_{M1}$                                                                                                                                                                                                   |            |       | $W_8$                                                                                                                                                             |    | No. 8                                                                                                                                                         |
| NO. 2                                                                                                                                                                                                      | 2          |       | $Y_8$                                                                                                                                                             |    | $Z_8$                                                                                                                                                         |
| $\alpha_2$                                                                                                                                                                                                 |            | deg   | $X_8$                                                                                                                                                             |    | Wind <sub>8</sub>                                                                                                                                             |
| $C_{M2}$                                                                                                                                                                                                   |            |       | $W_9$                                                                                                                                                             |    | No. 9                                                                                                                                                         |
| NO. 3                                                                                                                                                                                                      | 3          |       | $Y_9$                                                                                                                                                             |    | $Z_9$                                                                                                                                                         |
| $\alpha_3$                                                                                                                                                                                                 |            | deg   | $X_9$                                                                                                                                                             |    | Wind <sub>9</sub>                                                                                                                                             |
| $C_{M3}$                                                                                                                                                                                                   |            |       | $W_{10}$                                                                                                                                                          |    | No. 10                                                                                                                                                        |
| NO. 4                                                                                                                                                                                                      | 4          |       | $Y_{10}$                                                                                                                                                          |    | $Z_{10}$                                                                                                                                                      |
| $\alpha_4$                                                                                                                                                                                                 |            | deg   | $X_{10}$                                                                                                                                                          |    | Wind <sub>10</sub>                                                                                                                                            |
| $C_{M4}$                                                                                                                                                                                                   |            |       | $W_{11}$                                                                                                                                                          |    | No. 11                                                                                                                                                        |
| NO. 5                                                                                                                                                                                                      | 5          |       | $Y_{11}$                                                                                                                                                          |    | $Z_{11}$                                                                                                                                                      |
| $\alpha_5$                                                                                                                                                                                                 |            | deg   | $X_{11}$                                                                                                                                                          |    | Wind <sub>11</sub>                                                                                                                                            |
| $C_{M5}$                                                                                                                                                                                                   |            |       | $W_{12}$                                                                                                                                                          |    | No. 12                                                                                                                                                        |
| NO. 6                                                                                                                                                                                                      | 6          |       | $Y_{12}$                                                                                                                                                          |    | $Z_{12}$                                                                                                                                                      |
| $\alpha_6$                                                                                                                                                                                                 |            | deg   | $X_{12}$                                                                                                                                                          |    | Wind <sub>12</sub>                                                                                                                                            |
| $C_{M6}$                                                                                                                                                                                                   |            |       | $W_{13}$                                                                                                                                                          |    | No. 13                                                                                                                                                        |
| NO. 7                                                                                                                                                                                                      | 7          |       | $Y_{13}$                                                                                                                                                          |    | $Z_{13}$                                                                                                                                                      |
| $\alpha_7$                                                                                                                                                                                                 |            | deg   | $X_{13}$                                                                                                                                                          |    | Wind <sub>13</sub>                                                                                                                                            |
| $C_{M7}$                                                                                                                                                                                                   |            |       |                                                                                                                                                                   |    |                                                                                                                                                               |
| ① See Note 76.003<br>② Req'd for 76.002 and 76.003<br>③ Req'd for 76.003 only<br>* A minimum of two points must be used, a maximum of seven points may be used. First point must be for $\alpha = 0^\circ$ |            |       | Any number of "extra" weights may be used. One entry can be Instrument Package and Payload. If these are at Confluence Point make<br>$Y = Y_{CP}$<br>$X = X_{CP}$ |    | *A minimum of 2 Points must be used and a maximum of 13 may be used. First must be $Z_{MAX}$ and last must be $Z_{SURF}$ . 76.004 requires one value of wind. |

# 3.4.6 PROGRAM 76.004 - TRIM, FAMILY-2, SINGLE DESIGN ALTITUDE

| STEP      | KEY | STEP      | KEY | STEP      | KEY | STEP      | KEY | STEP      | KEY | STEP      | KEY |
|-----------|-----|-----------|-----|-----------|-----|-----------|-----|-----------|-----|-----------|-----|
| 0000--CLR |     | 0050-- 7  |     | 0100--CHS |     | 0150-- 7  |     | 0200-- 2  |     | 0250--XTO |     |
| 0001--FMT |     | 0051-- 7  |     | 0101--XTO |     | 0151-- 1  |     | 0201-- 2  |     | 0251-- 0  |     |
| 0002--FMT |     | 0052-- 7  |     | 0102-- 0  |     | 0152--XTO |     | 0202-- 9  |     | 0252-- 4  |     |
| 0003-- 1  |     | 0053-- 1  |     | 0103-- 3  |     | 0153-- 0  |     | 0203--XTO |     | 0253-- 8  |     |
| 0004-- a  |     | 0054-- 7  |     | 0104-- 7  |     | 0154-- 2  |     | 0204-- 0  |     | 0254-- 0  |     |
| 0005-- 0  |     | 0055--CHS |     | 0105-- .  |     | 0155-- 1  |     | 0205-- 6  |     | 0255--XTO |     |
| 0006-- G  |     | 0056--EEX |     | 0106-- 0  |     | 0156-- .  |     | 0206-- 6  |     | 0256-- 4  |     |
| 0007-- .  |     | 0057-- 1  |     | 0107-- 0  |     | 0157-- 6  |     | 0207-- .  |     | 0257-- 4  |     |
| 0008--GTO |     | 0058-- 0  |     | 0108-- 1  |     | 0158-- 5  |     | 0208-- 5  |     | 0258--XTO |     |
| 0009-- 7  |     | 0059--CHS |     | 0109-- 1  |     | 0159-- 7  |     | 0209--XTO |     | 0259-- 4  |     |
| 0010-- 6  |     | 0060--XTO |     | 0110-- 0  |     | 0160--XTO |     | 0210-- 0  |     | 0260-- 7  |     |
| 0011-- .  |     | 0061-- 0  |     | 0111-- 6  |     | 0161-- 0  |     | 0211-- 6  |     | 0261--XTO |     |
| 0012-- 0  |     | 0062-- 3  |     | 0112-- 4  |     | 0162-- 6  |     | 0212-- 7  |     | 0262-- 5  |     |
| 0013-- 0  |     | 0063-- 9  |     | 0113-- 5  |     | 0163-- 1  |     | 0213-- .  |     | 0263-- 0  |     |
| 0014-- 4  |     | 0064-- 2  |     | 0114--CHS |     | 0164-- .  |     | 0214-- 0  |     | 0264--XTO |     |
| 0015--CLR |     | 0065-- .  |     | 0115--XTO |     | 0165-- 2  |     | 0215-- 1  |     | 0265-- 5  |     |
| 0016--XTO |     | 0066-- 8  |     | 0116-- 0  |     | 0166-- 6  |     | 0216-- 3  |     | 0266-- 1  |     |
| 0017-- a  |     | 0067-- 1  |     | 0117-- 3  |     | 0167-- 9  |     | 0217-- 9  |     | 0267--XTO |     |
| 0018-- I  |     | 0068-- 3  |     | 0118-- 6  |     | 0168-- 1  |     | 0218-- 5  |     | 0268-- 0  |     |
| 0019-- M  |     | 0069-- 6  |     | 0119-- .  |     | 0169--XTO |     | 0219--XTO |     | 0269-- 5  |     |
| 0020--CLX |     | 0070-- 0  |     | 0120-- 0  |     | 0170-- 0  |     | 0220-- 0  |     | 0270-- 2  |     |
| 0021-- D  |     | 0071-- 6  |     | 0121-- 0  |     | 0171-- 6  |     | 0221-- 6  |     | 0271-- .  |     |
| 0022-- E  |     | 0072--CHS |     | 0122-- 3  |     | 0172-- 2  |     | 0222-- 8  |     | 0272-- 0  |     |
| 0023--YTO |     | 0073--EEX |     | 0123-- 6  |     | 0173-- .  |     | 0223-- .  |     | 0273-- 6  |     |
| 0024-- I  |     | 0074-- 5  |     | 0124-- 3  |     | 0174-- 8  |     | 0224-- 5  |     | 0274-- 5  |     |
| 0025-- G  |     | 0075--CHS |     | 0125-- 4  |     | 0175-- 0  |     | 0225-- 6  |     | 0275-- 9  |     |
| 0026-- N  |     | 0076--XTO |     | 0126--XTO |     | 0176-- 5  |     | 0226--XTO |     | 0276-- 8  |     |
| 0027--CNT |     | 0077-- 0  |     | 0127-- 0  |     | 0177--XTO |     | 0227-- 0  |     | 0277-- 8  |     |
| 0028-- A  |     | 0078-- 3  |     | 0128-- 4  |     | 0178-- 0  |     | 0228-- 6  |     | 0278--XTO |     |
| 0029-- L  |     | 0079-- 8  |     | 0129-- 0  |     | 0179-- 6  |     | 0229-- 9  |     | 0279-- 0  |     |
| 0030--XTO |     | 0080-- .  |     | 0130-- .  |     | 0180-- 3  |     | 0230-- .  |     | 0280-- 3  |     |
| 0031-- .  |     | 0081-- 4  |     | 0131-- 0  |     | 0181-- .  |     | 0231-- 0  |     | 0281-- 4  |     |
| 0032-- F  |     | 0082-- 2  |     | 0132-- 4  |     | 0182-- 4  |     | 0232-- 0  |     | 0282-- .  |     |
| 0033-- A  |     | 0083-- 6  |     | 0133-- 9  |     | 0183-- 3  |     | 0233-- 3  |     | 0283-- 0  |     |
| 0034-- M  |     | 0084-- 1  |     | 0134--XTO |     | 0184-- 5  |     | 0234-- 7  |     | 0284-- 0  |     |
| 0035-- .  |     | 0085-- 8  |     | 0135-- 0  |     | 0185--CHS |     | 0235--XTO |     | 0285-- 2  |     |
| 0036-- 2  |     | 0086-- 5  |     | 0136-- 1  |     | 0186--XTO |     | 0236-- 0  |     | 0286-- 3  |     |
| 0037--CHT |     | 0087--XTO |     | 0137-- 9  |     | 0187-- 0  |     | 0237-- 7  |     | 0287-- 7  |     |
| 0038--XTO |     | 0088-- 0  |     | 0138-- .  |     | 0188-- 6  |     | 0238-- 0  |     | 0288-- 8  |     |
| 0039-- .  |     | 0089-- 3  |     | 0139-- 1  |     | 0189-- 4  |     | 0239-- 1  |     | 0289--XTO |     |
| 0040-- B  |     | 0090-- 5  |     | 0140-- 0  |     | 0190-- .  |     | 0240-- 1  |     | 0290-- 0  |     |
| 0041-- A  |     | 0091-- .  |     | 0141-- 6  |     | 0191-- 4  |     | 0241--XTO |     | 0291-- 1  |     |
| 0042-- L  |     | 0092-- 4  |     | 0142--XTO |     | 0192-- 5  |     | 0242-- 4  |     | 0292-- 2  |     |
| 0043-- L  |     | 0093-- 3  |     | 0143-- 0  |     | 0193-- 7  |     | 0243-- 3  |     | 0293--FMT |     |
| 0044-- 0  |     | 0094-- 8  |     | 0144-- 2  |     | 0194--XTO |     | 0244--XTO |     | 0294--FMT |     |
| 0045-- 0  |     | 0095-- 9  |     | 0145-- 0  |     | 0195-- 0  |     | 0245-- 4  |     | 0295--INT |     |
| 0046-- H  |     | 0096-- 4  |     | 0146-- .  |     | 0196-- 6  |     | 0246-- 5  |     | 0296-- 0  |     |
| 0047--FMT |     | 0097-- 2  |     | 0147-- 0  |     | 0197-- 5  |     | 0247--XTO |     | 0297-- L  |     |
| 0048-- 1  |     | 0098--EEX |     | 0148-- 0  |     | 0198-- .  |     | 0248-- 4  |     | 0298-- .  |     |
| 0049-- .  |     | 0099-- 4  |     | 0149-- 0  |     | 0199-- 1  |     | 0249-- 6  |     | 0299--FMT |     |

| STEP   | KEY | STEP   | KEY | STEP   | KEY | STEP   | KEY | STEP   | KEY | STEP   | KEY |
|--------|-----|--------|-----|--------|-----|--------|-----|--------|-----|--------|-----|
| 0300-- | 1   | 0350-- | FMT | 0400-- | C   | 0450-- | a   | 0500-- | H   | 0550-- | 1   |
| 0301-- | STP | 0351-- | FMT | 0401-- | G   | 0451-- | A   | 0501-- | D   | 0551-- | X=Y |
| 0302-- | PHT | 0352-- | YE  | 0402-- | -   | 0452-- | CNT | 0502-- | CNT | 0552-- | 0   |
| 0303-- | XTO | 0353-- | -   | 0403-- | CLX | 0453-- | IND | 0503-- | YE  | 0553-- | 6   |
| 0304-- | 4   | 0354-- | C   | 0404-- | M   | 0454-- | XTO | 0504-- | CNT | 0554-- | 1   |
| 0305-- | 2   | 0355-- | 0   | 0405-- | CLX | 0455-- | YTO | 0505-- | I   | 0555-- | 2   |
| 0306-- | UP  | 0356-- | N   | 0406-- | H   | 0456-- | CLR | 0506-- | N   | 0556-- | 6   |
| 0307-- | 2   | 0357-- | F   | 0407-- | CLX | 0457-- | E   | 0507-- | CNT | 0557-- | RUP |
| 0308-- | UP  | 0358-- | .   | 0408-- | YTO | 0458-- | N   | 0508-- | YE  | 0558-- | PHT |
| 0309-- | 3   | 0359-- | 1   | 0409-- | FMT | 0459-- | XTO | 0509-- | CLR | 0559-- | XTO |
| 0310-- | DIV | 0360-- | XTO | 0410-- | 5   | 0460-- | .   | 0510-- | E   | 0560-- | 6   |
| 0311-- | DN  | 0361-- | .   | 0411-- | 7   | 0461-- | CHS | 0511-- | N   | 0561-- | XTO |
| 0312-- | KEY | 0362-- | FMT | 0412-- | .   | 0462-- | CNT | 0512-- | XTO | 0562-- | +   |
| 0313-- | H   | 0363-- | 2   | 0413-- | 3   | 0463-- | I   | 0513-- | .   | 0563-- | 5   |
| 0314-- | XTO | 0364-- | 6   | 0414-- | PHT | 0464-- | N   | 0514-- | CHS | 0564-- | 0   |
| 0315-- | 4   | 0365-- | .   | 0415-- | RUP | 0465-- | CNT | 0515-- | CNT | 0565-- | DN  |
| 0316-- | 1   | 0366-- | 6   | 0416-- | -   | 0466-- | YE  | 0516-- | I   | 0566-- | PNT |
| 0317-- | FMT | 0367-- | PHT | 0417-- | 2   | 0467-- | CLR | 0517-- | H   | 0567-- | KEY |
| 0318-- | FMT | 0368-- | XTO | 0418-- | .   | 0468-- | 0   | 0518-- | CNT | 0568-- | PHT |
| 0319-- | IND | 0369-- | 5   | 0419-- | 5   | 0469-- | XTO | 0519-- | YE  | 0569-- | PHT |
| 0320-- | E   | 0370-- | 4   | 0420-- | CHS | 0470-- | H   | 0520-- | CNT | 0570-- | UP  |
| 0321-- | I   | 0371-- | UP  | 0421-- | PHT | 0471-- | E   | 0521-- | A   | 0571-- | XFR |
| 0322-- | G   | 0372-- | FMT | 0422-- | RUP | 0472-- | a   | 0522-- | F   | 0572-- | 5   |
| 0323-- | H   | 0373-- | FMT | 0423-- | -   | 0473-- | IND | 0523-- | XTO | 0573-- | 4   |
| 0324-- | XTO | 0374-- | XFR | 0424-- | RUP | 0474-- | I   | 0524-- | E   | 0574-- | -   |
| 0325-- | FMT | 0375-- | -   | 0425-- | XTO | 0475-- | YTO | 0525-- | a   | 0575-- | XFR |
| 0326-- | 2   | 0376-- | C   | 0426-- | 3   | 0476-- | E   | 0526-- | E   | 0576-- | 5   |
| 0327-- | STP | 0377-- | 0   | 0427-- | PHT | 0477-- | CLX | 0527-- | H   | 0577-- | 5   |
| 0328-- | PHT | 0378-- | N   | 0428-- | RUP | 0478-- | E   | 0528-- | XTO | 0578-- | RUP |
| 0329-- | XTO | 0379-- | F   | 0429-- | PHT | 0479-- | H   | 0529-- | a   | 0579-- | KEY |
| 0330-- | 1   | 0380-- | .   | 0430-- | XTO | 0480-- | XTO | 0530-- | I   | 0580-- | -   |
| 0331-- | FMT | 0381-- | 1   | 0431-- | 4   | 0481-- | E   | 0531-- | E   | 0581-- | 6   |
| 0332-- | FMT | 0382-- | XTO | 0432-- | RUP | 0482-- | a   | 0532-- | YTO | 0582-- | X   |
| 0333-- | L   | 0383-- | FMT | 0433-- | CHS | 0483-- | CLR | 0533-- | CNT | 0583-- | YTO |
| 0334-- | E   | 0384-- | 3   | 0434-- | PHT | 0484-- | IND | 0534-- | C   | 0584-- | +   |
| 0335-- | N   | 0385-- | 1   | 0435-- | XTO | 0485-- | XTO | 0535-- | 0   | 0585-- | 5   |
| 0336-- | G   | 0386-- | .   | 0436-- | 6   | 0486-- | .   | 0536-- | H   | 0586-- | 2   |
| 0337-- | XTO | 0387-- | 9   | 0437-- | CNT | 0487-- | I   | 0537-- | 1   | 0587-- | RUP |
| 0338-- | H   | 0388-- | CHS | 0438-- | CNT | 0488-- | H   | 0538-- | L   | 0588-- | X   |
| 0339-- | CNT | 0389-- | PHT | 0439-- | FMT | 0489-- | CNT | 0539-- | E   | 0589-- | YTO |
| 0340-- | H   | 0390-- | XTO | 0440-- | FMT | 0490-- | XSO | 0540-- | XTO | 0590-- | +   |
| 0341-- | 1/X | 0391-- | 5   | 0441-- | I   | 0491-- | CLX | 0541-- | E   | 0591-- | 0   |
| 0342-- | L   | 0392-- | 5   | 0442-- | F   | 0492-- | XFR | 0542-- | FMT | 0592-- | 5   |
| 0343-- | L   | 0393-- | UP  | 0443-- | CNT | 0493-- | CNT | 0543-- | 8   | 0593-- | 1   |
| 0344-- | FMT | 0394-- | FMT | 0444-- | H   | 0494-- | I   | 0544-- | UP  | 0594-- | 8   |
| 0345-- | 3   | 0395-- | FMT | 0445-- | 0   | 0495-- | H   | 0545-- | UP  | 0595-- | UP  |
| 0346-- | STP | 0396-- | YE  | 0446-- | CNT | 0496-- | CNT | 0546-- | STP | 0596-- | UP  |
| 0347-- | PHT | 0397-- | CLX | 0447-- | E   | 0497-- | XFR | 0547-- | YTO | 0597-- | STP |
| 0348-- | XTC | 0398-- | XFR | 0448-- | YE  | 0498-- | CLP | 0548-- | 6   | 0598-- | YTO |
| 0349-- | 8   | 0399-- | CNT | 0449-- | XTO | 0499-- | A   | 0549-- | KEY | 0599-- | 6   |

| STEP      | KEY | STEP      | KEY | STEP      | KEY | STEP      | KEY | STEP      | KEY | STEP      | KEY |
|-----------|-----|-----------|-----|-----------|-----|-----------|-----|-----------|-----|-----------|-----|
| 0600--KEY |     | 0650--STP |     | 0700--XFR |     | 0750--XFR |     | 0800--0   |     | 0850--1   |     |
| 0601--n   |     | 0651--PNT |     | 0701--3   |     | 0751--H   |     | 0801--3   |     | 0851--RUP |     |
| 0602--X=Y |     | 0652--UP  |     | 0702--8   |     | 0752--.   |     | 0802--3   |     | 0852--RUP |     |
| 0603--0   |     | 0653--1   |     | 0703--+   |     | 0753--n   |     | 0803--5   |     | 0853--KEY |     |
| 0604--6   |     | 0654--.   |     | 0704--DH  |     | 0754--a   |     | 0804--UP  |     | 0854--0   |     |
| 0605--1   |     | 0655--6   |     | 0705--X   |     | 0755--E   |     | 0805--a   |     | 0855--.   |     |
| 0606--2   |     | 0656--8   |     | 0706--DH  |     | 0756--YTO |     | 0806--UP  |     | 0856--2   |     |
| 0607--GTO |     | 0657--7   |     | 0707--J   |     | 0757--YTO |     | 0807--6   |     | 0857--RUP |     |
| 0608--0   |     | 0658--8   |     | 0708--UP  |     | 0758--FMT |     | 0808--XKY |     | 0858--X   |     |
| 0609--5   |     | 0659--X   |     | 0709--UP  |     | 0759--PNT |     | 0809--0   |     | 0859--6   |     |
| 0610--5   |     | 0660--YTO |     | 0710--XFR |     | 0760--a   |     | 0810--8   |     | 0860--0   |     |
| 0611--6   |     | 0661--1   |     | 0711--1   |     | 0761--UP  |     | 0811--5   |     | 0861--+   |     |
| 0612--9   |     | 0662--1   |     | 0712--2   |     | 0762--XSQ |     | 0812--5   |     | 0862--YTO |     |
| 0613--UP  |     | 0663--FMT |     | 0713--X   |     | 0763--UP  |     | 0813--1   |     | 0863--b   |     |
| 0614--UP  |     | 0664--FMT |     | 0714--YTO |     | 0764--XFR |     | 0814--.   |     | 0864--XFR |     |
| 0615--FMT |     | 0665--G   |     | 0715--1   |     | 0765--3   |     | 0815--7   |     | 0865--IND |     |
| 0616--FMT |     | 0666--1/X |     | 0716--3   |     | 0766--7   |     | 0816--RUP |     | 0866--b   |     |
| 0617--R   |     | 0667--E   |     | 0717--DH  |     | 0767--X   |     | 0817--4   |     | 0867--RUP |     |
| 0618--L   |     | 0668--YTO |     | 0718--XFR |     | 0768--XFR |     | 0818--RUP |     | 0868--X   |     |
| 0619--XTO |     | 0669--YTO |     | 0719--3   |     | 0769--3   |     | 0819--RUP |     | 0869--1   |     |
| 0620--.   |     | 0670--CHT |     | 0720--4   |     | 0770--6   |     | 0820--XKY |     | 0870--XTO |     |
| 0621--F   |     | 0671--XTO |     | 0721--X   |     | 0771--RUP |     | 0821--0   |     | 0871--.   |     |
| 0622--XTO |     | 0672--a   |     | 0722--XFR |     | 0772--X   |     | 0822--8   |     | 0872--b   |     |
| 0623--.   |     | 0673--1   |     | 0723--4   |     | 0773--XFR |     | 0823--5   |     | 0873--XFR |     |
| 0624--M   |     | 0674--M   |     | 0724--2   |     | 0774--3   |     | 0824--5   |     | 0874--IND |     |
| 0625--YTO |     | 0675--CHT |     | 0725--X   |     | 0775--5   |     | 0825--1   |     | 0875--b   |     |
| 0626--L   |     | 0676--R   |     | 0726--YTO |     | 0776--+   |     | 0826--.   |     | 0876--+   |     |
| 0627--FMT |     | 0677--H   |     | 0727--2   |     | 0777--DH  |     | 0827--3   |     | 0877--XFR |     |
| 0628--STP |     | 0678--G   |     | 0728--XFR |     | 0778--+   |     | 0828--5   |     | 0878--8   |     |
| 0629--PNT |     | 0679--L   |     | 0729--1   |     | 0779--XFR |     | 0829--RUP |     | 0879--X   |     |
| 0630--XTO |     | 0680--E   |     | 0730--.   |     | 0780--8   |     | 0830--3   |     | 0880--XFR |     |
| 0631--1   |     | 0681--FMT |     | 0731--XSQ |     | 0781--X   |     | 0831--RUP |     | 0881--5   |     |
| 0632--0   |     | 0682--1   |     | 0732--UP  |     | 0782--XFR |     | 0832--RUP |     | 0882--4   |     |
| 0633--FMT |     | 0683--1   |     | 0733--XFR |     | 0783--5   |     | 0833--XKY |     | 0883--.   |     |
| 0634--FMT |     | 0684--UP  |     | 0734--1   |     | 0784--4   |     | 0834--0   |     | 0884--YTO |     |
| 0635--IND |     | 0685--UP  |     | 0735--3   |     | 0785--.   |     | 0835--8   |     | 0885--5   |     |
| 0636--1   |     | 0686--STP |     | 0736--X   |     | 0786--YTO |     | 0836--5   |     | 0886--a   |     |
| 0637--H.  |     | 0687--PNT |     | 0737--2   |     | 0787--7   |     | 0837--5   |     | 0887--XSQ |     |
| 0638--D   |     | 0688--PNT |     | 0738--DIV |     | 0788--XFR |     | 0838--.   |     | 0888--X   |     |
| 0639--CLX |     | 0689--XTO |     | 0739--XFR |     | 0789--4   |     | 0839--5   |     | 0889--XFR |     |
| 0640--K   |     | 0690--a   |     | 0740--4   |     | 0790--0   |     | 0840--5   |     | 0890--2   |     |
| 0641--H   |     | 0691--XFR |     | 0741--1   |     | 0791--UP  |     | 0841--RUP |     | 0891--1   |     |
| 0642--0   |     | 0692--1   |     | 0742--KEY |     | 0792--XFR |     | 0842--2   |     | 0892--X   |     |
| 0643--XTO |     | 0693--0   |     | 0743--X   |     | 0793--8   |     | 0843--RUP |     | 0893--XFR |     |
| 0644--YTO |     | 0694--UP  |     | 0744--YTO |     | 0794--X   |     | 0844--RUP |     | 0894--6   |     |
| 0645--FMT |     | 0695--UP  |     | 0745--1   |     | 0795--XFR |     | 0845--XKY |     | 0895--UP  |     |
| 0646--1   |     | 0696--XFR |     | 0746--4   |     | 0796--5   |     | 0846--0   |     | 0896--XFR |     |
| 0647--0   |     | 0697--3   |     | 0747--FMT |     | 0797--5   |     | 0847--8   |     | 0897--1   |     |
| 0648--UP  |     | 0698--9   |     | 0748--FMT |     | 0798--.   |     | 0848--5   |     | 0898--9   |     |
| 0649--UP  |     | 0699--X   |     | 0749--D   |     | 0799--YTO |     | 0849--5   |     | 0899--X   |     |

| STEP   | KEY | STEP   | KEY | STEP   | KEY | STEP   | KEY | STEP   | KEY | STEP   | KEY |
|--------|-----|--------|-----|--------|-----|--------|-----|--------|-----|--------|-----|
| 0900-- | a   | 0950-- | -   | 1000-- | UP  | 1050-- | 0   | 1100-- | 5   | 1150-- | PHT |
| 0901-- | X   | 0951-- | XFR | 1001-- | a   | 1051-- | 5   | 1101-- | .   | 1151-- | FMT |
| 0902-- | DN  | 0952-- | 1   | 1002-- | 0   | 1052-- | 6   | 1102-- | 0   | 1152-- | FMT |
| 0903-- | KEY | 0953-- | 4   | 1003-- | X   | 1053-- | .   | 1103-- | 1   | 1153-- | 1/X |
| 0904-- | +   | 0954-- | X   | 1004-- | XFR | 1054-- | 1   | 1104-- | CHS | 1154-- | FMT |
| 0905-- | XFR | 0955-- | YTO | 1005-- | 5   | 1055-- | CHS | 1105-- | UP  | 1155-- | XFR |
| 0906-- | 5   | 0956-- | 2   | 1006-- | 1   | 1056-- | UP  | 1106-- | XFR | 1156-- | 3   |
| 0907-- | UP  | 0957-- | 9   | 1007-- | +   | 1057-- | XFR | 1107-- | 4   | 1157-- | 3   |
| 0908-- | XFR | 0958-- | XFR | 1008-- | a   | 1058-- | 4   | 1108-- | 7   | 1158-- | PHT |
| 0909-- | 2   | 0959-- | 1   | 1009-- | N   | 1059-- | 4   | 1109-- | XTO | 1159-- | PHT |
| 0910-- | 0   | 0960-- | UP  | 1010-- | X   | 1060-- | XTO | 1110-- | 4   | 1160-- | FMT |
| 0911-- | X   | 0961-- | XFR | 1011-- | YTO | 1061-- | 4   | 1111-- | 8   | 1161-- | FMT |
| 0912-- | DN  | 0962-- | 3   | 1012-- | 3   | 1062-- | 5   | 1112-- | YTO | 1162-- | M   |
| 0913-- | +   | 0963-- | X   | 1013-- | 1   | 1063-- | YTO | 1113-- | 4   | 1163-- | E   |
| 0914-- | a   | 0964-- | XFR | 1014-- | XFR | 1064-- | 4   | 1114-- | 7   | 1164-- | C   |
| 0915-- | 0   | 0965-- | 2   | 1015-- | 3   | 1065-- | 4   | 1115-- | KEY | 1165-- | H   |
| 0916-- | X   | 0966-- | UP  | 1016-- | 0   | 1066-- | KEY | 1116-- | +   | 1166-- | .   |
| 0917-- | YTO | 0967-- | XFR | 1017-- | +   | 1067-- | +   | 1117-- | YTO | 1167-- | M   |
| 0918-- | b   | 0968-- | 7   | 1018-- | XFR | 1068-- | YTO | 1118-- | 4   | 1168-- | 0   |
| 0919-- | a   | 0969-- | X   | 1019-- | 2   | 1069-- | 4   | 1119-- | 6   | 1169-- | M   |
| 0920-- | UP  | 0970-- | DN  | 1020-- | 9   | 1070-- | 3   | 1120-- | KEY | 1170-- | E   |
| 0921-- | XFR | 0971-- | -   | 1021-- | CHS | 1071-- | KEY | 1121-- | a   | 1171-- | N   |
| 0922-- | 5   | 0972-- | YTO | 1022-- | +   | 1072-- | a   | 1122-- | +   | 1172-- | XTO |
| 0923-- | X   | 0973-- | b   | 1023-- | XTO | 1073-- | +   | 1123-- | YTO | 1173-- | FMT |
| 0924-- | XFR | 0974-- | XFR | 1024-- | 2   | 1074-- | GTO | 1124-- | a   | 1174-- | XFR |
| 0925-- | 1   | 0975-- | 1   | 1025-- | 9   | 1075-- | 1   | 1125-- | PSE | 1175-- | 3   |
| 0926-- | 9   | 0976-- | UP  | 1026-- | YTO | 1076-- | 1   | 1126-- | .   | 1176-- | 0   |
| 0927-- | X   | 0977-- | XFR | 1027-- | 0   | 1077-- | 2   | 1127-- | 2   | 1177-- | PHT |
| 0928-- | a   | 0978-- | 4   | 1028-- | 3   | 1078-- | 3   | 1128-- | X>Y | 1178-- | FMT |
| 0929-- | XSO | 0979-- | X   | 1029-- | 2   | 1079-- | XFR | 1129-- | 1   | 1179-- | FMT |
| 0930-- | UP  | 0980-- | XFR | 1030-- | 0   | 1080-- | 4   | 1130-- | 4   | 1180-- | A   |
| 0931-- | XFR | 0981-- | 2   | 1031-- | UP  | 1081-- | 6   | 1131-- | 8   | 1181-- | E   |
| 0932-- | 0   | 0982-- | UP  | 1032-- | XFR | 1082-- | X=Y | 1132-- | 1   | 1182-- | a   |
| 0933-- | X   | 0983-- | XFR | 1033-- | 4   | 1083-- | 1   | 1133-- | GTO | 1183-- | 0   |
| 0934-- | XFR | 0984-- | 3   | 1034-- | 3   | 1084-- | 1   | 1134-- | 7   | 1184-- | .   |
| 0935-- | 2   | 0985-- | 3   | 1035-- | X=Y | 1085-- | 3   | 1135-- | 6   | 1185-- | M   |
| 0936-- | 1   | 0986-- | X   | 1036-- | 1   | 1086-- | 7   | 1136-- | 0   | 1186-- | 0   |
| 0937-- | X   | 0987-- | DN  | 1037-- | 0   | 1087-- | DN  | 1137-- | FMT | 1187-- | M   |
| 0938-- | DN  | 0988-- | -   | 1038-- | 7   | 1088-- | X>Y | 1138-- | FMT | 1188-- | .   |
| 0939-- | -   | 0989-- | a   | 1039-- | 9   | 1089-- | 1   | 1139-- | a   | 1189-- | FMT |
| 0940-- | XFR | 0990-- | 0   | 1040-- | DN  | 1090-- | 1   | 1140-- | FMT | 1190-- | XFR |
| 0941-- | 6   | 0991-- | X   | 1041-- | X>Y | 1091-- | 0   | 1141-- | XFR | 1191-- | 2   |
| 0942-- | UP  | 0992-- | b   | 1042-- | 1   | 1092-- | 1   | 1142-- | 5   | 1192-- | 9   |
| 0943-- | XFR | 0993-- | +   | 1043-- | 0   | 1093-- | .   | 1143-- | PHT | 1193-- | PHT |
| 0944-- | 2   | 0994-- | YTO | 1044-- | 5   | 1094-- | 0   | 1144-- | FMT | 1194-- | FMT |
| 0945-- | 0   | 0995-- | 3   | 1045-- | 3   | 1095-- | 1   | 1145-- | FMT | 1195-- | FMT |
| 0946-- | X   | 0996-- | 0   | 1046-- | .   | 1096-- | GTO | 1146-- | XTO | 1196-- | E   |
| 0947-- | DN  | 0997-- | XFR | 1047-- | 1   | 1097-- | 1   | 1147-- | FMT | 1197-- | YE  |
| 0948-- | -   | 0998-- | 5   | 1048-- | GTO | 1098-- | 1   | 1148-- | XFR | 1198-- | XTO |
| 0949-- | b   | 0999-- | 2   | 1049-- | 1   | 1099-- | C   | 1149-- | 7   | 1199-- | a   |

| STEP   | KEY | STEP   | KEY | STEP   | KEY | STEP   | KEY | STEP   | KEY | STEP   | KEY |
|--------|-----|--------|-----|--------|-----|--------|-----|--------|-----|--------|-----|
| 1200-- | H   | 1250-- | F   | 1300-- | X   | 1350-- | G   | 1400-- | UP  | 1450-- | a   |
| 1201-- | YTO | 1251-- | FMT | 1301-- | FMT | 1351-- | a   | 1401-- | XFR | 1451-- | C   |
| 1202-- | CNT | 1252-- | PNT | 1302-- | FMT | 1352-- | 0   | 1402-- | I   | 1452-- | E   |
| 1203-- | H   | 1253-- | FMT | 1303-- | C   | 1353-- | YTO | 1403-- | +   | 1453-- | FMT |
| 1204-- | 0   | 1254-- | FMT | 1304-- | D   | 1354-- | YTO | 1404-- | DN  | 1454-- | PNT |
| 1205-- | M   | 1255-- | C   | 1305-- | FMT | 1355-- | CNT | 1405-- | FMT | 1455-- | KEY |
| 1206-- | .   | 1256-- | L   | 1306-- | PNT | 1356-- | L   | 1406-- | FMT | 1456-- | FMT |
| 1207-- | FMT | 1257-- | FMT | 1307-- | DN  | 1357-- | I   | 1407-- | XTO | 1457-- | FMT |
| 1208-- | XFR | 1258-- | UP  | 1308-- | FMT | 1358-- | F   | 1408-- | 0   | 1458-- | A   |
| 1209-- | 3   | 1259-- | XSO | 1309-- | FMT | 1359-- | XTO | 1409-- | XTO | 1459-- | H   |
| 1210-- | 1   | 1260-- | KEY | 1310-- | D   | 1360-- | FMT | 1410-- | A   | 1460-- | G   |
| 1211-- | PNT | 1261-- | UP  | 1311-- | a   | 1361-- | PNT | 1411-- | L   | 1461-- | L   |
| 1212-- | FMT | 1262-- | XFR | 1312-- | A   | 1362-- | UP  | 1412-- | CNT | 1462-- | E   |
| 1213-- | FMT | 1263-- | 1   | 1313-- | G   | 1363-- | b   | 1413-- | IND | 1463-- | CNT |
| 1214-- | YTO | 1264-- | 9   | 1314-- | FMT | 1364-- | +   | 1414-- | E   | 1464-- | XTO |
| 1215-- | 1/2 | 1265-- | X   | 1315-- | PNT | 1365-- | DN  | 1415-- | I   | 1465-- | 0   |
| 1216-- | H   | 1266-- | XFR | 1316-- | XTO | 1366-- | FMT | 1416-- | G   | 1466-- | CNT |
| 1217-- | CNT | 1267-- | 1   | 1317-- | 4   | 1367-- | FMT | 1417-- | H   | 1467-- | H   |
| 1218-- | 0   | 1268-- | 4   | 1318-- | 9   | 1368-- | XTO | 1418-- | XTO | 1468-- | 0   |
| 1219-- | F   | 1269-- | KEY | 1319-- | FMT | 1369-- | 0   | 1419-- | FMT | 1469-- | a   |
| 1220-- | CNT | 1270-- | X   | 1320-- | FMT | 1370-- | XTO | 1420-- | PNT | 1470-- | I   |
| 1221-- | M   | 1271-- | PNT | 1321-- | YE  | 1371-- | .   | 1421-- | -   | 1471-- | XSO |
| 1222-- | 0   | 1272-- | DN  | 1322-- | -   | 1372-- | L   | 1422-- | XFR | 1472-- | 0   |
| 1223-- | M   | 1273-- | XTO | 1323-- | C   | 1373-- | I   | 1423-- | 4   | 1473-- | H   |
| 1224-- | E   | 1274-- | b   | 1324-- | E   | 1374-- | F   | 1424-- | 9   | 1474-- | FMT |
| 1225-- | H   | 1275-- | FMT | 1325-- | H   | 1375-- | XTO | 1425-- | KEY | 1475-- | PNT |
| 1226-- | XTO | 1276-- | FMT | 1326-- | XTO | 1376-- | FMT | 1426-- | FMT | 1476-- | GTO |
| 1227-- | YTO | 1277-- | A   | 1327-- | E   | 1377-- | PNT | 1427-- | FMT | 1477-- | 1   |
| 1228-- | FMT | 1278-- | E   | 1328-- | a   | 1378-- | UP  | 1428-- | H   | 1478-- | 5   |
| 1229-- | XFR | 1279-- | a   | 1329-- | CNT | 1379-- | XFR | 1429-- | E   | 1479-- | 3   |
| 1230-- | 3   | 1280-- | 0   | 1330-- | 4   | 1380-- | 5   | 1430-- | XTO | 1480-- | 7   |
| 1231-- | 3   | 1281-- | CNT | 1331-- | a   | 1381-- | 0   | 1431-- | CNT | 1481-- | FMT |
| 1232-- | PNT | 1282-- | L   | 1332-- | E   | 1382-- | FMT | 1432-- | L   | 1482-- | FMT |
| 1233-- | a   | 1283-- | I   | 1333-- | YTO | 1383-- | FMT | 1433-- | I   | 1483-- | XTO |
| 1234-- | FMT | 1284-- | F   | 1334-- | YTO | 1384-- | YTO | 1434-- | F   | 1484-- | a   |
| 1235-- | FMT | 1285-- | XTO | 1335-- | .   | 1385-- | 1/2 | 1435-- | XTO | 1485-- | I   |
| 1236-- | XTO | 1286-- | FMT | 1336-- | FMT | 1386-- | H   | 1436-- | FMT | 1486-- | H   |
| 1237-- | a   | 1287-- | PNT | 1337-- | XFR | 1387-- | CNT | 1437-- | PNT | 1487-- | CNT |
| 1238-- | I   | 1288-- | XFR | 1338-- | 5   | 1388-- | E   | 1438-- | KEY | 1488-- | A   |
| 1239-- | M   | 1289-- | 2   | 1339-- | 4   | 1389-- | YE  | 1439-- | A   | 1489-- | H   |
| 1240-- | CNT | 1290-- | 1   | 1340-- | UP  | 1390-- | XTO | 1440-- | FMT | 1490-- | G   |
| 1241-- | A   | 1291-- | N   | 1341-- | XFR | 1391-- | a   | 1441-- | FMT | 1491-- | L   |
| 1242-- | H   | 1292-- | XFR | 1342-- | 5   | 1392-- | A   | 1442-- | XTO | 1492-- | E   |
| 1243-- | G   | 1293-- | 2   | 1343-- | +   | 1393-- | CNT | 1443-- | 0   | 1493-- | SFL |
| 1244-- | L   | 1294-- | 0   | 1344-- | DN  | 1394-- | IND | 1444-- | XTO | 1494-- | .   |
| 1245-- | E   | 1295-- | +   | 1345-- | PNT | 1395-- | XTO | 1445-- | A   | 1495-- | 2   |
| 1246-- | CNT | 1296-- | XFR | 1346-- | XFR | 1396-- | YTO | 1446-- | L   | 1496-- | CLR |
| 1247-- | 5   | 1297-- | 1   | 1347-- | 2   | 1397-- | .   | 1447-- | CNT | 1497-- | A   |
| 1248-- | XTO | 1298-- | 4   | 1348-- | FMT | 1398-- | FMT | 1448-- | F   | 1498-- | H   |
| 1249-- | C   | 1299-- | KEY | 1349-- | FMT | 1399-- | PNT | 1449-- | 0   | 1499-- | D   |

| STEP      | KEY | STEP      | KEY | STEP | KEY | STEP | KEY | STEP | KEY | STEP | KEY |
|-----------|-----|-----------|-----|------|-----|------|-----|------|-----|------|-----|
| 1500--CNT |     | 1550--XTO |     |      |     |      |     |      |     |      |     |
| 1501--CEX |     | 1551--CNT |     |      |     |      |     |      |     |      |     |
| 1502-- 0  |     | 1552-- π  |     |      |     |      |     |      |     |      |     |
| 1503--CNT |     | 1553-- α  |     |      |     |      |     |      |     |      |     |
| 1504--YTO |     | 1554-- 0  |     |      |     |      |     |      |     |      |     |
| 1505-- 0  |     | 1555-- B  |     |      |     |      |     |      |     |      |     |
| 1506-- α  |     | 1556-- .  |     |      |     |      |     |      |     |      |     |
| 1507-- 0  |     | 1557--CLR |     |      |     |      |     |      |     |      |     |
| 1508--XFR |     | 1558-- J  |     |      |     |      |     |      |     |      |     |
| 1509--CLX |     | 1559-- .  |     |      |     |      |     |      |     |      |     |
| 1510--CLR |     | 1560-- B  |     |      |     |      |     |      |     |      |     |
| 1511--XFR |     | 1561-- .  |     |      |     |      |     |      |     |      |     |
| 1512-- 0  |     | 1562--IND |     |      |     |      |     |      |     |      |     |
| 1513--1/X |     | 1563--CNT |     |      |     |      |     |      |     |      |     |
| 1514--CNT |     | 1564--CNT |     |      |     |      |     |      |     |      |     |
| 1515-- M  |     | 1565-- 7  |     |      |     |      |     |      |     |      |     |
| 1516--1/X |     | 1566-- 6  |     |      |     |      |     |      |     |      |     |
| 1517--YTO |     | 1567-- .  |     |      |     |      |     |      |     |      |     |
| 1518--XTO |     | 1568-- 0  |     |      |     |      |     |      |     |      |     |
| 1519--CNT |     | 1569-- 0  |     |      |     |      |     |      |     |      |     |
| 1520--YTO |     | 1570-- 4  |     |      |     |      |     |      |     |      |     |
| 1521--XTO |     | 1571--CLR |     |      |     |      |     |      |     |      |     |
| 1522-- A  |     | 1572--CLR |     |      |     |      |     |      |     |      |     |
| 1523-- α  |     | 1573--CLR |     |      |     |      |     |      |     |      |     |
| 1524--XTO |     | 1574--CLR |     |      |     |      |     |      |     |      |     |
| 1525--CLR |     | 1575--CLR |     |      |     |      |     |      |     |      |     |
| 1526-- 0  |     | 1576--FMT |     |      |     |      |     |      |     |      |     |
| 1527--INT |     | 1577--GTO |     |      |     |      |     |      |     |      |     |
| 1528-- E  |     | 1578-- 0  |     |      |     |      |     |      |     |      |     |
| 1529-- α  |     | 1579-- 0  |     |      |     |      |     |      |     |      |     |
| 1530--CNT |     | 1580-- 0  |     |      |     |      |     |      |     |      |     |
| 1531-- A  |     | 1581-- 0  |     |      |     |      |     |      |     |      |     |
| 1532-- G  |     | 1582--END |     |      |     |      |     |      |     |      |     |
| 1533-- A  |     |           |     |      |     |      |     |      |     |      |     |
| 1534-- I  |     |           |     |      |     |      |     |      |     |      |     |
| 1535-- H  |     |           |     |      |     |      |     |      |     |      |     |
| 1536--FMT |     |           |     |      |     |      |     |      |     |      |     |
| 1537-- K  |     |           |     |      |     |      |     |      |     |      |     |
| 1538--CLX |     |           |     |      |     |      |     |      |     |      |     |
| 1539--FMT |     |           |     |      |     |      |     |      |     |      |     |
| 1540--FMT |     |           |     |      |     |      |     |      |     |      |     |
| 1541-- α  |     |           |     |      |     |      |     |      |     |      |     |
| 1542-- E  |     |           |     |      |     |      |     |      |     |      |     |
| 1543-- A  |     |           |     |      |     |      |     |      |     |      |     |
| 1544-- D  |     |           |     |      |     |      |     |      |     |      |     |
| 1545--XFR |     |           |     |      |     |      |     |      |     |      |     |
| 1546--CNT |     |           |     |      |     |      |     |      |     |      |     |
| 1547-- N  |     |           |     |      |     |      |     |      |     |      |     |
| 1548-- E  |     |           |     |      |     |      |     |      |     |      |     |
| 1549-- YE |     |           |     |      |     |      |     |      |     |      |     |

# STORAGE REGISTERS

| STORAGE |                            |
|---------|----------------------------|
| b       | Temp.                      |
| a       | $\alpha$                   |
| 000     |                            |
| 001     | $W_B$                      |
| 002     | $L_G$                      |
| 003     | $m$                        |
| 004     | $\eta$                     |
| 005     | $k$                        |
| 006     | $S$                        |
| 007     | $\bar{L}$                  |
| 008     | $\bar{C}$                  |
| 009     |                            |
| 010     | $Z_B$                      |
| 011     | Wind, fps                  |
| 012     | $\rho_0, \text{slug/ft}^3$ |
| 013     | $\rho, "$                  |
| 014     | $K = g \sqrt{V_B^{4/3}}$   |
| 015     |                            |
| 016     |                            |
| 017     |                            |
| 018     |                            |
| 019     | $dC_L/d\alpha$             |
| 020     | $C_{p0}$                   |
| 021     | $dC_D/d\alpha^2$           |
| 022     |                            |
| 023     |                            |
| 024     |                            |
| 025     |                            |
| 026     |                            |
| 027     |                            |
| 028     |                            |
| 029     | Aero Mom                   |
| 030     | Mech. Mom                  |
| 031     | Extras Mom                 |
| 032     | $\Sigma$ Mom               |
| 033     | $\mu$                      |
| 034     | Sp. Lift, s.t.             |
| 035     | $a_0$                      |
| 036     | $a_1$ } $X_{CB}$           |
| 037     | $a_2$ }                    |
| 038     | $a_0$ } $P/P_0$            |
| 039     | $a_1$ } $1/\rho$           |

|     |                            |
|-----|----------------------------|
| 040 | $Y_{CB}/\bar{C}$           |
| 041 | $\sqrt{V_B^{2/3}}$         |
| 042 | $V_B$                      |
| 043 | $\Delta\alpha$ Trigger     |
| 044 | Prev. $\Delta\alpha$       |
| 045 | 2nd Prev. $\Delta\alpha$   |
| 046 | $\Delta\alpha$ Trigger     |
| 047 | Prev. $\Delta\alpha$       |
| 048 | 2nd Prev. $\Delta\alpha$   |
| 049 | Temp.                      |
| 050 | $\Sigma Wt. \text{ EXTRA}$ |
| 051 | $\Sigma Wt. (X-X^0)$       |
| 052 | $\Sigma Wt. (Y-Y^0)$       |
| 053 |                            |
| 054 | $X^{CP} = 26.6$            |
| 055 | $Y^{CP} = -31.9$           |
| 056 |                            |
| 057 |                            |
| 058 |                            |
| 059 |                            |
| 060 |                            |
| 061 | $X_0/\bar{C}$ } 1          |
| 062 | $dX/\bar{C}/d\alpha$       |
| 063 | $X_{CB}/\bar{C}$ } 2       |
| 064 | $dX/\bar{C}/d\alpha$       |
| 065 | $X_{CB}/\bar{C}$ } 3       |
| 066 | $dX/\bar{C}/d\alpha$       |
| 067 | $X_{CB}/\bar{C}$ } 4       |
| 068 | $dX/\bar{C}/d\alpha$       |
| 069 | $X_{CB}/\bar{C}$ } 5       |
| 070 | $dX/\bar{C}/d\alpha$       |
| 071 |                            |
| 072 |                            |
| 073 |                            |
| 074 |                            |
| 075 |                            |
| 076 |                            |
| 077 |                            |
| 078 |                            |
| 079 |                            |

|     |  |
|-----|--|
| 080 |  |
| 081 |  |
| 082 |  |
| 083 |  |
| 084 |  |
| 085 |  |
| 086 |  |
| 087 |  |
| 088 |  |
| 089 |  |
| 090 |  |
| 091 |  |
| 092 |  |
| 093 |  |
| 094 |  |
| 095 |  |
| 096 |  |
| 097 |  |
| 098 |  |
| 099 |  |
| 100 |  |
| 101 |  |
| 102 |  |
| 103 |  |
| 104 |  |
| 105 |  |
| 106 |  |
| 107 |  |
| 108 |  |

### 3.4.7 SAMPLE INPUT/OUTPUT PRINT

The following copy of the HP Printed Tape shows a typical problem and solution. For a discussion of the particulars of this problem, see Section 4.

|                  |                  |
|------------------|------------------|
| PROG.#76.004     |                  |
| TRIM,DESIGN ALT. |                  |
| FAM.2 T.BALLOON  |                  |
| VOL.             |                  |
| 45000.000*       |                  |
| WEIGHT           |                  |
| 970.000*         |                  |
| LENGTH HULL      |                  |
| 83.700*          |                  |
| X-CONF.PT.       |                  |
| 26.600*          |                  |
| Y-CONF.PT        |                  |
| -31.900*         |                  |
| X,Y CG-,M,H,S    |                  |
| 57.300*          |                  |
| -2.500*          |                  |
| 30.700           |                  |
| 29.400           |                  |
| 31.900           |                  |
| IF NO EXTRA MTS  |                  |
| ENT.# IN X       |                  |
| OTHERWISE,ENTER  |                  |
| MT.IN Z,Y IN Y   |                  |
| AND X IN X       |                  |
| ENT.# IN X AFTER |                  |
| ENTRIES COMPLETE |                  |
| 250.000          |                  |
| -31.900          |                  |
| 26.600           |                  |
| ALT.FT.NSL       |                  |
| 14000.000*       |                  |
| WIND,KNOTS       |                  |
| 25.000*          |                  |
| GUESS TRIM ANGLE |                  |
| 10.000*          |                  |
| DYN.PPRESS       |                  |
| 1.379            |                  |
| P                |                  |
| 20.758           |                  |
| T                |                  |
| 8.581            |                  |
| U                |                  |
| 30.204           |                  |
|                  | MECH.MOMENT      |
|                  | 8694.528         |
|                  | AERO.MOM.        |
|                  | -8718.038        |
|                  | EXTRAS MOM.      |
|                  | 0.000            |
|                  | SUM OF MOMENTS   |
|                  | -23.510          |
|                  | TRIM ANGLE ATCK  |
|                  | 7.570            |
|                  | CL               |
|                  | 0.371            |
|                  | AERO LIFT        |
|                  | 647.052          |
|                  | CD               |
|                  | 0.147            |
|                  | DRAG             |
|                  | 255.881          |
|                  | X-CENTER PRESS.  |
|                  | 47.358           |
|                  | GROSS LIFT       |
|                  | 1934.101         |
|                  | TOT.LIFT         |
|                  | 2581.153         |
|                  | SUM EXTRA MTS.   |
|                  | 250.000          |
|                  | TOTAL WEIGHT     |
|                  | 1220.000         |
|                  | NET LIFT         |
|                  | 1361.153         |
|                  | TOTAL FORCE      |
|                  | 1384.996         |
|                  | ANGLE TO HORIZON |
|                  | 79.353           |
|                  | READY NEXT PROG. |
|                  | J.B.M 76.004     |

### 3.4.8 NOTES

A. If incorrect data is entered, do not press STOP END to restart program. For proper restart, clearing all registers, press the following:

```
STOP
GO TO
1
5
3
7
CONT
```

B. Extra weight entry, STOPS 8, can also be used to include the payload if desired. It will not affect the trim angle if located at the confluence point.

|               |          |          |        |
|---------------|----------|----------|--------|
|               | (X)      | (Y)      | (Z)    |
|               | $X^{CP}$ | $Y^{CP}$ | $Wt_p$ |
| Stop 8, Enter |          |          |        |

It will affect the net lift and hence the total force and its angle.

C. This program was written for a Family-2 Balloon Design. It was tailored for a 45,000 CF size with several constants for this size built into the program. Should any of these differ when an actual 45,000 CF balloon is flown and measurements made, the following table indicates what step/numbers in the program should be changed. The table also indicates the changes required to make a universal program for any size Family-2 balloon.

| Step No. | As Written |                 | To Modify for Continued 45,000 CF Use |        | To Generalize for any Size Family-2 |                   |
|----------|------------|-----------------|---------------------------------------|--------|-------------------------------------|-------------------|
|          | Key        |                 | Key                                   |        | Key                                 |                   |
| 0363     | 2          | X of Confluence | n                                     | Insert | 4                                   | Stop No. 4        |
| 0364     | 6          | Point = 26.6 ft | n                                     | Mod.   | ↑                                   |                   |
| 0356     | .          | = $X^{CP}$      | .                                     | Dist.  | ↑                                   |                   |
| 0366     | 6          |                 | n                                     |        | STOP                                | Ent $X^{CP}$ in X |
| 0384     | 3          | Y of Confluence | n                                     | Insert | 5                                   | Stop No. 5        |
| 0385     | 1          | Point = 31.9 ft | n                                     | Mod.   | ↑                                   |                   |
| 0386     | .          | = $Y^{CP}$      | .                                     | Dist   | ↑                                   |                   |
| 0387     | 9          |                 | n                                     |        | ↑                                   |                   |
| 0388     | ChgS       |                 | ChgS                                  |        | STOP                                | Ent $Y^{CP}$ in X |

| <u>As Written</u> |                     | <u>To Modify for Continued 45,000 CU Use</u> |  | <u>To Generalize for any Size Family-2</u> |                   |
|-------------------|---------------------|----------------------------------------------|--|--------------------------------------------|-------------------|
| <u>Step No.</u>   | <u>Key</u>          | <u>Key</u>                                   |  | <u>Key</u>                                 |                   |
| 0410              | 5 X of Center of    | n Insert                                     |  | 6                                          | Stop No. 6        |
| 0411              | 7 Gravity = 57.3 ft | n Mod.                                       |  | ↑                                          |                   |
| 0412              | • = $X_{CG}$        | • Dist.                                      |  | ↑                                          |                   |
| 0413              | 3                   | n                                            |  | STOP                                       | Ent $X_{CG}$ in X |
| 0417              | 2 Y of Center of    | n Insert                                     |  | 7                                          | Stop No. 7        |
| 0418              | • Gravity = 2.5 ft  | • Mod.                                       |  | ↑                                          |                   |
| 0419              | 5 = $Y_{CG}$        | n Dist.                                      |  | ↑                                          |                   |
| 0420              | ChgS                | n(or ChgS)                                   |  | STOP                                       | Ent $Y_{CG}$ in X |

D. Conversely, several parameters left as entries might be desired as fixed inputs when only one specific 45,000 CF balloon (or other size) is being investigated. The volume, weight, and envelope length may be fixed by the following key-strokes

| Step No. | Key             | Step No. | Key               | Step No. | Key |
|----------|-----------------|----------|-------------------|----------|-----|
| 0030     | n               | 0316     | $X \rightarrow Y$ | 0332     | 1   |
| 0301     | n               | 0317     | $X^Y$             | 0333     | PNT |
| 0302     | n               | 0318     | $X \rightarrow$   | 0334     | FMT |
| 0303     | n               | 0319     | 4                 | 0335     | FMT |
| 0304     | n               | 0320     | 1                 | 0336     | H   |
| 0305     | n               | 0321     | FMT               | 0337     | U   |
| 0306     | $X \rightarrow$ | 0322     | FMT               | 0338     | L   |
| 0307     | 4               | 0323     | W                 | 0339     | L   |
| 0308     | 2               | 0324     | T                 | 0340     | FMT |
| 0309     | PNT             | 0325     | •                 | 0341     | n   |
| 0310     | ↑               | 0326     | FMT               | 0342     | n   |
| 0311     | 2               | 0327     | n                 | 0343     | n   |
| 0312     | ↑               | 0328     | n                 | 0344     | n   |
| 0313     | 3               | 0329     | n                 | 0345     | n   |
| 0314     | ÷               | 0330     | n                 | 0346     | n   |
| 0315     | ↓               | 0331     | $X \rightarrow$   |          |     |

If a volume other than 45,000 CF was being considered, the modifications shown in Note C must also be made.

### 3.5 Program 76.005 — FAMILY-2 Tethered Balloon Trim, Variable Altitude and Wind Profiles

#### 3.5.1 GENERAL DESCRIPTION

A type of tethered balloon, called the FAMILY-2, has an aerodynamic shape and two vertical and two horizontal fins. During its development model wind-tunnel and full scale static and flight tests were made in extensive detail. References 1 and 2 provide a sufficient amount of information on a 200,000 CF system to write a trim equation with more exact constants than any other balloon now available.

Program No. 76.005 (and 76.004) were approached with the idea of providing a quick solution to trim problems as well as inputs to the tether-cable program. They were tailored for a 45,000 CF balloon which the AFGL will receive in 1976. However, they can be easily converted into a completely general program as explained in Section 3.5.8.

Program No. 76.004 is concerned with the condition where the balloon is completely filled with gas, that is, its ballonnet is empty. It will be called the design condition. Program No. 76.005 was designed to accommodate both the design condition as well as other conditions at lower altitudes where the ballonnet is in various stages of air inflation.

Due to the extensive measurements made with the 200,000 CF FAMILY-2 balloon by the Range Measurements Lab of the Air Force Eastern Test Range, it was possible to obtain data which allowed use of the balloon center-of-pressure. Like the neutral-point, it is defined as the point where the pitching-moment is zero. This permits the elimination of one term in the moment equation developed under Program No. 76.003 where a fixed aerodynamic center was utilized. The longitudinal variation of CP with trim angle was computed in non-dimensional form.

Since the RML balloon features a large windscreen to cover its payload and the more general balloon being considered does not have a windscreen, the differences in aerodynamic characteristics had to be obtained from wind-tunnel tests of the two designs. Since flight data differed significantly from wind-tunnel data, the delta windscreen effects were applied to the flight data to obtain the full scale aerodynamic characteristics of a FAMILY-2 balloon without windscreen.

The center of buoyancy location was non-dimensionalized from flight measurements of the RML balloon assuming that the windscreen has no effect. The vertical location is a straight line function of trim angle-of-attack. However, the longitudinal location is a function of both trim angle and ballonnet fullness. For the case of an empty ballonnet, a curve-fit with a correlation of 0.99 was possible. This fit is used in Program No. 76.004, the design condition.

For the general case, Program No. 76.005, a complete fit of all four measured cases (Ballonnet Empty, 1/3 full, 2/3 full, and full) which is within the scope

of this computer program, was more difficult and permits larger errors than the design case. An error in the longitudinal position of the center-of-buoyancy of up to 0.3 ft in a balloon having an envelope length of 100 ft is an outer limit. Uncertainties in other balloon or atmospheric parameters could be larger sources of error. However, the effect of the center of buoyancy error can be noted where design conditions from the output from Program No. 76.004 and from the first output group from Program No. 76.005 are compared.

In Program No. 76.005 ballonnet fullness is computed at each lower altitude on the assumption that the initial flight altitude entered is the design altitude where the ballonnet is empty. Computations are first made for the design altitude, then proceed downward at delta-altitude increments to, and including, the surface altitude. No check on the ballonnet's ability to handle the total altitude excursion is made within this program. Therefore as an initial step, Program No. 76.001 can be utilized to obtain both the no-wind buoyancy/weight balance as well as the acceptability of the altitude excursion by the ballonnet.

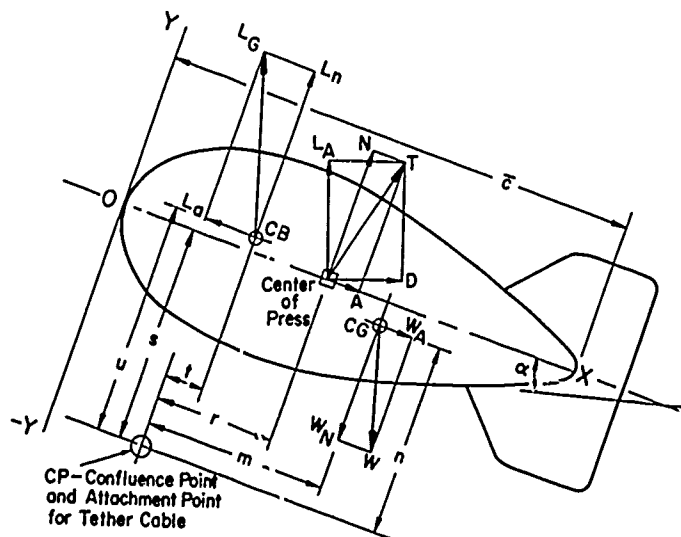
### 3.5.2 DEVELOPMENT OF PROGRAM AND EQUATIONS

**This case covers a specific tethered balloon type wherein:**

- a. the location of the aerodynamic center of pressure ( $C_M = 0$ ) is known and can be utilized rather than an arbitrary fixed aerodynamic reference center ( $C_M \neq 0$ ).
  - b. the fore and aft location of the center of pressure varies with angle of attack,  $\alpha$ .
  - c. the location of the center of buoyancy varies with  $\alpha$  and the "fullness" of the balloonet.
  - d. the balloon will be flown at the design altitude (balloonet empty) and at lower altitudes, where the balloonet fills with air as the gas volume decreases.
- A. The object of the program is to determine the trim conditions of the balloon and the total force and its angle which must be resisted by the tether-cable. The tether cable is attached at the confluence point of the multiple flying lines attached to the balloon's skin. Hence at trim:

$$\Sigma \text{ Moments at Confluence Point} = 0$$

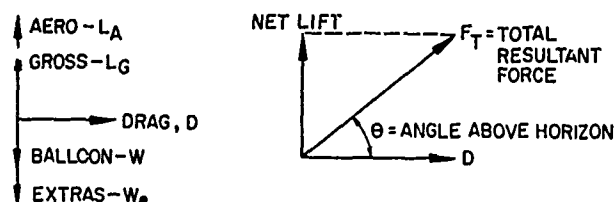
**Positive moments are clockwise**



The moment Eq. (10) developed for Program 76.003 in Section 3.3.2 is applicable here provided the aerodynamic pitching-moment is removed. The equation then becomes:

$$\begin{aligned}
 0 &= mW - tL + \tan \alpha (mW - uL) && \text{(Mech. Mom.)} \\
 &- K [ra \alpha - sb - sc\alpha^2 + \tan \alpha (sa \alpha + rb + rc\alpha^2)] && \text{(Aero Mom.)} \\
 &+ \cos \alpha [\Sigma W_e (x - x^{CP}) + \tan \alpha \Sigma W_e (y - y^{CP})] && \text{(Extras Mom.)}
 \end{aligned}$$

B. After solving for  $\alpha_{trim}$  the Aero Lift ( $L_A$ ) and Drag, can be calculated and used with buoyancy and Mass terms to obtain total Resultant Force ( $F_T$ ) and angle ( $\theta$ ) at the Confluence Point.



C. Use 2 constant form for density ratio (same in all programs)

$$\frac{\ln \rho / \rho_o}{Z} = a_o + a_1 a$$

where

$$\begin{aligned}
 a_1 &= -1.7772^{-10} \\
 a_o &= -2.81361^{-5}
 \end{aligned}$$

D. For 45,000 CF Balloon, let

$$X_{CG} = 57.3 \text{ ft}$$

$$Y_{CG} = -2.5$$

$$X^{CP} = 26.6$$

$$Y^{CP} = -31.9$$

$$s = 31.9$$

$$\bar{c} = 83.7$$

Built into program.  
See Notes to change to  
entry quantities or to  
change values

CG Location assumed unchanged with  $\alpha$  variation. RML tests for CG were made with empty ballonnet and therefore best for design condition.

E. Center of Buoyancy - All Ballonet Conditions

$$\text{Hull length} = \bar{c}$$

From Reference 1,  $\frac{Y_{CB}}{c}$  varies as a straight line between two conditions;

$$\frac{Y_{CB}}{c} = .00363 \text{ Ballonet Empty}$$

$$\frac{Y_{CB}}{c} = .06178 \text{ Ballonet Full}$$

$$\frac{Y_{CB}}{c} = .00363 + .05815 \gamma$$

where

$\gamma$  = Ballonet Fullness Fraction

Using Reference 1 measured data, Figure E4-10, the following equation permitted a reasonable fit to that curve presented.

$$\frac{X_{CB}}{c} = A_0 + f_0 \alpha + f_1 \alpha \gamma + f_2 \alpha \gamma^2 + g_0 \alpha^2 + g_1 \alpha^2 \gamma + g_2 \alpha^2 \gamma^2 + g_3 \alpha^2 \gamma^3$$

where

|                  |                   |
|------------------|-------------------|
| $A_0 = .427$     | $g_0 = .00004389$ |
| $f_0 = -.001030$ | $g_1 = .00005097$ |
| $f_1 = -.005411$ | $g_2 = .0002048$  |
| $f_2 = .004689$  | $g_3 = .0001692$  |

F. Aero Coefficients - Flight data corrected for no windscreen by difference in wind-tunnel data with and without windscreen.

a.  $C_L = .049 \alpha$  or  $dC_L/d\alpha = .049$

b.  $C_D = .106 + .00071 \alpha^2 = C_{D0} + \frac{dC_D}{d\alpha} \alpha^2$

$C_{D0} = .106$  = minimum drag at  $\alpha = 0$

$dC_D/d\alpha^2 = .00071$

c.  $\frac{Y_{CP}}{c} = 0$

d.  $\frac{X_{CP}}{c}$  from W.T. tests w/o windscreen. A series of straight lines is used to define the variation of  $X_{CP}/c$  with  $\alpha$ .

| Region | $\alpha$ Base | $\left(\frac{X_{CP}}{c}\right)$ Base | $\frac{d \frac{X_{CP}}{c}}{d\alpha}$ | $\alpha$ Range |
|--------|---------------|--------------------------------------|--------------------------------------|----------------|
| 1      | 0             | .657                                 | .2691                                | 0 - .55        |
| 2      | .55           | .805                                 | -.4350                               | .55 - 1.35     |
| 3      | 1.35          | .457                                 | .1229                                | 1.35 - 1.7     |
| 4      | 1.7           | .50                                  | .01395                               | 1.7 - 6.0      |
| 5      | 6.0           | .56                                  | .00370                               | 6.0 - 26+      |
|        | 26.0          | .634                                 |                                      |                |

$$\frac{X_{CP}}{c} = \left(\frac{X_{CP}}{c}\right)_{\text{Base}} + \frac{d \frac{X_{CP}}{c}}{d\alpha} (\alpha - \alpha_{\text{Base}})$$

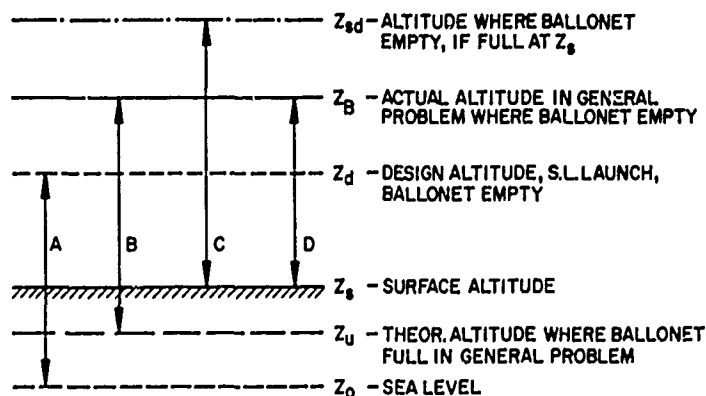
#### G. Ballonet Fullness Fraction

Let  $V_B$  = volume of balloon

$v$  = Volume of Ballonet

By definition:  $\frac{V_B - v}{V_B} = \frac{\rho_d}{\rho_0}$  which defines the maximum or design altitude which is accommodated by a ballonet of a given volume in a flight from an altitude,  $Z_O$ , where it is full of air.

(1)  $v = V_B \left(1 - \frac{\rho_d}{\rho_0}\right)$ , a fixed quantity for a given balloon. In actual use, there is a greater probability that the balloon will not be flown from  $Z_O$  (Sea Level). It would probably be flown from a ground station above sea level and thus have a maximum altitude higher than if launched from sea level. More typically, the full range of flight altitude required in a project might not require the full capability of the ballonet, that is, an empty ballonet at design or maximum altitude but a partially full condition at the surface. These various flight conditions are illustrated below.



Cases A, B, and C above represent the full range of altitudes a balloon can traverse with a given fixed ballonnet size, that is, the density ratio:

$$(2) \frac{\rho_d}{\rho_o} = \frac{\rho_B}{\rho_u} = \frac{\rho_{sd}}{\rho_s}$$

Case D is the more general case where the full capability of the ballonnet may not be required, that is, the ballonnet not full at  $Z_s$ .

To obtain a relationship for the variation of ballonnet volume with altitude consider:

Volume of gas at Sea Level =  $V_B \frac{\rho_d}{\rho_o}$ , which expands to:

Volume of gas at  $Z_d = V_B \frac{\rho_d}{\rho_d} = V_B$

In general, Volume of gas at  $Z = V_B \frac{\rho_d}{\rho_Z} = V_B \frac{\rho_d}{\rho_o} \frac{\rho_o}{\rho_Z}$

So, Volume of Ballonnet =  $V_B - \text{Vol of Gas}$

$$(3) v = V_B - V_B \frac{\rho_d}{\rho_o} \frac{\rho_o}{\rho_Z} = V_B (1 - \frac{\rho_d}{\rho_o} \frac{\rho_o}{\rho_Z})$$

At  $Z = 0$ ,  $v = V_B (1 - \frac{\rho_d}{\rho_o})$ , Ballonnet Full by Eq. (1) Definition

At  $Z = Z_d$ ,  $v = V_B (1 - 1) = 0$ , Ballonnet Empty

Therefore if  $\gamma = \text{Ballonnet Fullness Fraction}$ :

$$(4) \gamma = \frac{v_Z}{v_o} = \frac{V_B (1 - \frac{\rho_d}{\rho_o} \frac{\rho_o}{\rho_Z})}{V_B (1 - \frac{\rho_d}{\rho_o})} = \frac{1 - \frac{\rho_d}{\rho_o} \frac{\rho_o}{\rho_Z}}{1 - \rho_d / \rho_o}$$

To cover the general Case D above, the following is an equivalent definition:

$$\gamma = \frac{v_Z}{v_u} = \frac{1 - \frac{\rho_B}{\rho_u} \frac{\rho_u}{\rho_Z}}{1 - \frac{\rho_B}{\rho_u}}$$

but by the definitions in Eq. (2) above  $\frac{\rho_B}{\rho_u} = \frac{\rho_d}{\rho_o}$

$$\gamma = \frac{1 - \frac{\rho_d}{\rho_o} \frac{\rho_u}{\rho_Z}}{1 - \frac{\rho_d}{\rho_o}}$$

However, since the computer program evaluates density relationships,  $\rho/\rho_o$ , the use of  $\rho_u/\rho_Z$  is undesirable. Making use of Eq. (2) relationships,

$$\frac{\rho_d}{\rho_o} \frac{\rho_u}{\rho_Z} = \frac{\rho_d}{\rho_o} \frac{\rho_o}{\rho_Z} \frac{\rho_u}{\rho_o} \text{ and } \frac{\rho_u}{\rho_o} = \frac{\rho_B}{\rho_d}$$

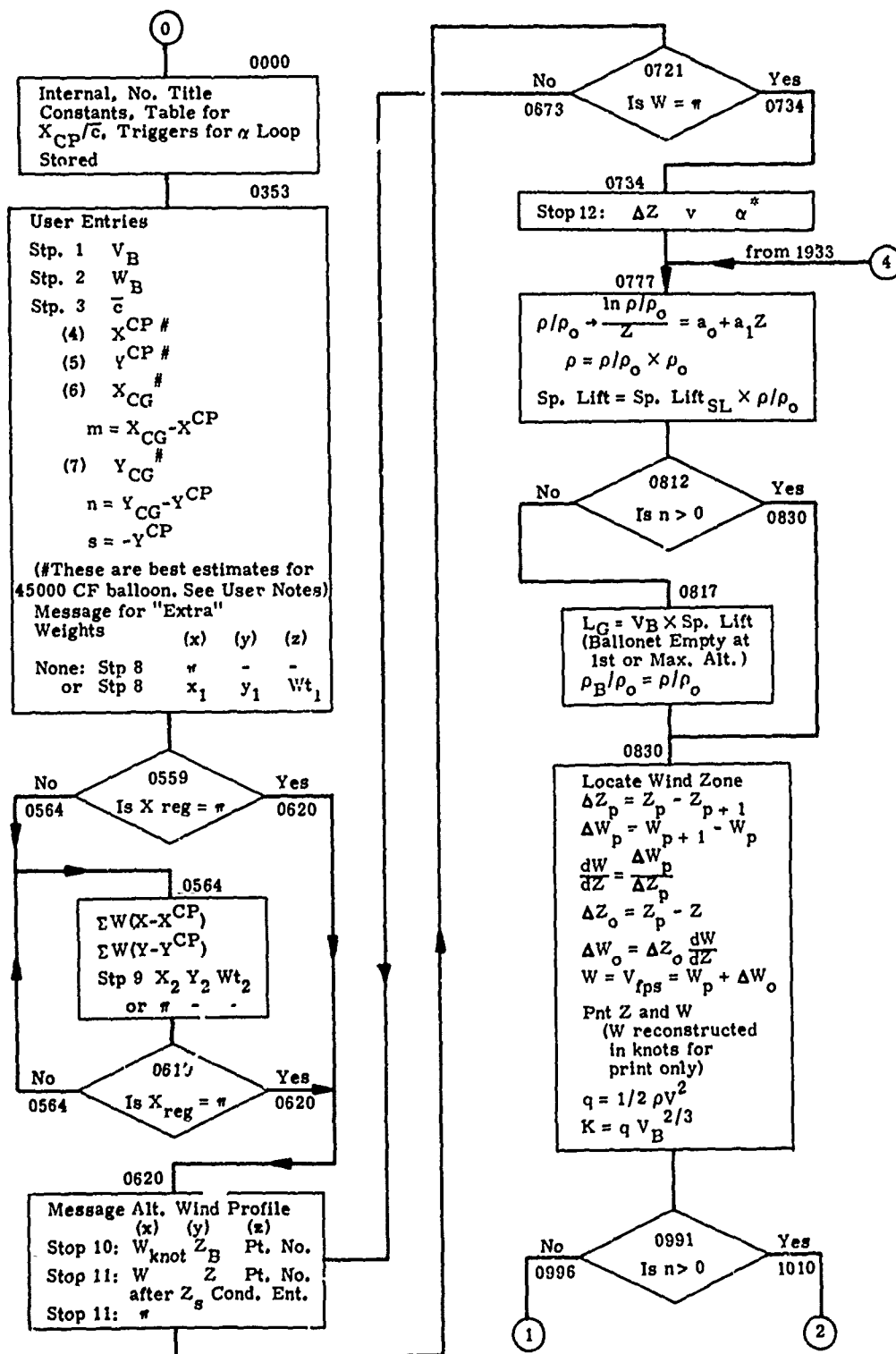
$$\frac{\rho_d}{\rho_o} \frac{\rho_u}{\rho_Z} = \frac{\rho_d}{\rho_o} \frac{\rho_o}{\rho_Z} \frac{\rho_B}{\rho_o} \frac{\rho_o}{\rho_d} = \frac{\rho_o}{\rho_Z} \frac{\rho_B}{\rho_o}$$

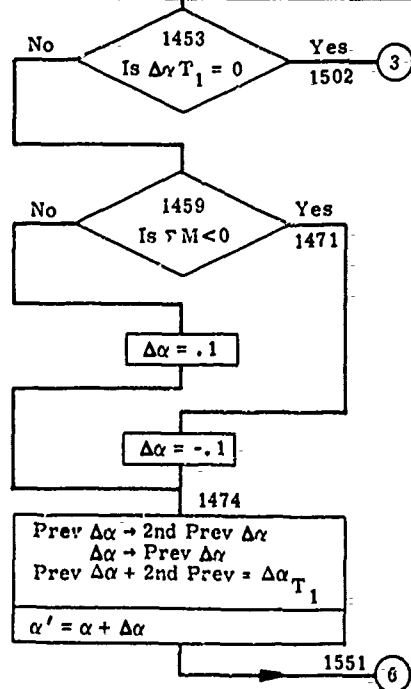
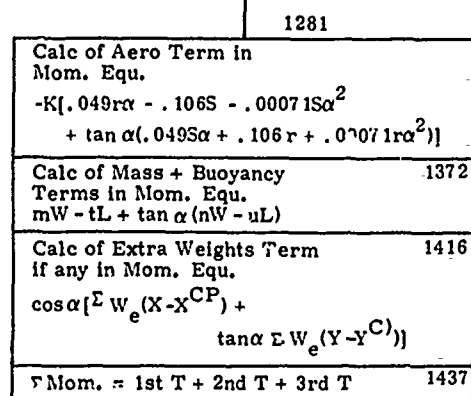
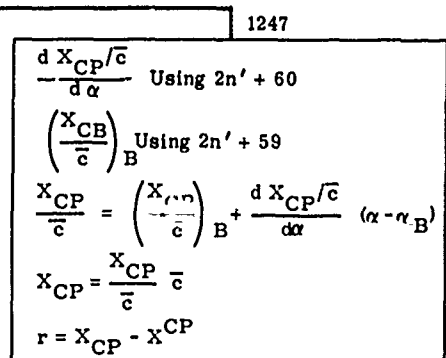
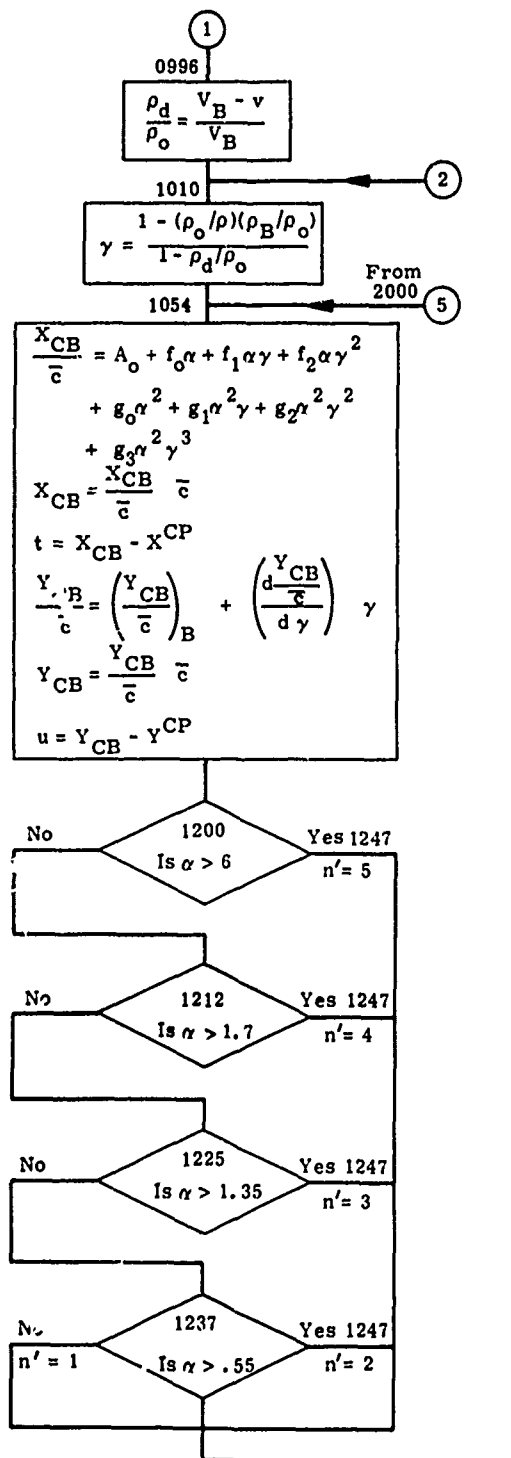
$$(5) \quad \gamma = \frac{1 - \frac{\rho_o}{\rho_Z} \frac{\rho_B}{\rho_o}}{1 - \frac{\rho_d}{\rho_o}}$$

Therefore, program is designed to:

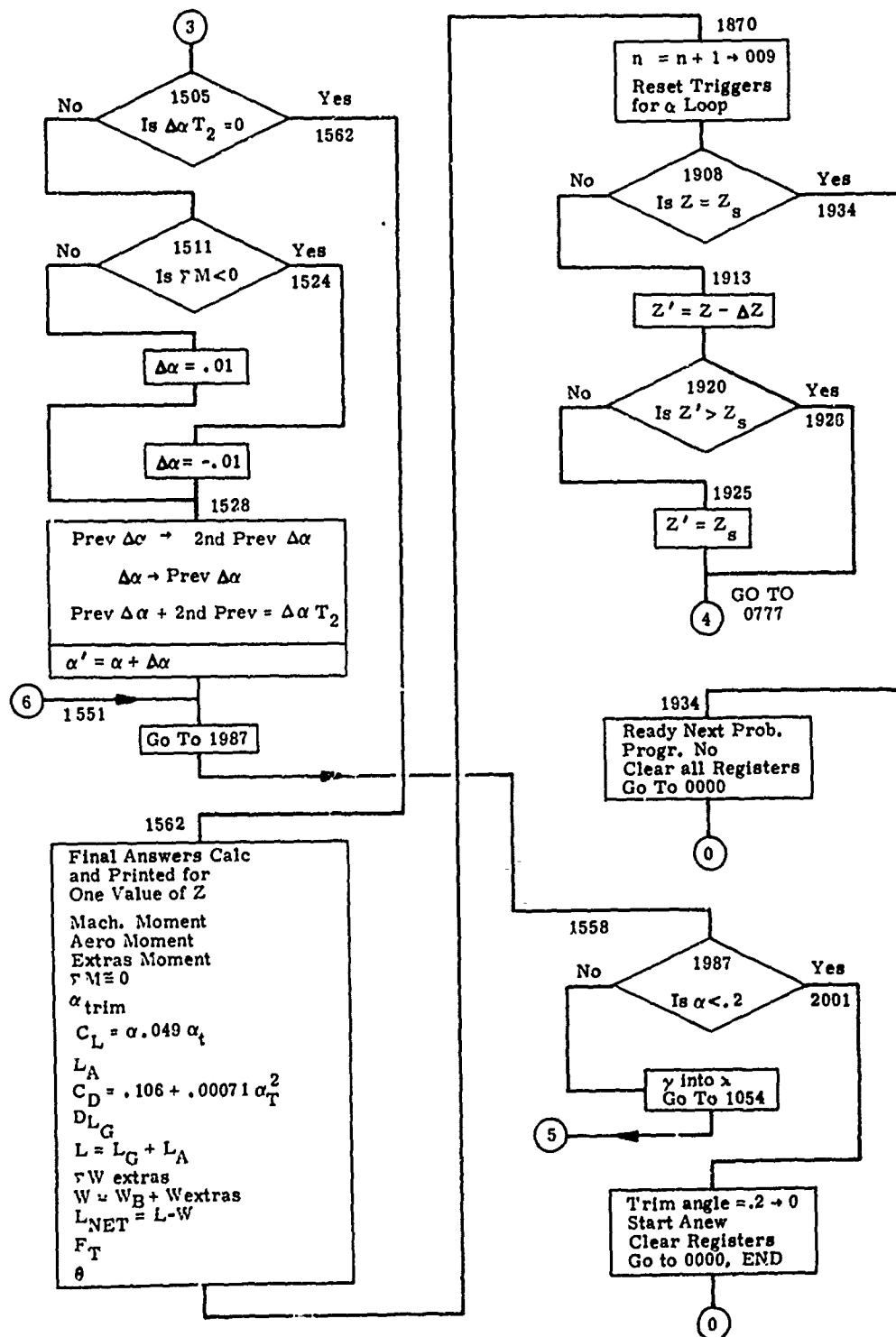
- a. Obtain  $\rho_d/\rho_o$  from Eq. (1)
- b. Obtain  $\rho_B/\rho_o$  from first or highest altitude calculation  
where ballonet is empty,  $\gamma = 0$
- c. Obtain  $\rho_Z/\rho_o$  computed at each lower altitude.

### 3.5.3 FLOW CHART





Note: In flow chart, n is also used as altitude point counter, n for CP region number, and p for wind profile point number.



### 3.5.4 OPERATING INSTRUCTIONS

| <u>KEY STROKES</u>                                                                                                                       | <u>ENTRIES</u> |       |             | <u>PRINTS</u>                                                                                                             |
|------------------------------------------------------------------------------------------------------------------------------------------|----------------|-------|-------------|---------------------------------------------------------------------------------------------------------------------------|
| RUN                                                                                                                                      |                |       |             |                                                                                                                           |
| END                                                                                                                                      |                |       |             |                                                                                                                           |
| FIX, 2, 3, ----                                                                                                                          |                |       |             | (No. of desired decimal places)                                                                                           |
| CONT                                                                                                                                     | (X)            | (Y)   | (Z)         | Program No. and Title                                                                                                     |
| Stop 1, Enter:                                                                                                                           | $V_B$          | —     | —           | $V_B$ , Balloon Volume, CF                                                                                                |
| CONT                                                                                                                                     |                |       |             |                                                                                                                           |
| Stop 2, Enter:                                                                                                                           | $W_B$          | —     | —           | $W_B$ , Balloon Weight, lb                                                                                                |
| CONT                                                                                                                                     |                |       |             |                                                                                                                           |
| Stop 3, Enter:                                                                                                                           | $\bar{c}$      | —     | —           | $\bar{c}$ , Length, Hill ft                                                                                               |
| (Stops 4, 5, 6, and 7 not in program as written. See notes for optional use of these for $X^{CP}$ , $Y^{CP}$ , $X_{CG}$ , and $Y_{CG}$ ) |                |       |             | See notes for optional                                                                                                    |
|                                                                                                                                          |                |       |             | Directions for "Extra" weights:                                                                                           |
|                                                                                                                                          |                |       |             | Ent. $\pi$ in x if none.                                                                                                  |
|                                                                                                                                          |                |       |             | Ent. Wt in Z, y in Y, x in X.                                                                                             |
|                                                                                                                                          |                |       |             | Ent. $\pi$ in X after all entries made.                                                                                   |
| Stop 8, Enter $\pi$ or:                                                                                                                  | $X_1$          | $Y_1$ | $W_1$       |                                                                                                                           |
| CONT                                                                                                                                     |                |       |             | $W_1$ (if entered)<br>$Y_1$ (if entered)<br>$X_1$ (if entered)                                                            |
| (If $\pi$ goes to Stop 10)                                                                                                               |                |       |             |                                                                                                                           |
| Stop 9, Enter $\pi$ or:                                                                                                                  | $X_2$          | $Y_2$ | $W_2$       |                                                                                                                           |
| CONT                                                                                                                                     |                |       |             | $W_2$ (if entered)<br>$Y_2$ (if entered)<br>$X_2$ (if entered)                                                            |
| (If $\pi$ goes to Stop 10)                                                                                                               |                |       |             |                                                                                                                           |
|                                                                                                                                          |                |       |             | Directions for Alt-Wind Profile:                                                                                          |
|                                                                                                                                          |                |       |             | Ent. $\pi$ in x after surface entry. [First Entries at Stop 10 must be Pt. No. for Max Balloon Altitude (Empty Ballonet)] |
| Stop 10, Enter:                                                                                                                          | $W$            | $Z_B$ | Pt. No. = 1 | 1, Pt. No.<br>$Z_B$ , Max Balloon Alt, ft MSL                                                                             |
| CONT                                                                                                                                     |                |       |             | $W$ , Wind, Knots                                                                                                         |
| Stop 11, Enter:                                                                                                                          | $W$            | $Z$   | Pt. No.     | Pt. No.<br>$Z$ , Alt, ft                                                                                                  |
| CONT                                                                                                                                     |                |       |             | $W$ , Wind, Knots                                                                                                         |

(After  $Z_s$  is entered)

Stop 11, Enter:  $\pi$  — —  
 CONT  
 Stop 12, Enter:  $\Delta Z$   $v$   $\alpha$   
 CONT

$\alpha$ , Guess trim angle, Deg  
 $v$ , Balloonet volume, CF  
 $\Delta Z$ , Desired decrements in  
 Alt, ft

(Program begins computations)

ALT  
 $Z$ , ft  
 WIND  
 $W$ , Knots  
 DYN. PRES.  
 $q$ , lb/ft<sup>2</sup>  
 BALLOONET FULLNESS  
 $\gamma$

Pause in  $\alpha$ -trim loop, step 1552,  $\alpha$  in X reg. and  $\gamma$  Moments in Y and Z as search  
 is made for  $\alpha$  trim where  $\gamma$  Moments = 0. When found, printouts then occur as  
 follows:

MECH. MOM.  
 Value of Mech. Moment,  
 ft-lb  
 AERO MOM.  
 Value of Aero Moment,  
 ft-lb  
 EXTRAS MOM.  
 Value of Extras Moment,  
 ft-lb  
 SUM OF MOM.  
 $\Sigma$  Moments  $\approx 0$   
 TRIM ANGLE ATCK  
 $\alpha$ , deg  
 $C_L$   $C_L$   
 AERO LIFT  
 $L_A$ , lb  
 $C_D$   $C_D$   
 DRAG  
 $D$ , lb  
 GROSS BUOY. LIFT  
 $L_G$ , lb  
 TOT. LIFT  
 $L = L_A + L_G$ , lb  
 SUM "EXTRA" WTS  
 $\Sigma W_{extra}$ , lb  
 TOT. WEIGHT  
 $W = W_B + \Sigma W_{extra}$ , lb  
 NET LIFT  
 $L_N = L - W$ , lb

TOTAL FORCE

$$F_T = \sqrt{L_N^2 + D^2}, \text{ lb}$$

ANGLE TO HORIZON

$$\theta = \arctan L_N/D, \text{ deg}$$

Program now brings Balloon down  $\Delta Z$  in altitude, recomputes wind,  $q$  and ballonnet fullness and goes through another  $\alpha$  trim search. When a  $Z$  value less than  $Z$ -surface is reached,  $Z$ -surface is substituted and the surface conditions are the last block of computed data. Completion is indicated by following:

Ready Next Problem

J.B.W. 76-005

A new set of data can now be entered at first stop in program after repeat of Title and number.

### 3.5.5. SAMPLE INPUT DATA FORM

| INPUT                                                                                                                                                                                                    |            |       | 76.002, 76.003, 76.004, and 76.005                                                                                                                                |    |                                                                                                                                                               |    |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|----|---------------------------------------------------------------------------------------------------------------------------------------------------------------|----|
|                                                                                                                                                                                                          |            |       | 76.003, 76.004, 76.005<br>EXTRA WEIGHT TABLE                                                                                                                      |    | 76.003 and 76.005<br>WIND PROFILE*                                                                                                                            |    |
| Balloon Volume                                                                                                                                                                                           | $V_B$      | cu ft | $W_1$                                                                                                                                                             | lb | No. 1                                                                                                                                                         | 1  |
| Balloonet Volume                                                                                                                                                                                         | $v$        | cu ft | $Y_1$                                                                                                                                                             | ft | $Z_{MAX}$ ft MSL                                                                                                                                              |    |
| Balloon Weight                                                                                                                                                                                           | $W_B$      | lb    | $X_1$                                                                                                                                                             | ft | Wind, knots                                                                                                                                                   |    |
| Hull Length                                                                                                                                                                                              | $\bar{L}$  | ft    | $W_2$                                                                                                                                                             |    | No. 2                                                                                                                                                         | 2  |
| ① Location of Confluence Pt.                                                                                                                                                                             | $Y_{CP}$   | ft    | $Y_2$                                                                                                                                                             |    | $Z_2$                                                                                                                                                         |    |
|                                                                                                                                                                                                          | $X_{CP}$   | ft    | $X_2$                                                                                                                                                             |    | Wind <sub>2</sub>                                                                                                                                             |    |
| ① Location of Center of Gravity                                                                                                                                                                          | $Y_{CG}$   | ft    | $W_3$                                                                                                                                                             |    | No. 3                                                                                                                                                         | 3  |
|                                                                                                                                                                                                          | $X_{CG}$   | ft    | $Y_3$                                                                                                                                                             |    | $Z_3$                                                                                                                                                         |    |
| ② Location of Center of Buoyancy                                                                                                                                                                         | $Y_{CB}$   | ft    | $X_3$                                                                                                                                                             |    | Wind <sub>3</sub>                                                                                                                                             |    |
|                                                                                                                                                                                                          | $X_{CB}$   | ft    | $W_4$                                                                                                                                                             |    | No. 4                                                                                                                                                         | 4  |
| ③ Location of Aero Reference Center                                                                                                                                                                      | $Y_{ARC}$  | ft    | $Y_4$                                                                                                                                                             |    | $Z_4$                                                                                                                                                         |    |
|                                                                                                                                                                                                          | $X_{ARC}$  | ft    | $X_4$                                                                                                                                                             |    | Wind <sub>4</sub>                                                                                                                                             |    |
| Altitude, Max                                                                                                                                                                                            | $Z_M$      | ft    | $W_5$                                                                                                                                                             |    | No. 5                                                                                                                                                         | 5  |
| Altitude, Surf                                                                                                                                                                                           | $Z_S$      | ft    | $Y_5$                                                                                                                                                             |    | $Z_5$                                                                                                                                                         |    |
| Increment of Alt                                                                                                                                                                                         | $\Delta Z$ | ft    | $X_5$                                                                                                                                                             |    | Wind <sub>5</sub>                                                                                                                                             |    |
| ① $dC_L/d\alpha$                                                                                                                                                                                         | $a$        |       | $W_6$                                                                                                                                                             |    | No. 6                                                                                                                                                         | 6  |
| ② $C_{D0}$                                                                                                                                                                                               | $b$        |       | $Y_6$                                                                                                                                                             |    | $Z_6$                                                                                                                                                         |    |
| ③ $dC_D/d\alpha^2$                                                                                                                                                                                       | $c$        |       | $X_6$                                                                                                                                                             |    | Wind <sub>6</sub>                                                                                                                                             |    |
| ③ $C_M$ TABLE*                                                                                                                                                                                           |            |       | $W_7$                                                                                                                                                             |    | No. 7                                                                                                                                                         | 7  |
|                                                                                                                                                                                                          | NO. 1      | 1     | $Y_7$                                                                                                                                                             |    | $Z_7$                                                                                                                                                         |    |
|                                                                                                                                                                                                          | $\alpha_1$ | deg   | $X_7$                                                                                                                                                             |    | Wind <sub>7</sub>                                                                                                                                             |    |
|                                                                                                                                                                                                          | $C_{M1}$   |       | $W_8$                                                                                                                                                             |    | No. 8                                                                                                                                                         | 8  |
|                                                                                                                                                                                                          | NO. 2      | 2     | $Y_8$                                                                                                                                                             |    | $Z_8$                                                                                                                                                         |    |
|                                                                                                                                                                                                          | $\alpha_2$ | deg   | $X_8$                                                                                                                                                             |    | Wind <sub>8</sub>                                                                                                                                             |    |
|                                                                                                                                                                                                          | $C_{M2}$   |       | $W_9$                                                                                                                                                             |    | No. 9                                                                                                                                                         | 9  |
|                                                                                                                                                                                                          | NO. 3      | 3     | $Y_9$                                                                                                                                                             |    | $Z_9$                                                                                                                                                         |    |
|                                                                                                                                                                                                          | $\alpha_3$ | deg   | $X_9$                                                                                                                                                             |    | Wind <sub>9</sub>                                                                                                                                             |    |
|                                                                                                                                                                                                          | $C_{M3}$   |       | $W_{10}$                                                                                                                                                          |    | No. 10                                                                                                                                                        | 10 |
|                                                                                                                                                                                                          | NO. 4      | 4     | $Y_{10}$                                                                                                                                                          |    | $Z_{10}$                                                                                                                                                      |    |
|                                                                                                                                                                                                          | $\alpha_4$ | deg   | $X_{10}$                                                                                                                                                          |    | Wind <sub>10</sub>                                                                                                                                            |    |
|                                                                                                                                                                                                          | $C_{M4}$   |       | $W_{11}$                                                                                                                                                          |    | No. 11                                                                                                                                                        | 11 |
|                                                                                                                                                                                                          | NO. 5      | 5     | $Y_{11}$                                                                                                                                                          |    | $Z_{11}$                                                                                                                                                      |    |
|                                                                                                                                                                                                          | $\alpha_5$ | deg   | $X_{11}$                                                                                                                                                          |    | Wind <sub>11</sub>                                                                                                                                            |    |
|                                                                                                                                                                                                          | $C_{M5}$   |       | $W_{12}$                                                                                                                                                          |    | No. 12                                                                                                                                                        | 12 |
|                                                                                                                                                                                                          | NO. 6      | 6     | $Y_{12}$                                                                                                                                                          |    | $Z_{12}$                                                                                                                                                      |    |
|                                                                                                                                                                                                          | $\alpha_6$ | deg   | $X_{12}$                                                                                                                                                          |    | Wind <sub>12</sub>                                                                                                                                            |    |
|                                                                                                                                                                                                          | $C_{M6}$   |       | $W_{13}$                                                                                                                                                          |    | No. 13                                                                                                                                                        | 13 |
|                                                                                                                                                                                                          | NO. 7      | 7     | $Y_{13}$                                                                                                                                                          |    | $Z_{13}$                                                                                                                                                      |    |
|                                                                                                                                                                                                          | $\alpha_7$ | deg   | $X_{13}$                                                                                                                                                          |    | Wind <sub>13</sub>                                                                                                                                            |    |
|                                                                                                                                                                                                          | $C_{M7}$   |       |                                                                                                                                                                   |    |                                                                                                                                                               |    |
| ① See Note 76.005<br>Req'd for 76.002 and 76.003<br>② Req'd for 76.003 only<br>* A minimum of two points must be used, a maximum of seven points may be used. First point must be for $\alpha = 0^\circ$ |            |       | Any number of "extra" weights may be used. One entry can be Instrument Package and Payload. If these are at Confluence Point make<br>$Y = Y_{CP}$<br>$X = X_{CP}$ |    | *A minimum of 2 points must be used and a maximum of 13 may be used. First must be $Z_{MAX}$ and last must be $Z_{SURF}$ . 76.004 requires one value of wind. |    |

3.5.6 PROGRAM 76.005 - TRIM, FAMILY-2, VARIABLE ALT. AND  
WIND PROFILES

| STEP      | KEY | STEP      | KEY | STEP      | KEY | STEP      | KEY | STEP      | KEY | STEP      | KEY |
|-----------|-----|-----------|-----|-----------|-----|-----------|-----|-----------|-----|-----------|-----|
| 0000--CLR |     | 0050-- 7  |     | 0100-- 5  |     | 0150-- 8  |     | 0200-- 0  |     | 0250-- 7  |     |
| 0001--FMT |     | 0051-- 7  |     | 0101-- 4  |     | 0151--XTO |     | 0201-- 2  |     | 0251--XTO |     |
| 0002--FMT |     | 0052-- 7  |     | 0102-- 1  |     | 0152-- 0  |     | 0202-- 0  |     | 0252-- 0  |     |
| 0003-- n  |     | 0053-- 2  |     | 0103-- 1  |     | 0153-- 2  |     | 0203-- .  |     | 0253-- 6  |     |
| 0004-- a  |     | 0054--CHS |     | 0104--CHS |     | 0154-- 7  |     | 0204-- 0  |     | 0254-- 5  |     |
| 0005-- 0  |     | 0055--EEX |     | 0105--XTO |     | 0155-- 1  |     | 0205-- 0  |     | 0255-- .  |     |
| 0006-- G  |     | 0056-- 1  |     | 0106-- 0  |     | 0156-- 6  |     | 0206-- 0  |     | 0256-- 1  |     |
| 0007-- .  |     | 0057-- 0  |     | 0107-- 2  |     | 0157-- 9  |     | 0207-- 7  |     | 0257-- 2  |     |
| 0008--GTO |     | 0058--CHS |     | 0108-- 3  |     | 0158-- 2  |     | 0208-- 1  |     | 0258-- 2  |     |
| 0009-- 7  |     | 0059--XTO |     | 0109-- .  |     | 0159--CHS |     | 0209--XTO |     | 0259-- 9  |     |
| 0010-- 6  |     | 0060-- 0  |     | 0110-- 0  |     | 0160--EEX |     | 0210-- 0  |     | 0260--XTO |     |
| 0011-- .  |     | 0061-- 3  |     | 0111-- 0  |     | 0161-- 7  |     | 0211-- 2  |     | 0261-- 0  |     |
| 0012-- 0  |     | 0062-- 9  |     | 0112-- 4  |     | 0162--CHS |     | 0212-- 1  |     | 0262-- 6  |     |
| 0013-- 0  |     | 0063-- 2  |     | 0113-- 6  |     | 0163--XTO |     | 0213-- .  |     | 0263-- 6  |     |
| 0014-- 5  |     | 0064-- .  |     | 0114-- 8  |     | 0164-- 0  |     | 0214-- 6  |     | 0264-- .  |     |
| 0015--CLR |     | 0065-- 8  |     | 0115-- 9  |     | 0165-- 2  |     | 0215-- 5  |     | 0265-- 5  |     |
| 0016--XTO |     | 0066-- 1  |     | 0116--XTO |     | 0166-- 8  |     | 0216-- 7  |     | 0266--XTO |     |
| 0017-- a  |     | 0067-- 3  |     | 0117-- 0  |     | 0167-- .  |     | 0217--XTO |     | 0267-- 0  |     |
| 0018-- I  |     | 0068-- 6  |     | 0118-- 2  |     | 0168-- 0  |     | 0218-- 0  |     | 0268-- 6  |     |
| 0019-- M  |     | 0069-- 1  |     | 0119-- 4  |     | 0169-- 0  |     | 0219-- 6  |     | 0269-- 7  |     |
| 0020--CLX |     | 0070--CHS |     | 0120-- 4  |     | 0170-- 3  |     | 0220-- 1  |     | 0270-- .  |     |
| 0021-- 0  |     | 0071--EEX |     | 0121-- 3  |     | 0171-- 6  |     | 0221-- .  |     | 0271-- 0  |     |
| 0022-- E  |     | 0072-- 5  |     | 0122-- 8  |     | 0172-- 3  |     | 0222-- 2  |     | 0272-- 1  |     |
| 0023-- C  |     | 0073--CHS |     | 0123-- 9  |     | 0173--XTO |     | 0223-- 6  |     | 0273-- 3  |     |
| 0024-- a  |     | 0074--XTO |     | 0124--EEX |     | 0174-- 0  |     | 0224-- 9  |     | 0274-- 9  |     |
| 0025-- .  |     | 0075-- 0  |     | 0125-- 8  |     | 0175-- 3  |     | 0225-- 1  |     | 0275-- 5  |     |
| 0026-- A  |     | 0076-- 3  |     | 0126--CHS |     | 0176-- 6  |     | 0226--XTO |     | 0276--XTO |     |
| 0027-- L  |     | 0077-- 8  |     | 0127--XTO |     | 0177-- .  |     | 0227-- 0  |     | 0277-- 0  |     |
| 0028--XTO |     | 0078-- .  |     | 0128-- 0  |     | 0178-- 0  |     | 0228-- 6  |     | 0278-- 6  |     |
| 0029--YTO |     | 0079-- 4  |     | 0129-- 2  |     | 0179-- 5  |     | 0229-- 2  |     | 0279-- 8  |     |
| 0030-- .  |     | 0080-- 2  |     | 0130-- 5  |     | 0180-- 8  |     | 0230-- .  |     | 0280-- .  |     |
| 0031--CLR |     | 0081-- 7  |     | 0131-- 5  |     | 0181-- 1  |     | 0231-- 8  |     | 0281-- 5  |     |
| 0032-- F  |     | 0082--XTO |     | 0132-- 0  |     | 0182-- 5  |     | 0232-- 0  |     | 0282-- 6  |     |
| 0033-- A  |     | 0083-- 0  |     | 0133-- 9  |     | 0183--XTO |     | 0233-- 5  |     | 0283--XTO |     |
| 0034-- M  |     | 0084-- 3  |     | 0134-- 7  |     | 0184-- 0  |     | 0234--XTO |     | 0284-- 0  |     |
| 0035-- .  |     | 0085-- 5  |     | 0135--CHS |     | 0185-- 3  |     | 0235-- 0  |     | 0285-- 6  |     |
| 0036-- 2  |     | 0086-- .  |     | 0136--EEX |     | 0186-- 7  |     | 0236-- 6  |     | 0286-- 9  |     |
| 0037--CHT |     | 0087-- 0  |     | 0137-- 8  |     | 0187-- .  |     | 0237-- 3  |     | 0287-- .  |     |
| 0038--XTO |     | 0088-- 0  |     | 0138--CHS |     | 0188-- 0  |     | 0238-- .  |     | 0288-- 0  |     |
| 0039-- .  |     | 0089-- 1  |     | 0139--XTO |     | 0189-- 4  |     | 0239-- 4  |     | 0289-- 0  |     |
| 0040-- B  |     | 0090-- 0  |     | 0140-- 0  |     | 0190-- 9  |     | 0240-- 3  |     | 0290-- 3  |     |
| 0041-- A  |     | 0091-- 3  |     | 0141-- 2  |     | 0191--XTO |     | 0241-- 5  |     | 0291-- 7  |     |
| 0042-- L  |     | 0092--CHS |     | 0142-- 6  |     | 0192-- 0  |     | 0242--CHS |     | 0292--XTO |     |
| 0043-- L  |     | 0093--XTO |     | 0143-- .  |     | 0193-- 1  |     | 0243--XTO |     | 0293-- 0  |     |
| 0044-- 0  |     | 0094-- 0  |     | 0144-- 0  |     | 0194-- 9  |     | 0244-- 0  |     | 0294-- 7  |     |
| 0045-- 0  |     | 0095-- 2  |     | 0145-- 0  |     | 0195-- .  |     | 0245-- 6  |     | 0295-- 0  |     |
| 0046-- H  |     | 0096-- 2  |     | 0146-- 0  |     | 0196-- 1  |     | 0246-- 4  |     | 0296-- 1  |     |
| 0047--FMT |     | 0097-- .  |     | 0147-- 2  |     | 0197-- 0  |     | 0247-- .  |     | 0297-- 1  |     |
| 0048-- 1  |     | 0098-- 0  |     | 0148-- 0  |     | 0198-- 6  |     | 0248-- 4  |     | 0298--XTO |     |
| 0049-- .  |     | 0099-- 0  |     | 0149-- 4  |     | 0199--XTO |     | 0249-- 5  |     | 0299-- 4  |     |

| STEP   | KEY | STEP   | KEY | STEP   | KEY | STEP   | KEY | STEP   | KEY | STEP   | KEY |
|--------|-----|--------|-----|--------|-----|--------|-----|--------|-----|--------|-----|
| 0300-- | 3   | 0350-- | 1   | 0400-- | 9   | 0450-- | XTO | 0500-- | N   | 0550-- | FMT |
| 0301-- | XTO | 0351-- | XTO | 0401-- | CHS | 0451-- | a   | 0501-- | CNT | 0551-- | 8   |
| 0302-- | 4   | 0352-- | 6   | 0402-- | XTO | 0452-- | A   | 0502-- | XFR | 0552-- | UP  |
| 0303-- | 5   | 0353-- | STP | 0403-- | 8   | 0453-- | CNT | 0503-- | CLR | 0553-- | UP  |
| 0304-- | XTO | 0354-- | PNT | 0404-- | 5   | 0454-- | IND | 0504-- | YE  | 0554-- | STP |
| 0305-- | 4   | 0355-- | XTO | 0405-- | 5   | 0455-- | E   | 0505-- | CNT | 0555-- | YTO |
| 0306-- | 6   | 0356-- | 4   | 0406-- | UP  | 0456-- | I   | 0506-- | I   | 0556-- | a   |
| 0307-- | XTO | 0357-- | 2   | 0407-- | 5   | 0457-- | G   | 0507-- | H   | 0557-- | XEY |
| 0308-- | 0   | 0358-- | UP  | 0408-- | 7   | 0458-- | H   | 0508-- | CNT | 0558-- | 1   |
| 0309-- | 4   | 0359-- | 2   | 0409-- | .   | 0459-- | XTO | 0509-- | YE  | 0559-- | X=Y |
| 0310-- | 8   | 0360-- | UP  | 0410-- | 3   | 0460-- | YTO | 0510-- | CLR | 0560-- | 0   |
| 0311-- | 0   | 0361-- | 3   | 0411-- | RUP | 0461-- | CLR | 0511-- | E   | 0561-- | 6   |
| 0312-- | XTO | 0362-- | DIV | 0412-- | -   | 0462-- | E   | 0512-- | N   | 0562-- | 2   |
| 0313-- | 4   | 0363-- | DN  | 0413-- | YTO | 0463-- | N   | 0513-- | XTO | 0563-- | 0   |
| 0314-- | 4   | 0364-- | XEY | 0414-- | 0   | 0464-- | XTO | 0514-- | .   | 0564-- | a   |
| 0315-- | XTO | 0365-- | H   | 0415-- | 0   | 0465-- | .   | 0515-- | CHS | 0565-- | RUP |
| 0316-- | 4   | 0366-- | XTO | 0416-- | 3   | 0466-- | CHS | 0516-- | CNT | 0566-- | PNT |
| 0317-- | 7   | 0367-- | 0   | 0417-- | 2   | 0467-- | CNT | 0517-- | I   | 0567-- | XTO |
| 0318-- | XTO | 0368-- | 4   | 0418-- | .   | 0468-- | I   | 0518-- | N   | 0568-- | a   |
| 0319-- | 5   | 0369-- | 1   | 0419-- | 5   | 0469-- | H   | 0519-- | CNT | 0569-- | XTO |
| 0320-- | 0   | 0370-- | 2   | 0420-- | CHS | 0470-- | CNT | 0520-- | YE  | 0570-- | +   |
| 0321-- | XTO | 0371-- | UP  | 0421-- | RUP | 0471-- | YE  | 0521-- | CNT | 0571-- | 5   |
| 0322-- | 5   | 0372-- | UP  | 0422-- | -   | 0472-- | CLR | 0522-- | A   | 0572-- | 0   |
| 0323-- | 1   | 0373-- | STP | 0423-- | YTO | 0473-- | 0   | 0523-- | F   | 0573-- | DN  |
| 0324-- | XTO | 0374-- | PNT | 0424-- | 0   | 0474-- | XTO | 0524-- | XTO | 0574-- | PNT |
| 0325-- | 0   | 0375-- | XTO | 0425-- | 0   | 0475-- | H   | 0525-- | E   | 0575-- | XEY |
| 0326-- | 5   | 0376-- | 0   | 0426-- | 4   | 0476-- | E   | 0526-- | a   | 0576-- | PNT |
| 0327-- | 2   | 0377-- | 0   | 0427-- | CHS | 0477-- | a   | 0527-- | A   | 0577-- | PNT |
| 0328-- | .   | 0378-- | 1   | 0428-- | XTO | 0478-- | IND | 0528-- | L   | 0578-- | UP  |
| 0329-- | 0   | 0379-- | 3   | 0429-- | 6   | 0479-- | I   | 0529-- | L   | 0579-- | XFR |
| 0330-- | 6   | 0380-- | UP  | 0430-- | FMT | 0480-- | YTO | 0530-- | CNT | 0580-- | 5   |
| 0331-- | 5   | 0381-- | UP  | 0431-- | FMT | 0481-- | E   | 0531-- | IND | 0581-- | 4   |
| 0332-- | 9   | 0382-- | STP | 0432-- | I   | 0482-- | CLX | 0532-- | E   | 0582-- | -   |
| 0333-- | 8   | 0383-- | PNT | 0433-- | F   | 0483-- | E   | 0533-- | I   | 0583-- | XFR |
| 0334-- | 8   | 0384-- | XTO | 0434-- | CNT | 0484-- | H   | 0534-- | G   | 0584-- | 5   |
| 0335-- | XTO | 0385-- | 0   | 0435-- | XTO | 0485-- | XTO | 0535-- | H   | 0585-- | 5   |
| 0336-- | 0   | 0386-- | 0   | 0436-- | H   | 0486-- | E   | 0536-- | XTO | 0586-- | RUP |
| 0337-- | 3   | 0387-- | 8   | 0437-- | E   | 0487-- | a   | 0537-- | YTO | 0587-- | XEY |
| 0338-- | 4   | 0388-- | 2   | 0438-- | a   | 0488-- | CLR | 0538-- | CNT | 0588-- | -   |
| 0339-- | .   | 0389-- | 6   | 0439-- | E   | 0489-- | IND | 0539-- | A   | 0589-- | a   |
| 0340-- | 0   | 0390-- | .   | 0440-- | CNT | 0490-- | XTO | 0540-- | a   | 0590-- | X   |
| 0341-- | 0   | 0391-- | 6   | 0441-- | A   | 0491-- | .   | 0541-- | E   | 0591-- | YTO |
| 0342-- | 2   | 0392-- | XTO | 0442-- | a   | 0492-- | I   | 0542-- | CLR | 0592-- | +   |
| 0343-- | 3   | 0393-- | 0   | 0443-- | E   | 0493-- | H   | 0543-- | E   | 0593-- | 5   |
| 0344-- | 7   | 0394-- | 5   | 0444-- | CNT | 0494-- | CNT | 0544-- | H   | 0594-- | 2   |
| 0345-- | 8   | 0395-- | 4   | 0445-- | H   | 0495-- | XSQ | 0545-- | XTO | 0595-- | RUP |
| 0346-- | XTO | 0396-- | UP  | 0446-- | 0   | 0496-- | CLX | 0546-- | E   | 0596-- | X   |
| 0347-- | 0   | 0397-- | 3   | 0447-- | CLR | 0497-- | XFR | 0547-- | a   | 0597-- | YTO |
| 0348-- | 1   | 0398-- | 1   | 0448-- | E   | 0498-- | CNT | 0548-- | E   | 0598-- | +   |
| 0349-- | 2   | 0399-- | .   | 0449-- | YE  | 0499-- | I   | 0549-- | D   | 0599-- | 0   |

| STEP   | KEY | STEP   | KEY | STEP   | KEY | STEP   | KEY | STEP   | KEY | STEP   | KEY |
|--------|-----|--------|-----|--------|-----|--------|-----|--------|-----|--------|-----|
| 0600-- | 5   | 0650-- | CHT | 0700-- | RUP | 0750-- | YTO | 0800-- | YTO | 0850-- | 8   |
| 0601-- | 1   | 0651-- | YE  | 0701-- | KEY | 0751-- | IND | 0801-- | 1   | 0851-- | 6   |
| 0602-- | 9   | 0652-- | CHT | 0702-- | 1   | 0752-- | a   | 0802-- | 3   | 0852-- | 4   |
| 0603-- | UP  | 0653-- | A   | 0703-- | .   | 0753-- | 1   | 0803-- | DN  | 0853-- | 1   |
| 0604-- | UP  | 0654-- | F   | 0704-- | 6   | 0754-- | 2   | 0804-- | XFR | 0854-- | UP  |
| 0605-- | STP | 0655-- | XTO | 0705-- | 8   | 0755-- | UP  | 0805-- | 3   | 0855-- | b   |
| 0606-- | YTO | 0656-- | E   | 0706-- | 7   | 0756-- | UP  | 0806-- | 4   | 0856-- | +   |
| 0607-- | a   | 0657-- | a   | 0707-- | 8   | 0757-- | STP | 0807-- | X   | 0857-- | YTO |
| 0608-- | KEY | 0658-- | YTO | 0708-- | X   | 0758-- | RUP | 0808-- | XFR | 0858-- | b   |
| 0609-- | π   | 0659-- | 1/X | 0709-- | YTO | 0759-- | PNT | 0809-- | 9   | 0859-- | GTO |
| 0610-- | X=Y | 0660-- | a   | 0710-- | IND | 0760-- | RUP | 0810-- | UP  | 0860-- | 0   |
| 0611-- | 0   | 0661-- | F   | 0711-- | a   | 0761-- | PNT | 0811-- | 0   | 0861-- | 8   |
| 0612-- | 6   | 0662-- | .   | 0712-- | 1   | 0762-- | RUP | 0812-- | X<Y | 0862-- | 3   |
| 0613-- | 2   | 0663-- | E   | 0713-- | 1   | 0763-- | PNT | 0813-- | 0   | 0863-- | 0   |
| 0614-- | 0   | 0664-- | H   | 0714-- | UP  | 0764-- | PNT | 0814-- | 8   | 0864-- | 2   |
| 0615-- | GTO | 0665-- | XTO | 0715-- | UP  | 0765-- | YTO | 0815-- | 3   | 0865-- | RUP |
| 0616-- | 0   | 0666-- | a   | 0716-- | STP | 0766-- | 0   | 0816-- | 0   | 0866-- | KEY |
| 0617-- | 5   | 0667-- | XFR | 0717-- | YTO | 0767-- | XTO | 0817-- | XFR | 0867-- | -   |
| 0618-- | 6   | 0668-- | FMT | 0718-- | 0   | 0768-- | 1   | 0818-- | 4   | 0868-- | YTO |
| 0619-- | 4   | 0669-- | STP | 0719-- | KEY | 0769-- | 6   | 0819-- | 2   | 0869-- | a   |
| 0620-- | 1   | 0670-- | YTO | 0720-- | π   | 0770-- | RUP | 0820-- | RUP | 0870-- | XFR |
| 0621-- | 0   | 0671-- | 1   | 0721-- | X=Y | 0771-- | XTO | 0821-- | X   | 0871-- | IND |
| 0622-- | UP  | 0672-- | 0   | 0722-- | 0   | 0772-- | 5   | 0822-- | YTO | 0872-- | a   |
| 0623-- | UP  | 0673-- | RUP | 0723-- | 7   | 0773-- | 7   | 0823-- | 2   | 0873-- | XTO |
| 0624-- | FMT | 0674-- | PNT | 0724-- | 3   | 0774-- | XFR | 0824-- | XFR | 0874-- | 5   |
| 0625-- | FMT | 0675-- | RUP | 0725-- | 4   | 0775-- | 1   | 0825-- | 1   | 0875-- | 8   |
| 0626-- | A   | 0676-- | PNT | 0726-- | XFR | 0776-- | 0   | 0826-- | 8   | 0876-- | RUP |
| 0627-- | L   | 0677-- | RUP | 0727-- | 0   | 0777-- | UP  | 0827-- | XTO | 0877-- | -   |
| 0628-- | XTO | 0678-- | PNT | 0728-- | KEY | 0778-- | UP  | 0828-- | 7   | 0878-- | 1   |
| 0629-- | .   | 0679-- | PNT | 0729-- | GTO | 0779-- | XFR | 0829-- | 3   | 0879-- | RUP |
| 0630-- | IND | 0680-- | YTO | 0730-- | 0   | 0780-- | 3   | 0830-- | b   | 0880-- | +   |
| 0631-- | I   | 0681-- | 0   | 0731-- | 6   | 0781-- | 9   | 0831-- | UP  | 0881-- | YTO |
| 0632-- | H   | 0682-- | KEY | 0732-- | 7   | 0782-- | X   | 0832-- | 1   | 0882-- | a   |
| 0633-- | D   | 0683-- | 2   | 0733-- | 3   | 0783-- | XFR | 0833-- | 1   | 0883-- | XFR |
| 0634-- | CHT | 0684-- | RUP | 0734-- | 1   | 0784-- | 3   | 0834-- | 2   | 0884-- | IND |
| 0635-- | π   | 0685-- | X   | 0735-- | XTO | 0785-- | 8   | 0835-- | X   | 0885-- | a   |
| 0636-- | a   | 0686-- | 7   | 0736-- | -   | 0786-- | +   | 0836-- | 7   | 0886-- | XTO |
| 0637-- | 0   | 0687-- | 9   | 0737-- | c   | 0787-- | DN  | 0837-- | 9   | 0887-- | 0   |
| 0638-- | F   | 0688-- | +   | 0738-- | XFR | 0788-- | X   | 0838-- | +   | 0888-- | 5   |
| 0639-- | 1   | 0689-- | YTO | 0739-- | IND | 0789-- | DN  | 0839-- | YTO | 0889-- | 9   |
| 0640-- | L   | 0690-- | a   | 0740-- | a   | 0790-- | J   | 0840-- | a   | 0890-- | 2   |
| 0641-- | E   | 0691-- | XFR | 0741-- | XTO | 0791-- | XTO | 0841-- | XFR | 0891-- | +   |
| 0642-- | E   | 0692-- | 0   | 0742-- | 1   | 0792-- | 1   | 0842-- | IND | 0892-- | YTO |
| 0643-- | H   | 0693-- | XTO | 0743-- | 5   | 0793-- | 8   | 0843-- | a   | 0893-- | a   |
| 0644-- | XTO | 0694-- | IND | 0744-- | UP  | 0794-- | UP  | 0844-- | UP  | 0894-- | XFR |
| 0645-- | .   | 0695-- | a   | 0745-- | 2   | 0795-- | UP  | 0845-- | XFR | 0895-- | IND |
| 0646-- | CHS | 0696-- | 1   | 0746-- | XTO | 0796-- | XFR | 0846-- | 1   | 0896-- | a   |
| 0647-- | CHT | 0697-- | +   | 0747-- | +   | 0797-- | 1   | 0847-- | 0   | 0897-- | KEY |
| 0648-- | 1   | 0698-- | YTO | 0748-- | a   | 0798-- | 2   | 0848-- | X>Y | 0898-- | XFR |
| 0649-- | H   | 0699-- | a   | 0749-- | -   | 0799-- | X   | 0849-- | 0   | 0899-- | 5   |

| STEP   | KEY | STEP   | KEY | STEP   | KEY | STEP   | KEY | STEP   | KEY | STEP   | KEY |
|--------|-----|--------|-----|--------|-----|--------|-----|--------|-----|--------|-----|
| 0900-- | 9   | 0950-- | K   | 1000-- | UP  | 1050-- | YTO | 1100-- | X   | 1150-- | 2   |
| 0901-- | -   | 0951-- | H   | 1001-- | XFR | 1051-- | .   | 1101-- | YTO | 1151-- | 2   |
| 0902-- | DN  | 0952-- | 0   | 1002-- | 0   | 1052-- | FMT | 1102-- | +   | 1152-- | X   |
| 0903-- | XEY | 0953-- | XTO | 1003-- | -   | 1053-- | PHT | 1103-- | 5   | 1153-- | XFR |
| 0904-- | DIV | 0954-- | YTO | 1004-- | DN  | 1054-- | UP  | 1104-- | 8   | 1154-- | 5   |
| 0905-- | XFR | 0955-- | FMT | 1005-- | XEY | 1055-- | XSQ | 1105-- | XFR | 1155-- | 8   |
| 0906-- | 5   | 0956-- | PHT | 1006-- | DIV | 1056-- | X   | 1106-- | 2   | 1156-- | +   |
| 0907-- | 8   | 0957-- | XFR | 1007-- | YTO | 1057-- | XFR | 1107-- | 5   | 1157-- | XFR |
| 0908-- | UP  | 0958-- | 1   | 1008-- | 7   | 1058-- | 5   | 1108-- | RUP | 1158-- | 3   |
| 0909-- | XFR | 0959-- | 3   | 1009-- | 4   | 1059-- | 7   | 1109-- | X   | 1159-- | 5   |
| 0910-- | 1   | 0960-- | XEY | 1010-- | XFR | 1060-- | XSQ | 1110-- | YTO | 1160-- | +   |
| 0911-- | 0   | 0961-- | XSQ | 1011-- | 1   | 1061-- | X   | 1111-- | +   | 1161-- | XFR |
| 0912-- | -   | 0962-- | X   | 1012-- | 8   | 1062-- | XFR | 1112-- | 5   | 1162-- | 8   |
| 0913-- | DN  | 0963-- | 2   | 1013-- | 1/X | 1063-- | 2   | 1113-- | 8   | 1163-- | X   |
| 0914-- | X   | 0964-- | DIV | 1014-- | UP  | 1064-- | 8   | 1114-- | XFR | 1164-- | XFR |
| 0915-- | XFR | 0965-- | XFR | 1015-- | XFR | 1065-- | X   | 1115-- | 5   | 1165-- | 5   |
| 0916-- | 5   | 0966-- | 4   | 1016-- | 7   | 1066-- | YTO | 1116-- | 7   | 1166-- | 4   |
| 0917-- | 9   | 0967-- | 1   | 1017-- | 3   | 1067-- | 5   | 1117-- | UP  | 1167-- | -   |
| 0918-- | +   | 0968-- | XEY | 1018-- | X   | 1068-- | 8   | 1118-- | XFR | 1168-- | YTO |
| 0919-- | 1   | 0969-- | X   | 1019-- | 1   | 1069-- | XFR | 1119-- | 6   | 1169-- | 7   |
| 0920-- | .   | 0970-- | YTO | 1020-- | XEY | 1070-- | 6   | 1120-- | 0   | 1170-- | XFR |
| 0921-- | 6   | 0971-- | 1   | 1021-- | -   | 1071-- | 0   | 1121-- | X   | 1171-- | 6   |
| 0922-- | 8   | 0972-- | 4   | 1022-- | 1   | 1072-- | XSQ | 1122-- | X   | 1172-- | 0   |
| 0923-- | 7   | 0973-- | FMT | 1023-- | UP  | 1073-- | UP  | 1123-- | UP  | 1173-- | UP  |
| 0924-- | 8   | 0974-- | FMT | 1024-- | XFR | 1074-- | XFR | 1124-- | XFR | 1174-- | XFR |
| 0925-- | YTO | 0975-- | D   | 1025-- | 7   | 1075-- | 5   | 1125-- | 2   | 1175-- | 3   |
| 0926-- | 1   | 0976-- | XFR | 1026-- | 4   | 1076-- | 7   | 1126-- | 4   | 1176-- | 7   |
| 0927-- | 1   | 0977-- | H   | 1027-- | -   | 1077-- | XSQ | 1127-- | RUP | 1177-- | X   |
| 0928-- | UP  | 0978-- | .   | 1028-- | DN  | 1078-- | X   | 1128-- | X   | 1178-- | XFR |
| 0929-- | DN  | 0979-- | 1   | 1029-- | DIV | 1079-- | XFR | 1129-- | YTO | 1179-- | 3   |
| 0930-- | DIV | 0980-- | a   | 1030-- | YTO | 1080-- | 2   | 1130-- | +   | 1180-- | 6   |
| 0931-- | XFR | 0981-- | E   | 1031-- | 6   | 1081-- | 7   | 1131-- | 5   | 1181-- | +   |
| 0932-- | 1   | 0982-- | YTO | 1032-- | 0   | 1082-- | X   | 1132-- | 8   | 1182-- | XFR |
| 0933-- | 0   | 0983-- | YTO | 1033-- | DN  | 1083-- | YTO | 1133-- | XFR | 1183-- | 8   |
| 0934-- | FMT | 0984-- | .   | 1034-- | FMT | 1084-- | +   | 1134-- | 2   | 1184-- | X   |
| 0935-- | FMT | 0985-- | FMT | 1035-- | FMT | 1085-- | 5   | 1135-- | 3   | 1185-- | XFR |
| 0936-- | A   | 0986-- | PHT | 1036-- | B   | 1086-- | 8   | 1136-- | XEY | 1186-- | 5   |
| 0937-- | L   | 0987-- | XFR | 1037-- | A   | 1087-- | XFR | 1137-- | XFR | 1187-- | 5   |
| 0938-- | XTO | 0988-- | 9   | 1038-- | L   | 1088-- | 5   | 1138-- | 5   | 1188-- | -   |
| 0939-- | .   | 0989-- | UP  | 1039-- | L   | 1089-- | 7   | 1139-- | 7   | 1189-- | YTO |
| 0940-- | FMT | 0990-- | 0   | 1040-- | 0   | 1090-- | XSQ | 1140-- | X   | 1190-- | 0   |
| 0941-- | PHT | 0991-- | XCY | 1041-- | H   | 1091-- | UP  | 1141-- | RUP | 1191-- | 3   |
| 0942-- | DN  | 0992-- | 1   | 1042-- | E   | 1092-- | UP  | 1142-- | RUP | 1192-- | 3   |
| 0943-- | FMT | 0993-- | 0   | 1043-- | XTO | 1093-- | XFR | 1143-- | X   | 1193-- | 5   |
| 0944-- | FMT | 0994-- | 1   | 1044-- | CHT | 1094-- | 6   | 1144-- | YTO | 1194-- | UP  |
| 0945-- | IND | 0995-- | 0   | 1045-- | F   | 1095-- | 0   | 1145-- | +   | 1195-- | XFR |
| 0946-- | I   | 0996-- | XFR | 1046-- | 1/X | 1096-- | X   | 1146-- | 5   | 1196-- | 5   |
| 0947-- | H   | 0997-- | 4   | 1047-- | L   | 1097-- | XFR | 1147-- | 8   | 1197-- | 7   |
| 0948-- | D   | 0998-- | 2   | 1048-- | L   | 1098-- | 2   | 1148-- | DN  | 1198-- | UP  |
| 0949-- | CLX | 0999-- | UP  | 1049-- | H   | 1099-- | 6   | 1149-- | XFR | 1199-- | 6   |

| STEP      | KEY | STEP      | KEY | STEP      | KEY | STEP      | KEY | STEP      | KEY | STEP      | KEY |
|-----------|-----|-----------|-----|-----------|-----|-----------|-----|-----------|-----|-----------|-----|
| 1200--X<Y |     | 1250-- X  |     | 1300-- X  |     | 1350-- 6  |     | 1400-- 3  |     | 1450--XFR |     |
| 1201-- 1  |     | 1251-- 6  |     | 1301-- DN |     | 1351--X<Y |     | 1401-- X  |     | 1451-- 4  |     |
| 1202-- 2  |     | 1252-- 0  |     | 1302--X<Y |     | 1352--XFR |     | 1402-- DN |     | 1452-- 3  |     |
| 1203-- 4  |     | 1253-- +  |     | 1303-- +  |     | 1353-- 2  |     | 1403-- -  |     | 1453--X=Y |     |
| 1204-- 7  |     | 1254--YTO |     | 1304--XFR |     | 1354-- 0  |     | 1404--XFR |     | 1454-- 1  |     |
| 1205-- 1  |     | 1255-- a  |     | 1305-- 5  |     | 1355-- X  |     | 1405-- 5  |     | 1455-- 5  |     |
| 1206-- .  |     | 1256--XFR |     | 1306-- UP |     | 1356--XFR |     | 1406-- 7  |     | 1456-- 0  |     |
| 1207-- 7  |     | 1257--IND |     | 1307--XFR |     | 1357-- 5  |     | 1407-- 0  |     | 1457-- 2  |     |
| 1208--RUP |     | 1258-- a  |     | 1308-- 2  |     | 1358-- 9  |     | 1408-- X  |     | 1458-- DN |     |
| 1209-- 4  |     | 1259--RUP |     | 1309-- 0  |     | 1359--X<Y |     | 1409--XFR |     | 1459--X>Y |     |
| 1210--RUP |     | 1260-- X  |     | 1310-- X  |     | 1360-- -  |     | 1410-- 5  |     | 1460-- 1  |     |
| 1211--RUP |     | 1261-- 1  |     | 1311-- DN |     | 1361-- DN |     | 1411-- 0  |     | 1461-- 4  |     |
| 1212--X<Y |     | 1262--RUP |     | 1312-- +  |     | 1362--X<Y |     | 1412-- +  |     | 1462-- 7  |     |
| 1213-- 1  |     | 1263--X<Y |     | 1313--XFR |     | 1363-- +  |     | 1413--YTO |     | 1463-- 1  |     |
| 1214-- 2  |     | 1264-- -  |     | 1314-- 5  |     | 1364--XFR |     | 1414-- 3  |     | 1464-- .  |     |
| 1215-- 4  |     | 1265--YTO |     | 1315-- 7  |     | 1365-- 1  |     | 1415-- 0  |     | 1465-- 1  |     |
| 1216-- 7  |     | 1266-- a  |     | 1316-- 0  |     | 1366-- 4  |     | 1416--XFR |     | 1466--GTO |     |
| 1217-- 1  |     | 1267--XFR |     | 1317-- X  |     | 1367--CHS |     | 1417-- 5  |     | 1467-- 1  |     |
| 1218-- .  |     | 1268--IND |     | 1318--XFR |     | 1368-- X  |     | 1418-- 2  |     | 1468-- 4  |     |
| 1219-- 3  |     | 1269-- a  |     | 1319-- 5  |     | 1369--YTO |     | 1419-- UP |     | 1469-- 7  |     |
| 1220-- 5  |     | 1270--RUP |     | 1320-- 7  |     | 1370-- 2  |     | 1420--XFR |     | 1470-- 4  |     |
| 1221--RUP |     | 1271-- +  |     | 1321-- UP |     | 1371-- 9  |     | 1421-- 5  |     | 1471-- .  |     |
| 1222-- 3  |     | 1272--XFR |     | 1322--XFR |     | 1372--XFR |     | 1422-- 7  |     | 1472-- 1  |     |
| 1223--RUP |     | 1273-- 8  |     | 1323-- 5  |     | 1373-- 1  |     | 1423-- 0  |     | 1473--CHS |     |
| 1224--RUP |     | 1274-- X  |     | 1324-- X  |     | 1374-- UP |     | 1424-- X  |     | 1474-- UP |     |
| 1225--X<Y |     | 1275--XFR |     | 1325--XFR |     | 1375--XFR |     | 1425--XFR |     | 1475--XFR |     |
| 1226-- 1  |     | 1276-- 5  |     | 1326-- 1  |     | 1376-- 3  |     | 1426-- 5  |     | 1476-- 4  |     |
| 1227-- 2  |     | 1277-- 4  |     | 1327-- 9  |     | 1377-- X  |     | 1427-- 1  |     | 1477-- 4  |     |
| 1228-- 4  |     | 1278-- -  |     | 1328-- X  |     | 1378--XFR |     | 1428-- +  |     | 1478--XTO |     |
| 1229-- 7  |     | 1279--YTO |     | 1329--YTO |     | 1379-- 2  |     | 1429--XFR |     | 1479-- 4  |     |
| 1230-- .  |     | 1280-- 5  |     | 1330-- 5  |     | 1380-- UP |     | 1430-- 5  |     | 1480-- 5  |     |
| 1231-- 5  |     | 1281--XFR |     | 1331-- 9  |     | 1381--XFR |     | 1431-- 7  |     | 1481--YTO |     |
| 1232-- 5  |     | 1282-- 5  |     | 1332-- DN |     | 1382-- 7  |     | 1432-- H  |     | 1482-- 4  |     |
| 1233--RUP |     | 1283-- 7  |     | 1333--XFR |     | 1383-- X  |     | 1433-- X  |     | 1483-- 4  |     |
| 1234-- 2  |     | 1284--XSQ |     | 1334-- 5  |     | 1384-- DN |     | 1434--YTO |     | 1484--X<Y |     |
| 1235--RUP |     | 1285-- X  |     | 1335-- 7  |     | 1385-- -  |     | 1435-- 3  |     | 1485-- +  |     |
| 1236--RUP |     | 1286--XFR |     | 1336--XSQ |     | 1386--YTO |     | 1436-- 1  |     | 1486--YTO |     |
| 1237--X<Y |     | 1287-- 2  |     | 1337-- UP |     | 1387-- 5  |     | 1437--XFR |     | 1487-- 4  |     |
| 1238-- 1  |     | 1288-- 1  |     | 1338--XFR |     | 1388-- 8  |     | 1438-- 3  |     | 1488-- 3  |     |
| 1239-- 2  |     | 1289-- X  |     | 1339-- 6  |     | 1389--XFR |     | 1439-- 0  |     | 1489--X<Y |     |
| 1240-- 4  |     | 1290--XFR |     | 1340-- X  |     | 1390-- 1  |     | 1440-- +  |     | 1490--XFR |     |
| 1241-- 7  |     | 1291-- 6  |     | 1341--XFR |     | 1391-- UP |     | 1441--XFR |     | 1491-- 5  |     |
| 1242-- 1  |     | 1292-- UP |     | 1342-- 2  |     | 1392--XFR |     | 1442-- 2  |     | 1492-- 7  |     |
| 1243--RUP |     | 1293--XFR |     | 1343-- 1  |     | 1393-- 4  |     | 1443-- 9  |     | 1493-- +  |     |
| 1244--RUP |     | 1294-- 1  |     | 1344-- X  |     | 1394-- X  |     | 1444-- +  |     | 1494--YTO |     |
| 1245--X<Y |     | 1295-- 9  |     | 1345--YTO |     | 1395--XFR |     | 1445-- 0  |     | 1495-- 5  |     |
| 1246-- 0  |     | 1296-- X  |     | 1346-- -  |     | 1396-- 2  |     | 1446--YTO |     | 1496-- 7  |     |
| 1247-- -  |     | 1297--XFR |     | 1347-- 5  |     | 1397-- UP |     | 1447-- 3  |     | 1497--GTO |     |
| 1248-- 2  |     | 1298-- 5  |     | 1348-- 9  |     | 1398--XFR |     | 1448-- 2  |     | 1498-- 1  |     |
| 1249--RUP |     | 1299-- 7  |     | 1349--XFR |     | 1399-- 3  |     | 1449-- UP |     | 1499-- 5  |     |

| STEP   | KEY  | STEP   | KEY | STEP   | KEY | STEP   | KEY  | STEP   | KEY  | STEP   | KEY |
|--------|------|--------|-----|--------|-----|--------|------|--------|------|--------|-----|
| 1500-- | 5    | 1550-- | 7   | 1600-- | PHT | 1650-- | M    | 1700-- | 8    | 1750-- | PHT |
| 1501-- | 1    | 1551-- | PSE | 1601-- | +   | 1651-- | CNT  | 1701-- | XFR  | 1751-- | UP  |
| 1502-- | XFR  | 1552-- | .   | 1602-- | XFR | 1652-- | A    | 1702-- | 2    | 1752-- | XFR |
| 1503-- | 4    | 1553-- | 2   | 1603-- | 3   | 1653-- | H    | 1703-- | 1    | 1753-- | 5   |
| 1504-- | 6    | 1554-- | GTO | 1604-- | 1   | 1654-- | G    | 1704-- | X    | 1754-- | 8   |
| 1505-- | X=Y  | 1555-- | 1   | 1605-- | +   | 1655-- | L    | 1705-- | XFR  | 1755-- | +   |
| 1506-- | 1    | 1556-- | 9   | 1606-- | FMT | 1656-- | E.   | 1706-- | 2    | 1756-- | DN  |
| 1507-- | 5    | 1557-- | 8   | 1607-- | FMT | 1657-- | CNT  | 1707-- | 0    | 1757-- | FMT |
| 1508-- | 6    | 1558-- | 7   | 1608-- | E   | 1658-- | A    | 1708-- | +    | 1758-- | FMT |
| 1509-- | 2    | 1559-- | GTO | 1609-- | YE  | 1659-- | XTO  | 1709-- | XFR  | 1759-- | XTO |
| 1510-- | DN   | 1560-- | 1   | 1610-- | XTO | 1660-- | C    | 1710-- | 1    | 1760-- | 0   |
| 1511-- | X>Y  | 1561-- | 0   | 1611-- | a   | 1661-- | K    | 1711-- | 4    | 1761-- | XTO |
| 1512-- | 1    | 1562-- | 5   | 1612-- | A   | 1662-- | FMT  | 1712-- | XKEY | 1762-- | .   |
| 1513-- | 5    | 1563-- | 4   | 1613-- | YTO | 1663-- | PHT  | 1713-- | X    | 1763-- | L   |
| 1514-- | 2    | 1564-- | FMT | 1614-- | CNT | 1664-- | FMT  | 1714-- | FMT  | 1764-- | I   |
| 1515-- | 4    | 1565-- | FMT | 1615-- | M   | 1665-- | FMT  | 1715-- | FMT  | 1765-- | F   |
| 1516-- | .    | 1566-- | M   | 1616-- | 0   | 1666-- | C    | 1716-- | C    | 1766-- | XTO |
| 1517-- | 0    | 1567-- | E   | 1617-- | M   | 1667-- | L    | 1717-- | D    | 1767-- | FMT |
| 1518-- | 1    | 1568-- | C   | 1618-- | E   | 1668-- | FMT  | 1718-- | FMT  | 1768-- | PNT |
| 1519-- | GTO  | 1569-- | H   | 1619-- | N   | 1669-- | UP   | 1719-- | PHT  | 1769-- | YTO |
| 1520-- | 1    | 1570-- | CNT | 1620-- | XTO | 1670-- | XSQ  | 1720-- | DN   | 1770-- | 5   |
| 1521-- | 5    | 1571-- | M   | 1621-- | FMT | 1671-- | XKEY | 1721-- | FMT  | 1771-- | 8   |
| 1522-- | 2    | 1572-- | 0   | 1622-- | PNT | 1672-- | UP   | 1722-- | FMT  | 1772-- | UP  |
| 1523-- | 8    | 1573-- | M   | 1623-- | DN  | 1673-- | XFR  | 1723-- | D    | 1773-- | XFR |
| 1524-- | .    | 1574-- | E   | 1624-- | FMT | 1674-- | 1    | 1724-- | a    | 1774-- | 1   |
| 1525-- | 0    | 1575-- | N   | 1625-- | FMT | 1675-- | 9    | 1725-- | A    | 1775-- | UP  |
| 1526-- | 1    | 1576-- | XTO | 1626-- | YTO | 1676-- | X    | 1726-- | G    | 1776-- | XFR |
| 1527-- | CHS  | 1577-- | FMT | 1627-- | 1/X | 1677-- | DN   | 1727-- | FMT  | 1777-- | 5   |
| 1528-- | UP   | 1578-- | XFR | 1628-- | M   | 1678-- | PHT  | 1728-- | PHT  | 1778-- | 0   |
| 1529-- | XFR  | 1579-- | 3   | 1629-- | CNT | 1679-- | UP   | 1729-- | UP   | 1779-- | +   |
| 1530-- | 4    | 1580-- | 0   | 1630-- | 0   | 1680-- | XFR  | 1730-- | XFR  | 1780-- | FMT |
| 1531-- | 7    | 1581-- | PNT | 1631-- | F   | 1681-- | 1    | 1731-- | 2    | 1781-- | FMT |
| 1532-- | XTO  | 1582-- | UP  | 1632-- | CNT | 1682-- | 4    | 1732-- | FMT  | 1782-- | YTO |
| 1533-- | 4    | 1583-- | XFR | 1633-- | M   | 1683-- | X    | 1733-- | FMT  | 1783-- | 1/X |
| 1534-- | 8    | 1584-- | 2   | 1634-- | 0   | 1684-- | DN   | 1734-- | G    | 1784-- | M   |
| 1535-- | YTO  | 1585-- | 9   | 1635-- | M   | 1685-- | FMT  | 1735-- | a    | 1785-- | X>Y |
| 1536-- | 4    | 1586-- | FMT | 1636-- | E   | 1686-- | FMT  | 1736-- | 0    | 1786-- | E   |
| 1537-- | 7    | 1587-- | FMT | 1637-- | H   | 1687-- | A    | 1737-- | YTO  | 1787-- | YE  |
| 1538-- | XKEY | 1588-- | A   | 1638-- | XTO | 1688-- | E    | 1738-- | YTO  | 1788-- | XTO |
| 1539-- | +    | 1589-- | E   | 1639-- | YTO | 1689-- | a    | 1739-- | CNT  | 1789-- | a   |
| 1540-- | YTO  | 1590-- | a   | 1640-- | FMT | 1690-- | 0    | 1740-- | B    | 1790-- | A   |
| 1541-- | 4    | 1591-- | 0   | 1641-- | PHT | 1691-- | CNT  | 1741-- | 1/X  | 1791-- | X>Y |
| 1542-- | 6    | 1592-- | CNT | 1642-- | XFR | 1692-- | L    | 1742-- | 0    | 1792-- | IND |
| 1543-- | XKEY | 1593-- | M   | 1643-- | 5   | 1693-- | I    | 1743-- | XFR  | 1793-- | XTO |
| 1544-- | XFR  | 1594-- | 0   | 1644-- | 7   | 1694-- | F    | 1744-- | .    | 1794-- | YTO |
| 1545-- | 5    | 1595-- | M   | 1645-- | FMT | 1695-- | XTO  | 1745-- | L    | 1795-- |     |
| 1546-- | 7    | 1596-- | E   | 1646-- | FMT | 1696-- | FMT  | 1746-- | I    | 1796-- | FMT |
| 1547-- | +    | 1597-- | N   | 1647-- | XTO | 1697-- | PHT  | 1747-- | F    | 1797-- | PHT |
| 1548-- | YTO  | 1598-- | XTO | 1648-- | a.  | 1698-- | XTO  | 1748-- | XTO  | 1798-- | DN  |
| 1549-- | 5    | 1599-- | FMT | 1649-- | I   | 1699-- | 5    | 1749-- | FMT  | 1799-- | FMT |

| STEP      | KEY | STEP      | KEY | STEP      | KEY | STEP      | KEY | STEP      | KEY | STEP | KEY |
|-----------|-----|-----------|-----|-----------|-----|-----------|-----|-----------|-----|------|-----|
| 1800--FMT |     | 1850--A   |     | 1900--7   |     | 1950--B   |     | 2000--4   |     |      |     |
| 1801--XTO |     | 1851--N   |     | 1901--XFR |     | 1951--.   |     | 2001--FMT |     |      |     |
| 1802--0   |     | 1852--G   |     | 1902--1   |     | 1952--FMT |     | 2002--FMT |     |      |     |
| 1803--XTO |     | 1853--L   |     | 1903--0   |     | 1953--K   |     | 2003--XTO |     |      |     |
| 1804--.   |     | 1854--E   |     | 1904--UP  |     | 1954--CLX |     | 2004--a   |     |      |     |
| 1805--IND |     | 1855--CNT |     | 1905--XFR |     | 1955--0   |     | 2005--I   |     |      |     |
| 1806--E   |     | 1856--XTO |     | 1906--1   |     | 1956--XTO |     | 2006--M   |     |      |     |
| 1807--I   |     | 1857--0   |     | 1907--5   |     | 1957--a   |     | 2007--CNT |     |      |     |
| 1808--G   |     | 1858--CNT |     | 1908--X=Y |     | 1958--XTO |     | 2008--A   |     |      |     |
| 1809--H   |     | 1859--H   |     | 1909--1   |     | 1959--b   |     | 2009--H   |     |      |     |
| 1810--XTO |     | 1860--0   |     | 1910--9   |     | 1960--FMT |     | 2010--G   |     |      |     |
| 1811--FMT |     | 1861--a   |     | 1911--3   |     | 1961--FMT |     | 2011--L   |     |      |     |
| 1812--PNT |     | 1862--I   |     | 1912--4   |     | 1962--J   |     | 2012--E   |     |      |     |
| 1813--.   |     | 1863--XSQ |     | 1913--XEY |     | 1963--.   |     | 2013--SFL |     |      |     |
| 1814--XFR |     | 1864--0   |     | 1914--UP  |     | 1964--B   |     | 2014--.   |     |      |     |
| 1815--5   |     | 1865--H   |     | 1915--XFR |     | 1965--.   |     | 2015--2   |     |      |     |
| 1816--8   |     | 1866--FMT |     | 1916--1   |     | 1966--IND |     | 2016--EEX |     |      |     |
| 1817--XEY |     | 1867--PNT |     | 1917--6   |     | 1967--.   |     | 2017--0   |     |      |     |
| 1818--FMT |     | 1868--PNT |     | 1918--.   |     | 1968--CNT |     | 2018--CLR |     |      |     |
| 1819--FMT |     | 1869--PNT |     | 1919--DN  |     | 1969--CNT |     | 2019--YTO |     |      |     |
| 1820--H   |     | 1870--XFR |     | 1920--X>Y |     | 1970--7   |     | 2020--XTO |     |      |     |
| 1821--E   |     | 1871--9   |     | 1921--1   |     | 1971--6   |     | 2021--A   |     |      |     |
| 1822--XTO |     | 1872--UP  |     | 1922--9   |     | 1972--.   |     | 2022--a   |     |      |     |
| 1823--CNT |     | 1873--1   |     | 1923--2   |     | 1973--0   |     | 2023--XTO |     |      |     |
| 1824--L   |     | 1874--+   |     | 1924--6   |     | 1974--0   |     | 2024--CNT |     |      |     |
| 1825--I   |     | 1875--YTO |     | 1925--DN  |     | 1975--5   |     | 2025--A   |     |      |     |
| 1826--F   |     | 1876--0   |     | 1926--XTO |     | 1976--CLR |     | 2026--N   |     |      |     |
| 1827--XTO |     | 1877--0   |     | 1927--1   |     | 1977--CLR |     | 2027--E   |     |      |     |
| 1828--FMT |     | 1878--9   |     | 1928--0   |     | 1978--CLR |     | 2028--IND |     |      |     |
| 1829--PNT |     | 1879--1   |     | 1929--GTO |     | 1979--CLR |     | 2029--FMT |     |      |     |
| 1830--XEY |     | 1880--1   |     | 1930--0   |     | 1980--CLR |     | 2030--K   |     |      |     |
| 1831--A   |     | 1881--XTO |     | 1931--7   |     | 1981--FMT |     | 2031--CLX |     |      |     |
| 1832--FMT |     | 1882--4   |     | 1932--7   |     | 1982--GTO |     | 2032--GTO |     |      |     |
| 1833--FMT |     | 1883--3   |     | 1933--7   |     | 1983--0   |     | 2033--0   |     |      |     |
| 1834--XTO |     | 1884--XTO |     | 1934--FMT |     | 1984--0   |     | 2034--END |     |      |     |
| 1835--0   |     | 1885--4   |     | 1935--FMT |     | 1985--0   |     |           |     |      |     |
| 1836--XTO |     | 1886--5   |     | 1936--a   |     | 1986--0.  |     |           |     |      |     |
| 1837--A   |     | 1887--XTO |     | 1937--E   |     | 1987--X>Y |     |           |     |      |     |
| 1838--L   |     | 1888--4   |     | 1938--A   |     | 1988--2   |     |           |     |      |     |
| 1839--CNT |     | 1889--6   |     | 1939--D   |     | 1989--0   |     |           |     |      |     |
| 1840--F   |     | 1890--XTO |     | 1940--XFR |     | 1990--0   |     |           |     |      |     |
| 1841--0   |     | 1891--0   |     | 1941--CNT |     | 1991--1   |     |           |     |      |     |
| 1842--a   |     | 1892--4   |     | 1942--H   |     | 1992--DN  |     |           |     |      |     |
| 1843--C   |     | 1893--8   |     | 1943--E   |     | 1993--XFR |     |           |     |      |     |
| 1844--E   |     | 1894--0   |     | 1944--YE  |     | 1994--6   |     |           |     |      |     |
| 1845--FMT |     | 1895--XTO |     | 1945--XTO |     | 1995--0   |     |           |     |      |     |
| 1846--PNT |     | 1896--4   |     | 1946--CNT |     | 1996--GTO |     |           |     |      |     |
| 1847--XEY |     | 1897--4   |     | 1947--a   |     | 1997--1   |     |           |     |      |     |
| 1848--FMT |     | 1898--XTO |     | 1948--a   |     | 1998--0   |     |           |     |      |     |
| 1849--FMT |     | 1899--4   |     | 1949--0   |     | 1999--5   |     |           |     |      |     |

# STORAGE REGISTERS

| STORAGE |                              |
|---------|------------------------------|
| b       | P Counter                    |
| a       | IND, USE                     |
| 000     | r                            |
| 001     | $W_B$                        |
| 002     | $L_0$                        |
| 003     | m                            |
| 004     | n                            |
| 005     | $L$                          |
| 006     | $s$                          |
| 007     | $t$                          |
| 008     | $c$                          |
| 009     | n Counter                    |
| 010     | Z                            |
| 011     | Wind, fps                    |
| 012     | $P_0$ , slug/ft <sup>2</sup> |
| 013     | $\rho$ "                     |
| 014     | $K = 9 \cdot V_B^{2/3}$      |
| 015     | $Z_s$                        |
| 016     | $\Delta Z$                   |
| 017     |                              |
| 018     | $P/P_0$                      |
| 019     | $dC_L/d\alpha$               |
| 020     | $C_{D0} (=K)$                |
| 021     | $dC_D/d\alpha (=K)$          |
| 022     | $f_0$                        |
| 023     | $f_1$                        |
| 024     | $f_2$                        |
| 025     | $g_0$                        |
| 026     | $g_1$                        |
| 027     | $g_2$                        |
| 028     | $g_3$                        |
| 029     | Aero. Mom.                   |
| 030     | Mech Mom                     |
| 031     | Extras Mom                   |
| 032     | $\Sigma$ Mom.                |
| 033     | $\mu$                        |
| 034     | Sp. Lift's, L                |
| 035     | $A_0$                        |
| 036     | $Y_{C0}/E$ $\gamma_{00}$     |
| 037     | $Y_{C0}/E$ Slope             |
| 038     | $a_0 \gamma P/P_0$           |
| 039     | $a_1 \gamma P/P_0$           |

|     |                                  |
|-----|----------------------------------|
| 040 |                                  |
| 041 | $\cdot V_B^{2/3}$                |
| 042 | $V_B$                            |
| 043 | $\Delta \alpha$ Trigger          |
| 044 | Prev. $\Delta \alpha$            |
| 045 | 2nd Prev. $\Delta \alpha$        |
| 046 | $\Delta \alpha$ Trigger          |
| 047 | Prev. $\Delta \alpha$            |
| 048 | 2nd Prev. $\Delta \alpha$        |
| 049 |                                  |
| 050 | $\Sigma Wt_{EXTRA}$              |
| 051 | $\Sigma Wt_{EXTRA} (X - X^{CP})$ |
| 052 | $\Sigma Wt_{EXTRA} (4 - Y^{CP})$ |
| 053 |                                  |
| 054 | $X^{CP} = 26.6$                  |
| 055 | $Y^{CP} = -31.9$                 |
| 056 |                                  |
| 057 | $\alpha$                         |
| 058 | Temp.                            |
| 059 | Temp.                            |
| 060 | $\gamma$                         |
| 061 | $X_{CP}/E$ } 1                   |
| 062 | $dX/E/d\alpha$                   |
| 063 | $X_{CP}/E$ } 2                   |
| 064 | $dX/E/d\alpha$                   |
| 065 | $X_{CP}/E$ } 3                   |
| 066 | $dX/E/d\alpha$                   |
| 067 | $X_{CP}/E$ } 4                   |
| 068 | $dX/E/d\alpha$                   |
| 069 | $X_{CP}/E$ } 5                   |
| 070 | $dX/E/d\alpha$                   |
| 071 |                                  |
| 072 |                                  |
| 073 | $b/P_0$                          |
| 074 | $P_d/P_0$                        |
| 075 |                                  |
| 076 |                                  |
| 077 |                                  |
| 078 |                                  |
| 079 |                                  |

|     |                       |
|-----|-----------------------|
| 080 |                       |
| 081 | $Z_1$                 |
| 082 | $W_1$                 |
| 083 | $Z_2$                 |
| 084 | $W_2$                 |
| 085 | $Z_3$                 |
| 086 | $W_3$                 |
| 087 | $Z_4$ $\downarrow$    |
| 088 | $W_4$ $\downarrow$    |
| 089 | $Z_5$ $\downarrow$    |
| 090 | $W_5$ $\downarrow$    |
| 091 | $Z_6$ 0               |
| 092 | $W_6$ $\downarrow$    |
| 093 | $Z_7$ 0               |
| 094 | $W_7$                 |
| 095 | $Z_8$ $\downarrow$    |
| 096 | $W_8$ $\downarrow$    |
| 097 | $Z_9$ $\downarrow$    |
| 098 | $W_9$ $\downarrow$    |
| 099 | $Z_{10}$ 1            |
| 100 | $W_{10}$ $\downarrow$ |
| 101 | $Z_{11}$ $\downarrow$ |
| 102 | $W_{11}$ $\downarrow$ |
| 103 | $Z_{12}$ $\downarrow$ |
| 104 | $W_{12}$              |
| 105 | $Z_{13}$              |
| 106 | $W_{13}$              |
| 107 | +1 Z Ext.             |
| 108 |                       |

### 3.5.7 SAMPLE INPUT/OUTPUT PRINT

The following copy of the HP Printed Tape shows a typical problem and solution. For a discussion of the particulars of this problem, see Section 4.

PROG.#76.005  
TRIM,DECR.ALTS.  
FAM.2 T.BALLOON  
45000.000\*  
970.000\*  
83.700\*

IF THERE ARE NO  
EXTRA WEIGHTS  
ENT.# IN X  
OTHERWISE,ENTER  
WT.IN Z,Y IN Y  
X IN X  
ENT.# IN X AFTER  
ALL WEIGHTS ARE  
ENTERED

250.000  
-31.900  
26.600

ALT.WIND PROFILE  
ENT.# IN X AFTER  
SURF.ENTRY

1.000  
14000.000  
25.000

2.000  
13000.000  
25.000

3.000  
10000.000  
60.000

4.000  
8000.000  
-15.000

5.000  
5000.000  
-30.000

6.000  
4000.000  
-20.000

12.000  
13522.000  
1000.000

ALT. 14000.000  
WIND,KNOTS 25.000  
DYN.PRESS. 1.379  
BALLONET FULLNS. 0.000  
MECH MOMENT 8512.252  
AERO MOMENT -8537.371  
EXTRAS MOMENT 0.000  
SUM OF MOMENTS -25.118  
TRIM ANGLE ATCK 7.490

CL 0.367  
AERO LIFT 640.213  
CD 0.146  
DRAG 254.388  
GROSS BUOY.LIFT 1934.099  
TOT.LIFT 2574.312  
SUM"EXTRA"MTS. 250.000  
TOT.WEIGHT 1220.000  
NET LIFT 1354.312  
TOTAL FORCE 1377.997  
ANGLE TO HORIZON 79.362

ALT. 13000.000  
WIND,KNOTS 25.000  
DYN.PRESS. 1.425  
BALLONET FULLNS. 0.108

MECH MOMENT 9013.180  
AERO MOMENT -9009.932  
EXTRAS MOMENT 0.000  
SUM OF MOMENTS 3.247  
TRIM ANGLE ATCK 7.570  
CL 0.371  
AERO LIFT 668.716  
CD 0.147  
DRAG 264.448  
GROSS BUOY.LIFT 1934.099  
TOT.LIFT 2602.815  
SUM"EXTRA"MTS. 250.000  
TOT.WEIGHT 1220.000  
NET LIFT 1382.815  
TOTAL FORCE 1407.875  
ANGLE TO HORIZON 79.174

ALT. 12000.000  
WIND,KNOTS 36.667  
DYN.PRESS. 3.167  
BALLONET FULLNS. 0.211

ALT. 10000.000  
 WIND, KNOTS 60.000  
 DYH. PRESS. 9.041  
 BALLONET FULLNS. 0.405  
 MECH MOMENT 10787.353  
 AERO MOMENT -10834.080  
 EXTRAS MOMENT 0.000  
 SUM OF MOMENTS -46.727  
 TRIM ANGLE ATCK 4.480  
 CL 0.220  
 AERO LIFT 2510.905  
 CD 0.120  
 DRAG 1375.439  
 GROSS BUOY. LIFT 1934.099  
 TOT. LIFT 4445.004  
 SUM "EXTRA" MTS. 250.000  
 TOT. WEIGHT 1220.000  
 NET LIFT 3225.004  
 TOTAL FORCE 3506.004  
 ANGLE TO HORIZON 66.902

ALT. 5000.000  
 WIND, KNOTS -30.000  
 DYH. PRESS. 2.637  
 BALLONET FULLNS. 0.822  
 MECH MOMENT 9743.951  
 AERO MOMENT -9759.784  
 EXTRAS MOMENT 0.000  
 SUM OF MOMENTS -15.833  
 TRIM ANGLE ATCK 5.930  
 CL 0.291  
 AERO LIFT 969.242  
 CD 0.131  
 DRAG 436.862  
 GROSS BUOY. LIFT 1934.099  
 TOT. LIFT 2903.342  
 SUM "EXTRA" MTS. 250.000  
 TOT. WEIGHT 1220.000  
 NET LIFT 1683.342  
 TOTAL FORCE 1739.105  
 ANGLE TO HORIZON 75.452

ALT. 4000.000  
 WIND, KNOTS -20.000  
 DYH. PRESS. 1.207  
 BALLONET FULLNS. 0.895  
 MECH MOMENT 8492.403  
 AERO MOMENT -8472.253  
 EXTRAS MOMENT 0.000  
 SUM OF MOMENTS 20.149  
 TRIM ANGLE ATCK 7.990  
 CL 0.392  
 AERO LIFT 597.938  
 CD 0.151  
 DRAG 231.115  
 GROSS BUOY. LIFT 1934.099  
 TOT. LIFT 2532.037  
 SUM "EXTRA" MTS. 250.000  
 TOT. WEIGHT 1220.000  
 NET LIFT 1312.037  
 TOTAL FORCE 1332.237  
 ANGLE TO HORIZON 80.010

READY NEXT PROB.  
 J.B.M. 76.005

### 3.5.8 NOTES

A. If incorrect data is entered, do not press STOP END to restart program. For a proper restart, clearing all registers, press the following:

STOP  
GO TO  
1  
9  
3  
4  
CONT

B. Extra Weight entry, STOPS 8, 9

The payload weight can be included here if desired. It will not affect the trim angle if located at the confluence point:

|                | (X)      | (Y)      | (Z)    |
|----------------|----------|----------|--------|
| STOP 8 (or 9): | $X^{CP}$ | $Y^{CP}$ | $Wt_P$ |

It will affect the net lift and hence the total force and its angle.

C. Altitude-Wind entries STOPS 10, 11

1. First wind entry, STOP 10, must be Point No. 1 in (Z), starting Max altitude (Ballonet empty) in Y, and the wind at that altitude in X.
2. Up to 12 more Alt-Wind Points may be entered (STOPS 11) to define the wind profile from max altitude to the surface.
3. The last entry must be the surface altitude and surface wind.
4. A "π" is then entered to cause the program to continue on to STOP 12.

D. This program was written for a Family-2 Balloon Design. It was tailored for a 45,000 CF size with several constants for this size built into the program. Should any of these differ when an actual 45,000 CF balloon is flown and measurements made, the following table indicates what step numbers in the program should be changed. The table also indicates the changes required to make a universal program for any size Family-2 balloon.

| <u>As Written</u> |                     | <u>To Modify for<br/>Continued 45,000<br/>CF Use</u> |                           | <u>To Generalize for<br/>Any Size<br/>Family-2 Balloon</u> |                   |
|-------------------|---------------------|------------------------------------------------------|---------------------------|------------------------------------------------------------|-------------------|
| <u>Step No.</u>   | <u>Key</u>          | <u>Key</u>                                           |                           | <u>Key</u>                                                 |                   |
| 0388              | 2 X of Confluence   | n                                                    | } Insert<br>Mod.<br>Dist. | 4                                                          | Stop No. 4        |
| 0389              | 6 Point = 26.6 ft   | n                                                    |                           | ↑                                                          |                   |
| 0390              | · = $X^{CP}$        | ·                                                    |                           | STOP                                                       | Ent $X^{CP}$ in X |
| 0391              | 6                   | n                                                    |                           | PNT                                                        |                   |
| 0397              | 3 Y of Confluence   | n                                                    | } Insert<br>Mod.<br>Dist. | 5                                                          | Stop No. 5        |
| 0398              | 1 Point = 31.9 ft   | n                                                    |                           | ↑                                                          |                   |
| 0399              | · = $Y^{CP}$        | ·                                                    |                           | ↑                                                          |                   |
| 0400              | 9                   | n                                                    |                           | STOP                                                       | Ent $Y^{CP}$ in X |
| 0401              | Chg S               | Chg S                                                |                           | PNT                                                        |                   |
| 0407              | 5 X of Center of    | n                                                    | } Insert<br>Mod.<br>Dist. | 6                                                          | Stop No. 6        |
| 0408              | 7 Gravity = 57.3 ft | n                                                    |                           | ↑                                                          |                   |
| 0409              | · = $X_{CG}$        | ·                                                    |                           | STOP                                                       | Ent $X_{CG}$ in X |
| 0410              | 3                   | n                                                    |                           | PNT                                                        |                   |
| 0417              | 2 Y of Center of    | n                                                    | } Insert<br>Mod.<br>Dist. | 7                                                          | Stop No. 7        |
| 0418              | · Gravity = 2.5-ft  | n                                                    |                           | ↑                                                          |                   |
| 0419              | 5 = $Y_{CG}$        | n                                                    |                           | STOP                                                       | Ent $Y_{CG}$ in X |
| 0420              | Chg S               | Chg S                                                |                           | PNT                                                        |                   |

E. Conversely, several parameters left as entries might be desired as fixed inputs when only one specific 45,000 CF balloon (or other size) is being investigated. The volume, weight, and envelope length may be made fixed by the following key strokes:

| <u>Step No.</u> | <u>Key</u> |                      | <u>Step No.</u> | <u>Key</u>  | <u>Step No.</u> | <u>Key</u> |                     |
|-----------------|------------|----------------------|-----------------|-------------|-----------------|------------|---------------------|
| 0353            | n          | Vol<br>of<br>Balloon | 0363            | 2           | 0373            | 1          | Wt<br>of<br>Balloon |
| 0354            | n          |                      | 0364            | ↑           | 0374            | n          |                     |
| 0355            | n          |                      | 0365            | 3           | 0375            | n          |                     |
| 0358            | n          |                      | 0366            | ÷           | 0376            | n          |                     |
| 0357            | n          |                      | 0367            | ↓           | 0377            | n          |                     |
| 0358            | n          |                      | 0368            | $x \circ y$ | 0378            | X→         |                     |
| 0359            | X→         |                      | 0369            | $x^y$       | 0379            | 1          |                     |
| 0360            | 4          |                      | 0370            | X→          | 0380            | CNT        |                     |
| 0361            | 2          |                      | 0371            | 0           | 0381            | n          | $\bar{c}$           |
| 0362            | ↑          |                      | 0372            | 4           | 0382            | n          |                     |
|                 |            |                      |                 |             | 0383            | n          |                     |
|                 |            |                      |                 |             | 0384            | n          |                     |
|                 |            |                      |                 |             | 0385            | n          |                     |
|                 |            |                      |                 |             | 0386            | X→         |                     |
|                 |            |                      |                 |             | 0387            | 8          |                     |

The ballonnet volume, v, is incorporated by the following changes:

| <u>Step No.</u> | <u>Key</u> |                       | <u>Step No.</u> | <u>Key</u>  |                                      |
|-----------------|------------|-----------------------|-----------------|-------------|--------------------------------------|
| 0753            | n          | Vol.<br>of<br>Balloon | 0763            | STOP        | Entry $\alpha$ in Y, $\Delta Z$ in X |
| 0754            | n          |                       | 0764            | $x \circ y$ |                                      |
| 0755            | n          |                       | 0765            | PNT         |                                      |
| 0756            | n          |                       | 0766            | X→          |                                      |
| 0757            | n          |                       | 0767            | 5           |                                      |
| 0758            | X→         |                       | 0768            | 7           |                                      |
| 0759            | 0          |                       | 0769            | Y→          |                                      |
| 0760            | CNT        |                       | 0770            | 1           |                                      |
| 0761            | 1          |                       | 0771            | 6           |                                      |
| 0762            | 2          |                       | 0772            | $x \circ y$ |                                      |
|                 |            |                       | 0773            | PNT         |                                      |

If a volume other than 45,000 CF was being considered, the modifications shown in Note D must also be made.

3.6 Program No. 76.006 — Tether Cable, 2-Dimensional Case, Variable Wind Profile,  
Optional Internal Variable Drag Coefficient

3.6.1 GENERAL DESCRIPTION

In the flight of a tethered-balloon one is typically concerned about the ability of the balloon (a) to lift the weight of the cable, (b) to retain a reasonable magnitude of cable tension at the ground, (c) to keep the cable tension at the top within a safe limit, and (d) to keep the balloon within a reasonable definition of the word "overhead" under varying conditions of altitude and wind.

All of the forces introduced by the balloon can be summed up into one force and its angle. This total force,  $F_T$ , and the angle  $\theta$ , can be computed by Program No. 76.003, 76.004, or 76.005. These two parameters are then treated as inputs to this cable Program No. 76.006.

The basic forces acting on the cable, in addition to the total force,  $F_T$ , acting at the top of the cable, are the aerodynamic drag and the cable weight. The weight is easily specified.

The drag is more difficult since it is a variable function of atmospheric density, wind velocity, and cable diameter. In addition, since the program was intended for use to altitudes up to 65,000 ft, the effect of Reynold's Number on drag coefficient could not be ignored. Accordingly, an option was permitted in the operation of the program to permit the user to either specify a cylinder,  $C_D$ , or to allow the program to compute a  $C_D$ . The former is held constant for all conditions while the latter varies with altitude-wind-velocity-diameter, per Section 3.6.2.

In concept, the cable is broken into rigid elements of a specified length,  $K$ , and the forces acting on this length evaluated to obtain a magnitude and angle which the next lower element must align with and provide equal restraint. Thereby, a series of outputs is possible at each of many points proceeding downwards from the balloon to the surface. The cable's space, position, angle, tension, and length are shown as outputs.

During the downward progression of calculations, the cable tension,  $T$ , and angle,  $\theta$ , are monitored for the condition of zero tension or horizontal cable. Under such conditions, the balloon has not provided sufficient lifting force for the size and weight of cable involved and the cable is said to be unable to reach the surface. For a given balloon and cable, a lower flight altitude is indicated. If such an event occurs at the surface, the cable is lying on the ground without tension. Hauling in some cable would bring the balloon to a lower altitude and lift the cable off the ground.

For a complete evaluation, the behavior of the tether cable during its ascent or descent and at its maximum altitude should be examined. Use of Program No. 76.003 or 76.005 to provide solutions for balloon  $F_T$  and  $\theta$  for maximum and

intermediate altitudes is suggested. Each of these solutions using the appropriate altitude and wind as the starting values in Program No. 76.006 will provide the complete analysis. It should be cautioned that this program as well as the others in this report provide answers for static conditions and do not attempt to consider the dynamics of balloon, cable, or system motion.

### 3.6.2 DEVELOPMENT OF PROGRAM AND EQUATIONS

This tether cable program will consider the 2-dimensional case only where the winds, cable, balloon and ground winch all lie in the plane of this paper. A negative wind may be used indicating flow from right to left in the diagram below.

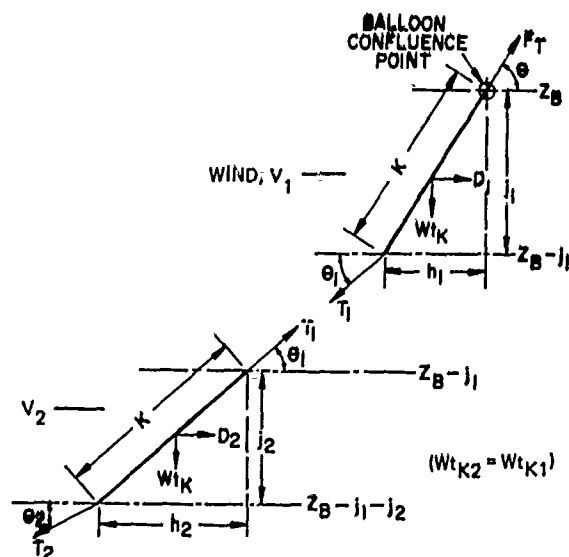
A. The objective of the program is, starting at the top of the tether cable where it is attached to the Confluence Point, to evaluate its tension, angle, space position, etc. moving downward to the earth's surface. Consider the cable as a series of rigid cylindrical elements of length,  $K$ , attached by freely pivoting connectors. Consider the wind to be constant over length,  $K$ .

Assume no moments are produced on short element  $K$ .  
 $\Sigma$  Forces in Horiz. Dir on 1st Element

$$(1) F_T \cos \theta + D_1 = T_1 \cos \theta_1$$

$\Sigma$  Forces in Vert. Dir. on 1st Element

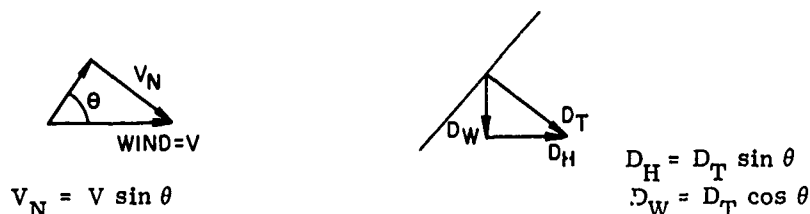
$$(2) F_T \sin \theta = W_1 + T_1 \sin \theta_1$$



In considering drag due to wind, one method would require a table of cylinder  $C_D$  values vs pitch angles. Since  $C_D$  is also affected by  $R$  (Reynolds No), such a double variable table would be cumbersome. Instead a pitch angle of  $0^\circ$  will be assumed and a wind component flow concept similar to wing-sweep will be utilized. This breaks the wind into a component normal to the cylinder as the drag producer and assumes that the other component parallel to the cylinder produces a negligible

skin friction. (Note: this may be improper at supercritical values of  $R$  but is better than neglecting pitch or assuming that  $C_D$  is a constant, a difficulty of other more simple programs.)

Therefore



$$(3) D_T = C_D qA = C_D A \frac{\rho}{2} V_N^2 = C_D A \rho / 2 V^2 (\sin \theta)^2$$

$$(4) D_H = C_D A \rho / 2 V^2 (\sin \theta)^3 = C_D qA (\sin \theta)^3$$

$$(5) D_W = C_D A \rho / 2 (\sin \theta)^2 \cos \theta = C_D qA (\sin \theta)^2 \cos \theta$$

However, the use of  $V_N$  will be required in calc. of  $R_n = \frac{\rho V_N d}{\mu}$  and  $q_N = \frac{\rho}{2} V_N^2$

$$(6) D_T = C_D A \rho / 2 V_N^2 = C_D A q_N$$

$$(7) D_H = C_D A \rho / 2 V_N^2 \sin \theta = C_D A q_N \sin \theta$$

$$(8) D_W = C_D A \rho / 2 V_N^2 \cos \theta = C_D A q_N \cos \theta$$

$$\text{Eq. (1)} \rightarrow (9) F_T \cos \theta + D_{H1} = T_1 \cos \theta_1$$

$$\text{Eq. (2)} \rightarrow (10) F_T \sin \theta = W_1 + D_{W1} + T_1 \sin \theta_1$$

$$(11) T_1 = \frac{F_T \cos \theta + D_{H1}}{\cos \theta_1}$$

$$(12) \frac{F_T \cos \theta + D_{H1}}{\cos \theta} \sin \theta_1 = F_T \sin \theta - W_1 - D_{W1}$$

$$(13) \tan \theta_1 = \frac{F_T \sin \theta - W_1 - D_{W1}}{F_T \cos \theta + D_{H1}}$$

$$(14) \theta_1 = \arctan \frac{F_T \sin \theta - (W_1 + D_{W1})}{F_T \cos \theta + D_{H1}}$$

← Angle of next lower element

$$(15) T_1 = \frac{F_T \cos \theta + D_{H1}}{\cos \theta_1}$$

← Tension at top of next lower element

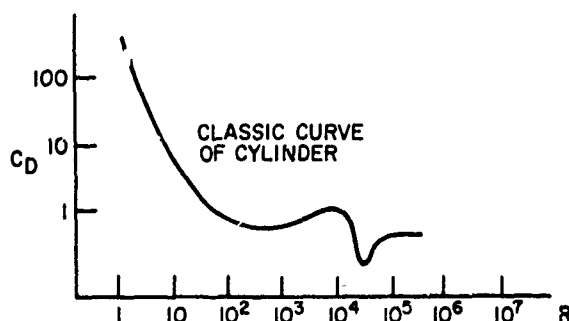
NOTE: Before obtaining values of  $\theta_1$  and  $T_1$ , the space position of the bottom end of the element is determined by:

Vert. Displ: (15)  $j_1 = K \sin \theta$

Hor. Displ: (16)  $h_1 = K \cos \theta$

Program proceeds on down, one K element at a time, until the sum of the  $j \approx Z - Z_s$ .

B. Reynolds No. vs  $C_D$   $R = \frac{\rho V_N \text{ diam.}}{\mu}$



(17a) For  $R < 1$ , assumed Stokes condition:  $C_D = (10.9/R)/(.87 - \log R)$

To incorporate conditions where  $R > 1$  into program, series of straight lines on a semi-log plot were used as approximations. At  $R_{cr}$  area used roughness cond.

$k/d = 0.009 \left( \frac{\text{height rough}}{\text{diam.}} \right)$ , Reference 3.

(17b)  $R > 1$   $C_D = C_{D \text{ Base Point}} + K_R (\log R - \log R_{\text{Base Point}})$ . This is obtained by working from low end of R towards larger values, and taking slopes of  $C_D$ -R moving left to right on plot.

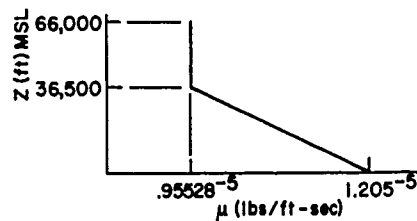
Under Condition B, ( $R > 1$ ), the following constants are included in program storage for  $C_D$  solution.

| <u>Region</u> |               | <u><math>R_{\text{Base}}</math></u> | <u><math>C_{D \text{ Base}}</math></u> | <u><math>K_R</math></u> |
|---------------|---------------|-------------------------------------|----------------------------------------|-------------------------|
| $n_{CD}$      | $R < 9$       | 1                                   | 12.5                                   | -10                     |
| $n_{CD}$      | $R < 900$     | 9                                   | 2.18                                   | -1                      |
| $n_{CD}$      | $R < 4500$    | 900                                 | .98                                    | 0                       |
| $n_{CD}$      | $R < 9000$    | 4500                                | .98                                    | .7308                   |
| $n_{CD}$      | $R < 40,000$  | 9000                                | 1.2                                    | 0                       |
| $n_{CD}$      | $R < 50,000$  | 40,000                              | 1.2                                    | -4.54                   |
| $n_{CD}$      | $R < 250,000$ | 50,000                              | .76                                    | .3434                   |
| $n_{CD}$      | $R > 250,000$ | 25,000                              | 1.0                                    | 0                       |

3. Hoerner, S. F. (1958) Fluid Dynamic Drag, Publ. by author.

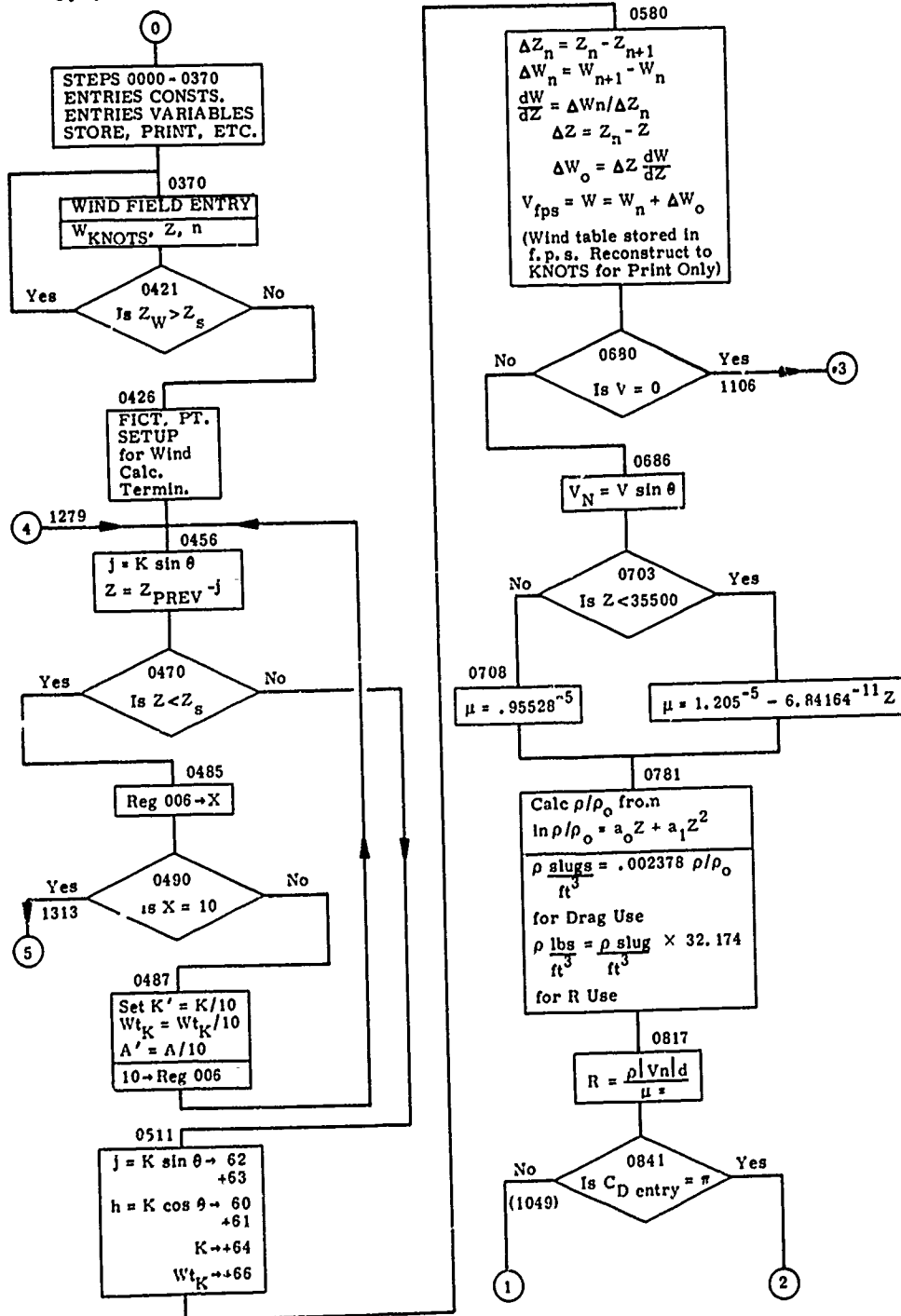
C. Coefficient of Viscosity,  $\mu$ , for  $R = \frac{\rho V_N d}{\mu}$

The 1962 Std. Atm. values of  $\mu$  plotted shows that, within accuracies needed in this  $C_D$  usage, 2 straight lines are sufficient to define the variation of  $\mu$  with altitude.

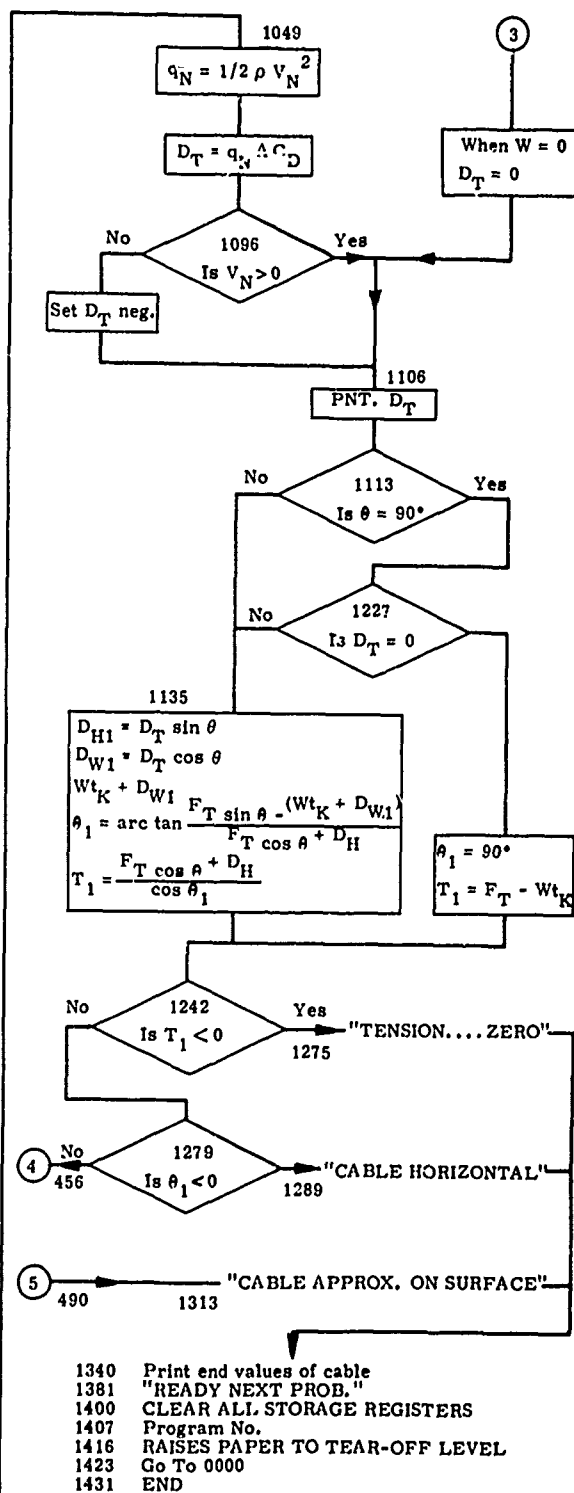
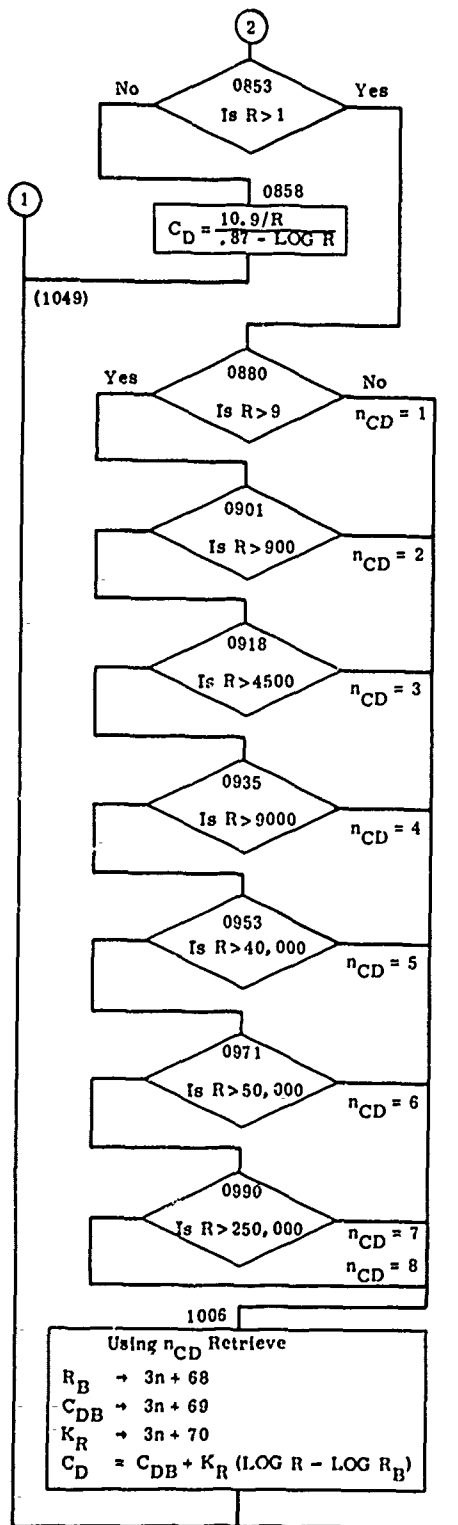


- (18a) From  $Z = 0$  to  $36,500$ :  $\mu = 1.205^{-5} - 6.8416 \times 10^{-11} Z$ ,  
 (18b) From  $Z = 36,500$  to  $66,000$ :  $\mu = .95528^{-5}$ .

### 3.6.3 FLOW CHART



Note: In flow chart, n is used for wind profile point number,  $n_{CD}$  for  $C_D$ -R region number.



### 3.6.4 OPERATING INSTRUCTIONS

| <u>KEY STROKES</u> |                                                                                                                   | <u>ENTRIES</u>                     |                                      |
|--------------------|-------------------------------------------------------------------------------------------------------------------|------------------------------------|--------------------------------------|
| RUN                |                                                                                                                   |                                    |                                      |
| END                |                                                                                                                   |                                    |                                      |
| FIX, 2, 3, ----    |                                                                                                                   |                                    |                                      |
|                    |                                                                                                                   |                                    | (No. of decimal places desired)      |
| CONT               | (X)                                                                                                               | (Y)                                | (Z)                                  |
| Stop 1-1-1, Enter: | $\pi$ or $C_D^*$                                                                                                  | $Z_{\text{Surf}}$ , (ft, MSL)      | $Z_{\text{Balloon}}$ , (ft, MSL)     |
|                    | *Enter $\pi$ to use built-in cylinder $C_D$ variation or Enter $C_D$ value which will be used throughout program. |                                    |                                      |
| CONT               |                                                                                                                   |                                    |                                      |
| Stop 2-2-2, Enter: | 0 or $K^*$<br>(Element Length)                                                                                    | Wt/1000 ft(lb)<br>(cable)          | Diam. (in.)<br>(cable)               |
|                    | *Enter 0 to set $K = \frac{Z_B - Z_S}{100}$ or Enter K in ft                                                      |                                    |                                      |
| CONT               |                                                                                                                   |                                    |                                      |
| Stop 3-3-3, Enter: | $\theta$ (deg.)<br>(Angle to Horiz.)                                                                              | $F_T$ (lb)<br>(Balloon tot. Force) | —                                    |
| CONT               |                                                                                                                   |                                    |                                      |
| Stop 4-4-4, Enter: | Wind (Knots)                                                                                                      | Z (ft)<br>(First Entry Z Balloon)  | Wind Entry Number<br>First Entry #1) |
| CONT               |                                                                                                                   |                                    |                                      |
| Stop 4-4-4, Enter: | Wind                                                                                                              | Z                                  | Wind Entry Number                    |
|                    | Until, last set of entries <u>must</u> be for<br>$Z = Z_{\text{surface}}$                                         |                                    |                                      |

#### CONT

The above entries will be printed out in groups as they are entered as follows:

|                |                                                                                    |
|----------------|------------------------------------------------------------------------------------|
| $Z_B$          | Balloon Altitude, ft MSL                                                           |
| $Z_S$          | Surface Altitude, ft MSL                                                           |
| $\pi$ or $C_D$ | $\pi$ to indicate internal use of variable $C_D$<br>$C_D$ to use as constant $C_D$ |
| Diam.          | Diameter of cable, in.                                                             |
| Wt/1000        | Weight of 1000 ft of cable, lb                                                     |
| K              | Element length, ft either K entered or<br>$K = \frac{Z_B - Z_S}{100}$              |

$F_T$  Total balloon force, lb  
 $\theta$  Angle of  $F_T$  to horizon, deg

"Enter Wind Field"

1 First wind entry No.  
 $Z_B$  Altitude, (balloon), ft MSL  
 $W$  Wind, (at balloon), knots  
2 Second Entry  
 $Z$  Alt  
 $W$  Wind  
3 Third Entry  
 $Z$  Alt  
 $W$  Wind  
-  
-  
-  
-  
-  
# Last Entry No. (Max. 11 Sets of Entries)  
 $Z_S$  Altitude - (surface)  
 $W$  Wind (at surface)

A. The following parameters are then printed for each K element downward to surface. NOTE: To avoid print of any or all of these replace "PRINT" with "CONT" at associated program step numbers.

| STEP<br>NO. |               |                                                                         |
|-------------|---------------|-------------------------------------------------------------------------|
| 479         | $Z$           | Altitude, ft MSL of element bottom                                      |
| 530         | $j$           | Vert. Dist., top to bottom of element, ft                               |
| 534         | $\Sigma j$    | Total Vert. Dist., balloon to bottom of element                         |
| 547         | $h$           | Horizontal Dist., top to bottom of element, ft                          |
| 551         | $\Sigma h$    | Total Horiz. Dist., balloon to bottom of element                        |
| 561         | $\Sigma K$    | Total element (cable) lengths, ft                                       |
| 565         | $\Sigma Wt_K$ | Total element (cable) weights, lb                                       |
| 675         | $W$           | Wind at bottom of element, knots, assumed acting over length of element |
| 834         | $R$           | Reynolds number                                                         |
| 1050        | $C_D$         | Drag Coefficient                                                        |
| 1083        | $q$           | Dynamic pressure, lb/ft <sup>2</sup>                                    |
| 1106        | $D_T$         | Total Element drag, lb                                                  |
| 1147        | $D_H$         | Horiz Component of Drag, lb                                             |

|                  |            |                                                            |
|------------------|------------|------------------------------------------------------------|
| 1160             | $D_W$      | Vert. Component of Drag, lb                                |
| 1194<br>1211     | $\theta_1$ | Angle of next element, deg                                 |
| 1202-3<br>1273-4 | $T_1$      | Tension, top of next element, lb<br>(bottom of this elem.) |

B. Ending of Program:

| When cable reaches near surface<br>( $<K$ ), prints "CABLE APPROX.<br>AT SURFACE" |                                     | If $T_1 < 0$ , prints<br>"TENSION IS<br>ZERO" | If $\theta_1 < 0$ ,<br>prints "CABLE<br>HORIZONTAL" |
|-----------------------------------------------------------------------------------|-------------------------------------|-----------------------------------------------|-----------------------------------------------------|
| $Z$                                                                               | Altitude, ft<br>(surf)              | (where $T_1 \approx 0$ )                      | (where $\theta \approx 0$ )                         |
| $\theta_1$                                                                        | Angle at winch,<br>deg              | "                                             | $\sim 0$                                            |
| $T_1$                                                                             | Tension at winch                    | $\sim 0$                                      | (where $\theta_1 \approx 0$ )                       |
| $r_j$                                                                             | Vert. Dist., ft<br>( $Z_B - Z_S$ )  | (where $T_1 \approx 0$ )                      | "                                                   |
| $r_h$                                                                             | Horiz. Dist., ft<br>(ball. - winch) | "                                             | "                                                   |
| $r_K$                                                                             | Cable Length, ft                    | "                                             | "                                                   |
| $rWt_K$                                                                           | Cable Weight, lb                    | "                                             | "                                                   |
| $\Sigma D_W$                                                                      | Tot. Vert. Comp. of<br>Drag, lbs.   | "                                             | "                                                   |
| $\Sigma D_W + rWt$                                                                | Sum Vertical Forces,<br>lbs.        | "                                             | "                                                   |
| $\Sigma D_H$                                                                      | Tot. Hor. Comp. of<br>Drag, lb      | "                                             | "                                                   |

### 3.6.5 SAMPLE INPUT DATA FORM

|                                                                                                         |                        |        |                  |
|---------------------------------------------------------------------------------------------------------|------------------------|--------|------------------|
| INPUT                                                                                                   |                        | 76.006 |                  |
| Altitude, Max. Starting.                                                                                | $Z_B$                  |        | ft, MSL          |
| Altitude, Surface                                                                                       | $Z_S$                  |        | ft, MSL          |
| Cable Diameter                                                                                          |                        |        | in.              |
| Cable Weight/1000 ft                                                                                    |                        |        | lb               |
| Total Force                                                                                             | $F_T$                  |        | lb               |
| Angle of $F_T$                                                                                          | $\theta$               |        | deg              |
| WIND PROFILE                                                                                            |                        |        |                  |
| Must use minimum of 2 points. No. 1 always $Z_B$ . Last point always $Z_S$ .<br>Max. No. of points: 11. | No. 1<br>$Z_B$<br>Wind | 1      | ft, MSL<br>knots |
|                                                                                                         | No. 2<br>$Z$<br>Wind   | 2      |                  |
|                                                                                                         | No. 3<br>$Z$<br>Wind   | 3      |                  |
|                                                                                                         | No. 4<br>$Z$<br>Wind   | 4      |                  |
|                                                                                                         | No. 5<br>$Z$<br>Wind   | 5      |                  |
|                                                                                                         | No. 6<br>$Z$<br>Wind   | 6      |                  |
|                                                                                                         | No. 7<br>$Z$<br>Wind   | 7      |                  |
|                                                                                                         | No. 8<br>$Z$<br>Wind   | 8      |                  |
|                                                                                                         | No. 9<br>$Z$<br>Wind   | 9      |                  |
|                                                                                                         | No. 10<br>$Z$<br>Wind  | 10     |                  |
|                                                                                                         | No. 11<br>$Z$<br>Wind  | 11     |                  |

From Output of  
76.003, 4,  
or 5

# 3.6.6 PROGRAM 76.006 - TETHER CABLE, 2-DIMENSIONAL

| STEP   | KEY. | STEP   | KEY | STEP   | KEY | STEP   | KEY | STEP   | KEY | STEP   | KEY |
|--------|------|--------|-----|--------|-----|--------|-----|--------|-----|--------|-----|
| 0000-- | CLP  | 0050-- | 7   | 0100-- | 1   | 0150-- | 1   | 0200-- | 0   | 0250-- | 1   |
| 0001-- | FHT  | 0051-- | 7   | 0101-- | 2   | 0151-- | 0   | 0201-- | 0   | 0251-- | UP  |
| 0002-- | FHT  | 0052-- | 1   | 0102-- | .   | 0152-- | XTO | 0202-- | XTO | 0252-- | UP  |
| 0003-- | #    | 0053-- | 6   | 0103-- | 5   | 0153-- | 7   | 0203-- | 0   | 0253-- | STP |
| 0004-- | a    | 0054-- | 7   | 0104-- | XTO | 0154-- | 9   | 0204-- | 8   | 0254-- | RUP |
| 0005-- | 0    | 0055-- | CHS | 0105-- | 0   | 0155-- | XTO | 0205-- | 6   | 0255-- | PHT |
| 0006-- | G    | 0056-- | EEX | 0106-- | 7   | 0156-- | 8   | 0206-- | 4   | 0256-- | XTO |
| 0007-- | a    | 0057-- | 1   | 0107-- | 2   | 0157-- | 5   | 0207-- | .   | 0257-- | 3   |
| 0008-- | A    | 0058-- | 0   | 0108-- | 1   | 0158-- | XTO | 0208-- | 5   | 0258-- | RUP |
| 0009-- | M    | 0059-- | CHS | 0109-- | 0   | 0159-- | 0   | 0209-- | 4   | 0259-- | PHT |
| 0010-- | CHT  | 0060-- | XTO | 0110-- | CHS | 0160-- | 9   | 0210-- | CHS | 0260-- | XTO |
| 0011-- | GTO  | 0061-- | 0   | 0111-- | XTO | 0161-- | 4   | 0211-- | XTO | 0261-- | 4   |
| 0012-- | 7    | 0062-- | 3   | 0112-- | 0   | 0162-- | 4   | 0212-- | 0   | 0262-- | RUP |
| 0013-- | 6    | 0063-- | 9   | 0113-- | 7   | 0163-- | 5   | 0213-- | 8   | 0263-- | PHT |
| 0014-- | .    | 0064-- | 2   | 0114-- | 3   | 0164-- | 0   | 0214-- | 8   | 0264-- | XTO |
| 0015-- | 0    | 0065-- | .   | 0115-- | 9   | 0165-- | 0   | 0215-- | 5   | 0265-- | 0   |
| 0016-- | 0    | 0066-- | 8   | 0116-- | XTO | 0166-- | XTO | 0216-- | 0   | 0266-- | 7   |
| 0017-- | 6    | 0067-- | 1   | 0117-- | 0   | 0167-- | 0   | 0217-- | 0   | 0267-- | 0   |
| 0018-- | CLR  | 0068-- | 3   | 0118-- | 7   | 0168-- | 8   | 0218-- | 0   | 0268-- | 2   |
| 0019-- | 2    | 0069-- | 6   | 0119-- | .   | 0169-- | 0   | 0219-- | 0   | 0269-- | UP  |
| 0020-- | -    | 0070-- | 0   | 0120-- | 2   | 0170-- | .   | 0220-- | XTO | 0270-- | UP  |
| 0021-- | CHT  | 0071-- | 6   | 0121-- | .   | 0171-- | 7   | 0221-- | 0   | 0271-- | STP |
| 0022-- | D    | 0072-- | CHS | 0122-- | 9   | 0172-- | 3   | 0222-- | 8   | 0272-- | RUP |
| 0023-- | I    | 0073-- | EEX | 0123-- | 8   | 0173-- | 0   | 0223-- | 9   | 0273-- | PHT |
| 0024-- | M    | 0074-- | 5   | 0124-- | XTO | 0174-- | 8   | 0224-- | .   | 0274-- | RUP |
| 0025-- | E    | 0075-- | CHS | 0125-- | 0   | 0175-- | XTO | 0225-- | 7   | 0275-- | PHT |
| 0026-- | N    | 0076-- | XTO | 0126-- | 7   | 0176-- | 0   | 0226-- | 6   | 0276-- | XTO |
| 0027-- | YTO  | 0077-- | 0   | 0127-- | 5   | 0177-- | 8   | 0227-- | XTO | 0277-- | 0   |
| 0028-- | I    | 0078-- | 3   | 0128-- | 1   | 0178-- | 2   | 0228-- | 0   | 0278-- | 0   |
| 0029-- | 0    | 0079-- | 8   | 0129-- | CHS | 0179-- | 9   | 0229-- | 9   | 0279-- | 7   |
| 0030-- | H    | 0080-- | 1   | 0130-- | XTO | 0180-- | 0   | 0230-- | 0   | 0280-- | 1   |
| 0031-- | A    | 0081-- | .   | 0131-- | 0   | 0181-- | 0   | 0231-- | .   | 0281-- | 2   |
| 0032-- | L    | 0082-- | 6   | 0132-- | 7   | 0182-- | 0   | 0232-- | 3   | 0282-- | DIV |
| 0033-- | CLR  | 0083-- | 8   | 0133-- | 6   | 0183-- | XTO | 0233-- | 4   | 0283-- | YTO |
| 0034-- | XTO  | 0084-- | 7   | 0134-- | 9   | 0184-- | 0   | 0234-- | 3   | 0284-- | 9   |
| 0035-- | E    | 0085-- | 8   | 0135-- | 0   | 0185-- | 8   | 0235-- | 4   | 0285-- | DN  |
| 0036-- | XTO  | 0086-- | XTO | 0136-- | 0   | 0186-- | 3   | 0236-- | XTO | 0286-- | 0   |
| 0037-- | H    | 0087-- | 0   | 0137-- | XTO | 0187-- | 1   | 0237-- | 0   | 0287-- | X=Y |
| 0038-- | E    | 0088-- | 3   | 0138-- | 0   | 0188-- | .   | 0238-- | 9   | 0288-- | 0   |
| 0039-- | a    | 0089-- | 7   | 0139-- | 7   | 0189-- | 2   | 0239-- | 1   | 0289-- | 3   |
| 0040-- | CHT  | 0090-- | 1   | 0140-- | 7   | 0190-- | XTO | 0240-- | 2   | 0290-- | 9   |
| 0041-- | C    | 0091-- | XTO | 0141-- | .   | 0191-- | 8   | 0241-- | 5   | 0291-- | 7   |
| 0042-- | A    | 0092-- | 6   | 0142-- | 9   | 0192-- | 4   | 0242-- | 0   | 0292-- | GTO |
| 0043-- | B    | 0093-- | XTO | 0143-- | 8   | 0193-- | XTO | 0243-- | 0   | 0293-- | 0   |
| 0044-- | L    | 0094-- | 7   | 0144-- | XTO | 0194-- | 0   | 0244-- | 0   | 0294-- | 3   |
| 0045-- | E    | 0095-- | 1   | 0145-- | 7   | 0195-- | 8   | 0245-- | 0   | 0295-- | 0   |
| 0046-- | FHT  | 0096-- | XTO | 0146-- | 8   | 0196-- | 7   | 0246-- | XTO | 0296-- | 9   |
| 0047-- | I    | 0097-- | 0   | 0147-- | XTO | 0197-- | 4   | 0247-- | 0   | 0297-- | XFR |
| 0048-- | .    | 0098-- | 9   | 0148-- | 0   | 0198-- | 0   | 0248-- | 9   | 0298-- | 3   |
| 0049-- | 7    | 0099-- | 3   | 0149-- | 8   | 0199-- | 0   | 0249-- | 2   | 0299-- | UP  |

| STEP      | KEY | STEP      | KEY | STEP      | KEY | STEP      | KEY | STEP      | KEY | STEP      | KEY |
|-----------|-----|-----------|-----|-----------|-----|-----------|-----|-----------|-----|-----------|-----|
| 0300--XFR |     | 0350--XTO |     | 0400--YTO |     | 0450--XTO |     | 0500--XTO |     | 0550-- 1  |     |
| 0301-- 4  |     | 0351-- 4  |     | 0401-- a  |     | 0451-- +  |     | 0501--DIV |     | 0551--PNT |     |
| 0302-- -  |     | 0352-- 1  |     | 0402--RUP |     | 0452-- a  |     | 0502-- 7  |     | 0552--XFR |     |
| 0303-- 1  |     | 0353--FMT |     | 0403--XEY |     | 0453--YTO |     | 0503--XTO |     | 0553-- 7  |     |
| 0304-- 0  |     | 0354--FMT |     | 0404--XFR |     | 0454--IND |     | 0504--DIV |     | 0554--XTO |     |
| 0305-- 0  |     | 0355-- E  |     | 0405-- 3  |     | 0455-- a  |     | 0505-- 2  |     | 0555-- +  |     |
| 0306--    |     | 0356-- N  |     | 0406-- 7  |     | 0456--XFR |     | 0506--GTO |     | 0556-- 6  |     |
| 0307-- 0  |     | 0357--XTO |     | 0407-- X  |     | 0457-- 2  |     | 0507-- 0  |     | 0557-- 6  |     |
| 0308--DIV |     | 0358--    |     | 0408--YTO |     | 0458-- M  |     | 0508-- 4  |     | 0558--XFR |     |
| 0309-- DN |     | 0359--IND |     | 0409--IND |     | 0459-- UP |     | 0509-- 5  |     | 0559-- 6  |     |
| 0310--PNT |     | 0360-- I  |     | 0410-- a  |     | 0460--XFR |     | 0510-- 6  |     | 0560-- 4  |     |
| 0311-- UP |     | 0361-- N  |     | 0411-- 1  |     | 0461-- 5  |     | 0511--XFR |     | 0561--PNT |     |
| 0312-- 1  |     | 0362-- D  |     | 0412--XTO |     | 0462-- X  |     | 0512-- 2  |     | 0562--XFR |     |
| 0313-- 0  |     | 0363--CNT |     | 0413-- -  |     | 0463--XFR |     | 0513-- M  |     | 0563-- 6  |     |
| 0314-- 0  |     | 0364-- F  |     | 0414-- a  |     | 0464-- 4  |     | 0514-- UP |     | 0564-- 6  |     |
| 0315-- 0  |     | 0365-- I  |     | 0415--XFR |     | 0465-- !  |     | 0515--XFR |     | 0565--PNT |     |
| 0316-- UP |     | 0366-- E  |     | 0416--IND |     | 0466--XEY |     | 0516-- 5  |     | 0566--CNT |     |
| 0317--XFR |     | 0367-- L  |     | 0417-- a  |     | 0467-- -  |     | 0517-- X  |     | 0567--CNT |     |
| 0318-- 7  |     | 0368-- D  |     | 0418-- UP |     | 0468--XFR |     | 0518--YTO |     | 0568--CNT |     |
| 0319--XEY |     | 0369--FMT |     | 0419--XFR |     | 0469-- 4  |     | 0519-- 6  |     | 0569--CNT |     |
| 0320--DIV |     | 0370-- 4  |     | 0420-- 4  |     | 0470--X>Y |     | 0520-- 2  |     | 0570--CNT |     |
| 0321-- DN |     | 0371-- UP |     | 0421--X<Y |     | 0471-- 0  |     | 0521--YTO |     | 0571--CNT |     |
| 0322-- X  |     | 0372-- UP |     | 0422-- 0  |     | 0472-- 4  |     | 0522-- +  |     | 0572--CNT |     |
| 0323--YTO |     | 0373--STP |     | 0423-- 3  |     | 0473-- 8  |     | 0523-- 6  |     | 0573--CNT |     |
| 0324-- 7  |     | 0374--RUP |     | 0424-- 7  |     | 0474-- 5  |     | 0524-- 3  |     | 0574--CNT |     |
| 0325--XFR |     | 0375--PNT |     | 0425-- 0  |     | 0475--YTO |     | 0525--XTO |     | 0575--CNT |     |
| 0326-- 4  |     | 0376--RUP |     | 0426-- UP |     | 0476-- 4  |     | 0526-- +  |     | 0576--CNT |     |
| 0327--RUP |     | 0377--PNT |     | 0427-- 2  |     | 0477-- 1  |     | 0527-- 6  |     | 0577--CNT |     |
| 0328-- X  |     | 0378--RUP |     | 0428--XTO |     | 0478-- DN |     | 0528-- 4  |     | 0578--CNT |     |
| 0329--XTO |     | 0379--PNT |     | 0429-- +  |     | 0479--PNT |     | 0529--XEY |     | 0579--CNT |     |
| 0330-- 5  |     | 0380--PNT |     | 0430-- a  |     | 0480--GTO |     | 0530--PNT |     | 0580-- 6  |     |
| 0331--YTO |     | 0381--YTO |     | 0431--XFR |     | 0481-- 0  |     | 0531--XFR |     | 0581-- UP |     |
| 0332-- 0  |     | 0382-- 3  |     | 0432-- 5  |     | 0482-- 5  |     | 0532-- 6  |     | 0582-- 1  |     |
| 0333-- 0  |     | 0383-- 5  |     | 0433-- UP |     | 0483-- 1  |     | 0533-- 3  |     | 0583-- +  |     |
| 0334-- 8  |     | 0384--XEY |     | 0434-- 2  |     | 0484-- 1  |     | 0534--PNT |     | 0584-- 2  |     |
| 0335-- 3  |     | 0385-- 2  |     | 0435-- X  |     | 0485--XFR |     | 0535--XFR |     | 0585-- X  |     |
| 0336-- UP |     | 0386--RUP |     | 0436-- DN |     | 0486-- 6  |     | 0536-- 2  |     | 0586-- 9  |     |
| 0337-- UP |     | 0387-- X  |     | 0437-- -  |     | 0487-- UP |     | 0537-- H  |     | 0587-- +  |     |
| 0338--STP |     | 0388-- 9  |     | 0438--YTO |     | 0488-- 1  |     | 0538-- X  |     | 0588--YTO |     |
| 0339--YTO |     | 0389-- +  |     | 0439--IND |     | 0489-- 0  |     | 0539--YTO |     | 0589-- a  |     |
| 0340-- 1  |     | 0390--YTO |     | 0440-- a  |     | 0490--X=Y |     | 0540-- 6  |     | 0590--XFR |     |
| 0341--XEY |     | 0391-- a  |     | 0441-- 1  |     | 0491-- 1  |     | 0541-- 0  |     | 0591--IND |     |
| 0342--PNT |     | 0392--XFR |     | 0442--XTO |     | 0492-- 3  |     | 0542--YTO |     | 0592-- a  |     |
| 0343--YTO |     | 0393-- 3  |     | 0443-- -  |     | 0493-- 1  |     | 0543-- +  |     | 0593-- UP |     |
| 0344-- 2  |     | 0394-- 5  |     | 0444-- a  |     | 0494-- 3  |     | 0544-- 6  |     | 0594--XFR |     |
| 0345--XEY |     | 0395--XTO |     | 0445--XFR |     | 0495--XTO |     | 0545-- 1  |     | 0595-- 4  |     |
| 0346--PNT |     | 0396--IND |     | 0446--IND |     | 0496-- 6  |     | 0546-- DN |     | 0596-- 1  |     |
| 0347--PNT |     | 0397-- a  |     | 0447-- a  |     | 0497--XTO |     | 0547--PNT |     | 0597--X>Y |     |
| 0348--XFR |     | 0398-- 1  |     | 0448-- UP |     | 0498--DIV |     | 0548--XFR |     | 0598-- 0  |     |
| 0349-- 3  |     | 0399-- +  |     | 0449-- 2  |     | 0499-- 5  |     | 0549-- 6  |     | 0599-- 6  |     |

| STEP   | KEY | STEP   | KEY | STEP   | KEY | STEP   | KEY | STEP   | KEY | STEP   | KEY |
|--------|-----|--------|-----|--------|-----|--------|-----|--------|-----|--------|-----|
| 0600-- | 1   | 0650-- | -   | 0700-- | 5   | 0750-- | CNT | 0800-- | 3   | 0850-- | 9   |
| 0601-- | 3   | 0651-- | DN  | 0701-- | 0   | 0751-- | CNT | 0801-- | 7   | 0851-- | 1   |
| 0602-- | 1   | 0652-- | KEY | 0702-- | 0   | 0752-- | CNT | 0802-- | 8   | 0852-- | RUP |
| 0603-- | UP  | 0653-- | DIV | 0703-- | X>Y | 0753-- | CNT | 0803-- | 0   | 0853-- | X>Y |
| 0604-- | 5   | 0654-- | XFR | 0704-- | 0   | 0754-- | CNT | 0804-- | X   | 0854-- | 0   |
| 0605-- | +   | 0655-- | 3   | 0705-- | 7   | 0755-- | CNT | 0805-- | YTO | 0855-- | 8   |
| 0606-- | YTO | 0656-- | 5   | 0706-- | 2   | 0756-- | CNT | 0806-- | 0   | 0856-- | 8   |
| 0607-- | 6   | 0657-- | UP  | 0707-- | 5   | 0757-- | CNT | 0807-- | 4   | 0857-- | 0   |
| 0608-- | GTO | 0658-- | XFR | 0708-- | .   | 0758-- | CNT | 0808-- | 2   | 0858-- | UP  |
| 0609-- | 0   | 0659-- | 4   | 0709-- | 9   | 0759-- | CNT | 0809-- | 3   | 0859-- | 1   |
| 0610-- | 5   | 0660-- | 1   | 0710-- | 5   | 0760-- | CNT | 0810-- | 2   | 0860-- | 0   |
| 0611-- | 8   | 0661-- | -   | 0711-- | 5   | 0761-- | CNT | 0811-- | .   | 0861-- | .   |
| 0612-- | 0   | 0662-- | DN  | 0712-- | 2   | 0762-- | CNT | 0812-- | 1   | 0862-- | 9   |
| 0613-- | 2   | 0663-- | X   | 0713-- | 8   | 0763-- | CNT | 0813-- | 7   | 0863-- | KEY |
| 0614-- | RUP | 0664-- | XFR | 0714-- | EEX | 0764-- | CNT | 0814-- | 4   | 0864-- | DIV |
| 0615-- | KEY | 0665-- | 3   | 0715-- | 5   | 0765-- | CNT | 0815-- | 0   | 0865-- | K   |
| 0616-- | -   | 0666-- | 6   | 0716-- | CHS | 0766-- | CNT | 0816-- | X   | 0866-- | 4   |
| 0617-- | YTO | 0667-- | +   | 0717-- | XTO | 0767-- | CNT | 0817-- | XFR | 0867-- | UP  |
| 0618-- | a   | 0668-- | UP  | 0718-- | 4   | 0768-- | CNT | 0818-- | 4   | 0868-- | .   |
| 0619-- | XFR | 0669-- | DN  | 0719-- | 3   | 0769-- | CNT | 0819-- | 3   | 0869-- | 8   |
| 0620-- | IND | 0670-- | XFR | 0720-- | GTO | 0770-- | CNT | 0820-- | DIV | 0870-- | 7   |
| 0621-- | a   | 0671-- | 3   | 0721-- | 0   | 0771-- | CNT | 0821-- | XFR | 0871-- | KEY |
| 0622-- | RUP | 0672-- | 7   | 0722-- | 7   | 0772-- | CNT | 0822-- | 9   | 0872-- | -   |
| 0623-- | YTO | 0673-- | DIV | 0723-- | 8   | 0773-- | CNT | 0823-- | X   | 0873-- | DN  |
| 0624-- | 3   | 0674-- | DN  | 0724-- | 1   | 0774-- | CNT | 0824-- | XFR | 0874-- | DIV |
| 0625-- | 5   | 0675-- | PNT | 0725-- | 6   | 0775-- | CNT | 0825-- | 5   | 0875-- | GTO |
| 0626-- | -   | 0676-- | YTO | 0726-- | .   | 0776-- | CNT | 0826-- | 1   | 0876-- | 1   |
| 0627-- | 1   | 0677-- | 0   | 0727-- | 8   | 0777-- | CNT | 0827-- | KEY | 0877-- | 0   |
| 0628-- | RUP | 0678-- | 4   | 0728-- | 4   | 0778-- | CNT | 0828-- | G   | 0878-- | 4   |
| 0629-- | +   | 0679-- | 6   | 0729-- | 1   | 0779-- | CNT | 0829-- | X   | 0879-- | 9   |
| 0630-- | YTO | 0680-- | 0   | 0730-- | 6   | 0780-- | CNT | 0830-- | YTO | 0880-- | UP  |
| 0631-- | a   | 0681-- | X=Y | 0731-- | 4   | 0781-- | DN  | 0831-- | 4   | 0881-- | 0   |
| 0632-- | XFR | 0682-- | 1   | 0732-- | EEX | 0782-- | DN  | 0832-- | 8   | 0882-- | 0   |
| 0633-- | IND | 0683-- | 1   | 0733-- | 1   | 0783-- | XFR | 0833-- | DN  | 0883-- | 9   |
| 0634-- | a   | 0684-- | 0   | 0734-- | 1   | 0784-- | 3   | 0834-- | PNT | 0884-- | X<Y |
| 0635-- | XTO | 0685-- | 6   | 0735-- | CHS | 0785-- | 9   | 0835-- | UP  | 0885-- | 0   |
| 0636-- | 0   | 0686-- | XFR | 0736-- | X   | 0786-- | X   | 0836-- | XFR | 0886-- | 8   |
| 0637-- | 3   | 0687-- | 2   | 0737-- | 1   | 0787-- | XFR | 0837-- | 7   | 0887-- | 9   |
| 0638-- | 6   | 0688-- | M   | 0738-- | .   | 0788-- | 3   | 0838-- | 0   | 0888-- | 7   |
| 0639-- | 2   | 0689-- | X   | 0739-- | 2   | 0789-- | 8   | 0839-- | UP  | 0889-- | 1   |
| 0640-- | +   | 0690-- | YTO | 0740-- | 0   | 0790-- | +   | 0840-- | 1   | 0890-- | XTO |
| 0641-- | YTO | 0691-- | 5   | 0741-- | 5   | 0791-- | DN  | 0841-- | X=Y | 0891-- | 0   |
| 0642-- | a   | 0692-- | 1   | 0742-- | EEX | 0792-- | X   | 0842-- | 0   | 0892-- | GTO |
| 0643-- | XFR | 0693-- | XFR | 0743-- | 5   | 0793-- | DN  | 0843-- | 8   | 0893-- | 1   |
| 0644-- | IND | 0694-- | 4   | 0744-- | CHS | 0794-- | J   | 0844-- | 5   | 0894-- | 0   |
| 0645-- | a   | 0695-- | 1   | 0745-- | KEY | 0795-- | UP  | 0845-- | 1   | 0895-- | 0   |
| 0646-- | KEY | 0696-- | UP  | 0746-- | -   | 0796-- | .   | 0846-- | GTO | 0896-- | 6   |
| 0647-- | XFR | 0697-- | UP  | 0747-- | YTO | 0797-- | 0   | 0847-- | 1   | 0897-- | 0   |
| 0648-- | 3   | 0698-- | 3   | 0748-- | 4   | 0798-- | 0   | 0848-- | 0   | 0898-- | 9   |
| 0649-- | 6   | 0699-- | 5   | 0749-- | 3   | 0799-- | 2   | 0849-- | 4   | 0899-- | 0   |

| STEP   | KEY | STEP   | KEY | STEP   | KEY | STEP   | KEY | STEP   | KEY | STEP   | KEY |
|--------|-----|--------|-----|--------|-----|--------|-----|--------|-----|--------|-----|
| 0900-- | 0   | 0950-- | 0   | 1000-- | 0   | 1050-- | PNT | 1100-- | 5   | 1150-- | N   |
| 0901-- | X<Y | 0951-- | 0   | 1001-- | 0   | 1051-- | CHT | 1101-- | RUP | 1151-- | X   |
| 0902-- | 0   | 0952-- | 0   | 1002-- | 6   | 1052-- | CHT | 1102-- | CHS | 1152-- | X<Y |
| 0903-- | 9   | 0953-- | X<Y | 1003-- | 8   | 1053-- | CHT | 1103-- | UP  | 1153-- | XTO |
| 0904-- | 1   | 0954-- | 0   | 1004-- | XTO | 1054-- | CHT | 1104-- | UP  | 1154-- | 5   |
| 0905-- | 4   | 0955-- | 9   | 1005-- | 0   | 1055-- | CHT | 1105-- | RUP | 1155-- | 0   |
| 0906-- | 2   | 0956-- | 6   | 1006-- | XFR | 1056-- | CHT | 1106-- | PNT | 1156-- | XTO |
| 0907-- | XTO | 0957-- | 6   | 1007-- | 0   | 1057-- | CHT | 1107-- | UP  | 1157-- | +   |
| 0908-- | 0   | 0958-- | 5   | 1008-- | UP  | 1058-- | CHT | 1108-- | XFR | 1158-- | 6   |
| 0909-- | GTO | 0959-- | XTO | 1009-- | 3   | 1059-- | CHT | 1109-- | 2   | 1159-- | 7   |
| 0910-- | 1   | 0960-- | 0   | 1010-- | X   | 1060-- | CHT | 1110-- | UP  | 1160-- | PNT |
| 0911-- | 0   | 0961-- | GTO | 1011-- | 6   | 1061-- | CHT | 1111-- | 9   | 1161-- | UP  |
| 0912-- | 0   | 0962-- | 1   | 1012-- | 8   | 1062-- | CHT | 1112-- | 0   | 1162-- | XFR |
| 0913-- | 6   | 0963-- | 0   | 1013-- | +   | 1063-- | CHT | 1113-- | X=Y | 1163-- | 7   |
| 0914-- | 4   | 0964-- | 0   | 1014-- | YTO | 1064-- | CHT | 1114-- | 1   | 1164-- | +   |
| 0915-- | 5   | 0965-- | 6   | 1015-- | a   | 1065-- | CHT | 1115-- | 1   | 1165-- | XFR |
| 0916-- | 0   | 0966-- | 5   | 1016-- | XFR | 1066-- | CHT | 1116-- | 2   | 1166-- | 1   |
| 0917-- | 0   | 0967-- | 0   | 1017-- | IND | 1067-- | CHT | 1117-- | 3   | 1167-- | RUP |
| 0918-- | X<Y | 0968-- | 0   | 1018-- | a   | 1068-- | CHT | 1118-- | GTO | 1168-- | X   |
| 0919-- | 0   | 0969-- | 0   | 1019-- | K   | 1069-- | CHT | 1119-- | 1   | 1169-- | XFR |
| 0920-- | 9   | 0970-- | 0   | 1020-- | 4   | 1070-- | UP  | 1120-- | 1   | 1170-- | 4   |
| 0921-- | 3   | 0971-- | X<Y | 1021-- | UP  | 1071-- | XFR | 1121-- | 3   | 1171-- | 9   |
| 0922-- | 1   | 0972-- | 0   | 1022-- | 2   | 1072-- | 5   | 1122-- | 5   | 1172-- | +   |
| 0923-- | 3   | 0973-- | 9   | 1023-- | RUP | 1073-- | 1   | 1123-- | DN  | 1173-- | YTO |
| 0924-- | XTO | 0974-- | 8   | 1024-- | +   | 1074-- | XSO | 1124-- | X<Y | 1174-- | 3   |
| 0925-- | 0   | 0975-- | 4   | 1025-- | YTO | 1075-- | UP  | 1125-- | UP  | 1175-- | 5   |
| 0926-- | GTO | 0976-- | 6   | 1026-- | a   | 1076-- | XFR | 1126-- | 0   | 1176-- | DN  |
| 0927-- | 1   | 0977-- | XTO | 1027-- | XFR | 1077-- | 4   | 1127-- | X=Y | 1177-- | XFR |
| 0928-- | 0   | 0978-- | 0   | 1028-- | 4   | 1078-- | 2   | 1128-- | 1   | 1178-- | 2   |
| 0929-- | 0   | 0979-- | GTO | 1029-- | 8   | 1079-- | X   | 1129-- | 2   | 1179-- | M   |
| 0930-- | 6   | 0980-- | 1   | 1030-- | K   | 1080-- | 2   | 1130-- | 0   | 1180-- | UP  |
| 0931-- | 9   | 0981-- | 0   | 1031-- | 4   | 1081-- | DIV | 1131-- | 9   | 1181-- | XFR |
| 0932-- | 0   | 0982-- | 0   | 1032-- | RUP | 1082-- | DN  | 1132-- | DN  | 1182-- | 1   |
| 0933-- | 0   | 0983-- | 6   | 1033-- | -   | 1083-- | PNT | 1133-- | X<Y | 1183-- | X   |
| 0934-- | 0   | 0984-- | 2   | 1034-- | XFR | 1084-- | XTO | 1134-- | UP  | 1184-- | DN  |
| 0935-- | X<Y | 0985-- | 5   | 1035-- | IND | 1085-- | 4   | 1135-- | DN  | 1185-- | X<Y |
| 0936-- | 0   | 0986-- | 0   | 1036-- | a   | 1086-- | 7   | 1136-- | M   | 1186-- | -   |
| 0937-- | 9   | 0987-- | 0   | 1037-- | X   | 1087-- | X   | 1137-- | X<Y | 1187-- | XFR |
| 0938-- | 4   | 0988-- | 0   | 1038-- | 1   | 1088-- | XFR | 1138-- | X   | 1188-- | 3   |
| 0939-- | 8   | 0989-- | 0   | 1039-- | RUP | 1089-- | 8   | 1139-- | YTO | 1189-- | 5   |
| 0940-- | 4   | 0990-- | X<Y | 1040-- | X<Y | 1090-- | X   | 1140-- | 4   | 1190-- | DIV |
| 0941-- | XTO | 0991-- | 1   | 1041-- | -   | 1091-- | XFR | 1141-- | 9   | 1191-- | X<Y |
| 0942-- | 0   | 0992-- | 0   | 1042-- | YTO | 1092-- | 5   | 1142-- | YTO | 1192-- | L   |
| 0943-- | GTO | 0993-- | 0   | 1043-- | a   | 1093-- | 1   | 1143-- | +   | 1193-- | 0   |
| 0944-- | 1   | 0994-- | 3   | 1044-- | XFR | 1094-- | UP  | 1144-- | 6   | 1194-- | PNT |
| 0945-- | 0   | 0995-- | 7   | 1045-- | IND | 1095-- | 0   | 1145-- | 5   | 1195-- | XTO |
| 0946-- | 0   | 0996-- | XTO | 1046-- | a   | 1096-- | X<Y | 1146-- | X<Y | 1196-- | 2   |
| 0947-- | 6   | 0997-- | 0   | 1047-- | RUP | 1097-- | 1   | 1147-- | PNT | 1197-- | N   |
| 0948-- | 4   | 0998-- | GTO | 1048-- | +   | 1098-- | 1   | 1148-- | XFR | 1198-- | DIV |
| 0949-- | 0   | 0999-- | 1   | 1049-- | DN  | 1099-- | 0   | 1149-- | 2   | 1199-- | DN  |

| STEP      | KEY | STEP      | KEY | STEP      | KEY | STEP      | KEY | STEP      | KEY | STEP | KEY |
|-----------|-----|-----------|-----|-----------|-----|-----------|-----|-----------|-----|------|-----|
| 1200--XTO |     | 1250-- 7  |     | 1300-- I  |     | 1350--PNT |     | 1400-- J  |     |      |     |
| 1201-- 1  |     | 1251-- 5  |     | 1301--XSQ |     | 1351--XFR |     | 1401-- .  |     |      |     |
| 1202--PNT |     | 1252--FMT |     | 1302-- 0  |     | 1352-- 6  |     | 1402-- B  |     |      |     |
| 1203--PNT |     | 1253--FMT |     | 1303-- N  |     | 1353-- 3  |     | 1403-- .  |     |      |     |
| 1204--GTO |     | 1254--XTO |     | 1304--XTO |     | 1354--PNT |     | 1404--IND |     |      |     |
| 1205-- 1  |     | 1255-- E  |     | 1305-- A  |     | 1355--XFR |     | 1405-- .  |     |      |     |
| 1206-- 2  |     | 1256-- H  |     | 1306-- L  |     | 1356-- 6  |     | 1406--CNT |     |      |     |
| 1207-- 4  |     | 1257--YTO |     | 1307--FMT |     | 1357-- 1  |     | 1407--CNT |     |      |     |
| 1208-- 0  |     | 1258-- I  |     | 1308--GTO |     | 1358--PNT |     | 1408-- 7  |     |      |     |
| 1209-- 9  |     | 1259-- 0  |     | 1309-- 1  |     | 1359--XFR |     | 1409-- 6  |     |      |     |
| 1210-- 0  |     | 1260-- N  |     | 1310-- 3  |     | 1360-- 6  |     | 1410-- .  |     |      |     |
| 1211--PNT |     | 1261-- .  |     | 1311-- 4  |     | 1361-- 4  |     | 1411-- 0  |     |      |     |
| 1212--XTO |     | 1262-- .  |     | 1312-- 0  |     | 1362--PNT |     | 1412-- 0  |     |      |     |
| 1213-- 2  |     | 1263-- .  |     | 1313--FMT |     | 1363--XFR |     | 1413-- 6  |     |      |     |
| 1214--XFR |     | 1264-- .  |     | 1314--FMT |     | 1364-- 6  |     | 1414--CLR |     |      |     |
| 1215-- 1  |     | 1265--XSQ |     | 1315-- C  |     | 1365-- 6  |     | 1415--CLR |     |      |     |
| 1216-- UP |     | 1266-- E  |     | 1316-- A  |     | 1366--PNT |     | 1416--CLR |     |      |     |
| 1217--XFR |     | 1267-- a  |     | 1317-- B  |     | 1367--PNT |     | 1417--CLR |     |      |     |
| 1218-- 7  |     | 1268-- 0  |     | 1318-- L  |     | 1368-- UP |     | 1418--CLR |     |      |     |
| 1219-- -  |     | 1269--FMT |     | 1319-- E  |     | 1369--XFR |     | 1419--FMT |     |      |     |
| 1220-- DH |     | 1270--GTO |     | 1320--CNT |     | 1370-- 6  |     | 1420-- K  |     |      |     |
| 1221--XTO |     | 1271-- 1  |     | 1321-- A  |     | 1371-- 7  |     | 1421--CLX |     |      |     |
| 1222-- 1  |     | 1272-- 3  |     | 1322-- n  |     | 1372--PNT |     | 1422--GTO |     |      |     |
| 1223--PNT |     | 1273-- 4  |     | 1323-- n  |     | 1373-- +  |     | 1423-- 0  |     |      |     |
| 1224--PNT |     | 1274-- 0  |     | 1324-- a  |     | 1374-- DH |     | 1424-- 0  |     |      |     |
| 1225--CNT |     | 1275--XFR |     | 1325-- 0  |     | 1375--PNT |     | 1425-- 0  |     |      |     |
| 1226--CNT |     | 1276-- 2  |     | 1326-- YE |     | 1376--XFR |     | 1426-- 0  |     |      |     |
| 1227--CNT |     | 1277-- UP |     | 1327-- .  |     | 1377-- 6  |     | 1427--END |     |      |     |
| 1228--CNT |     | 1278-- 0  |     | 1328--CLR |     | 1378-- 5  |     |           |     |      |     |
| 1229--CNT |     | 1279--X>Y |     | 1329-- 0  |     | 1379--PNT |     |           |     |      |     |
| 1230--CNT |     | 1280-- 1  |     | 1330-- H  |     | 1380--PNT |     |           |     |      |     |
| 1231--CNT |     | 1281-- 2  |     | 1331--CNT |     | 1381--FMT |     |           |     |      |     |
| 1232--CNT |     | 1282-- 0  |     | 1332--YTO |     | 1382--FMT |     |           |     |      |     |
| 1233--CNT |     | 1283-- 9  |     | 1333--1/X |     | 1383-- a  |     |           |     |      |     |
| 1234--CNT |     | 1284--GTO |     | 1334-- a  |     | 1384-- E  |     |           |     |      |     |
| 1235--CNT |     | 1285-- 0  |     | 1335-- F  |     | 1385-- A  |     |           |     |      |     |
| 1236--CNT |     | 1286-- 4  |     | 1336-- A  |     | 1386-- D  |     |           |     |      |     |
| 1237--CNT |     | 1287-- 5  |     | 1337-- C  |     | 1387--XFR |     |           |     |      |     |
| 1238--CNT |     | 1288-- 6  |     | 1338-- E  |     | 1388--CNT |     |           |     |      |     |
| 1239--CNT |     | 1289--FMT |     | 1339--FMT |     | 1389-- H  |     |           |     |      |     |
| 1240-- UP |     | 1290--FMT |     | 1340--XFR |     | 1390-- E  |     |           |     |      |     |
| 1241-- 0  |     | 1291-- C  |     | 1341-- 4  |     | 1391-- YE |     |           |     |      |     |
| 1242--X>Y |     | 1292-- A  |     | 1342-- 1  |     | 1392--XTO |     |           |     |      |     |
| 1243-- 1  |     | 1293-- B  |     | 1343--PNT |     | 1393--CNT |     |           |     |      |     |
| 1244-- 2  |     | 1294-- L  |     | 1344--XFR |     | 1394-- n  |     |           |     |      |     |
| 1245-- 5  |     | 1295-- E  |     | 1345-- 2  |     | 1395-- a  |     |           |     |      |     |
| 1246-- 2  |     | 1296--CNT |     | 1346--PNT |     | 1396-- 0  |     |           |     |      |     |
| 1247--GTO |     | 1297-- H  |     | 1347--XFR |     | 1397-- B  |     |           |     |      |     |
| 1248-- 1  |     | 1298-- 0  |     | 1348-- 1  |     | 1398-- .  |     |           |     |      |     |
| 1249-- 2  |     | 1299-- a  |     | 1349--PNT |     | 1399--CLR |     |           |     |      |     |

# STORAGE REGISTERS

| STORAGE |                                   |
|---------|-----------------------------------|
| b       | $\eta_{WU} (= 1.5 \text{ START})$ |
| a       | Ind. Use                          |
| 000     | $\eta_{Co}$                       |
| 001     | $F_T$                             |
| 002     | $\theta$                          |
| 003     | $Z_a$                             |
| 004     | $Z_s$                             |
| 005     | $K$                               |
| 006     | 1040                              |
| 007     | $W_1 / \eta_{Co} + W_{EK}$        |
| 008     | Area front                        |
| 009     | Diam. ft                          |
| 010     |                                   |
| 011     | $Z_1 = Z_a$                       |
| 012     | $W_1, f_{ps}$                     |
| 013     | $Z_2$                             |
| 014     | $W_2$                             |
| 015     | $Z_3$                             |
| 016     | $W_3$                             |
| 017     | $Z_4$                             |
| 018     | $W_4$                             |
| 019     | $Z_5$                             |
| 020     | $W_5$                             |
| 021     | $Z_6$                             |
| 022     | $W_6$                             |
| 023     | $Z_7$                             |
| 024     | $W_7$                             |
| 025     | $Z_8$                             |
| 026     | $W_8$                             |
| 027     | $Z_9$                             |
| 028     | $W_9$                             |
| 029     | $Z_{10}$                          |
| 030     | $W_{10}$                          |
| 031     | $Z_{11}$                          |
| 032     | $W_{11}$                          |
| 033     | $Z_{12}$                          |
| 034     |                                   |
| 035     | Temp.                             |
| 036     | Temp                              |
| 037     | 1.6878                            |
| 038     | $a_0 \} p/o$                      |
| 039     | $a_1 \} /o$                       |

|     |                        |
|-----|------------------------|
| 040 |                        |
| 041 | $Z$                    |
| 042 | $P, \text{ slug/ft}^3$ |
| 043 | $u$                    |
| 044 |                        |
| 045 |                        |
| 046 | $W_{Eas} = V_T$        |
| 047 | $q$                    |
| 048 | $R$                    |
| 049 | $DH$                   |
| 050 | $DW$                   |
| 051 | $VH$                   |
| 052 |                        |
| 053 |                        |
| 054 |                        |
| 055 |                        |
| 056 |                        |
| 057 |                        |
| 058 |                        |
| 059 |                        |
| 060 | $h$                    |
| 061 | $\Sigma H$             |
| 062 | $J$                    |
| 063 | $\Sigma U$             |
| 064 | $\Sigma K$             |
| 065 | $\Sigma DH$            |
| 066 | $\Sigma W_{EK}$        |
| 067 | $\Sigma DW$            |
| 068 |                        |
| 069 |                        |
| 070 | $\eta_{Co}$            |
| 071 | $R_a \}$               |
| 072 | $Coa \} 1$             |
| 073 | $K_R \}$               |
| 074 | $R_a \}$               |
| 075 | $Coa \} 2$             |
| 076 | $K_R \}$               |
| 077 | $R_a \}$               |
| 078 | $Coa \} 3$             |
| 079 | $K_R \}$               |

|     |            |
|-----|------------|
| 080 | $R_a \}$   |
| 081 | $Coa \} 4$ |
| 082 | $K_R \}$   |
| 083 | $R_a \}$   |
| 084 | $Coa \} 5$ |
| 085 | $K_R \}$   |
| 086 | $R_a \}$   |
| 087 | $Coa \} 6$ |
| 088 | $K_R \}$   |
| 089 | $R_a \}$   |
| 090 | $Coa \} 7$ |
| 091 | $K_R \}$   |
| 092 | $R_a \}$   |
| 093 | $Coa \} 8$ |
| 094 | $K_R \}$   |
| 095 |            |
| 096 |            |
| 097 |            |
| 098 |            |
| 099 |            |
| 100 |            |
| 101 |            |
| 102 |            |
| 103 |            |
| 104 |            |
| 105 |            |
| 106 |            |
| 107 |            |
| 108 |            |

### 3.6.7 SAMPLE INPUT/OUTPUT PRINT

The following copy of the HP Printed Tape shows a typical problem and solution. For a discussion of the particulars of this problem, see Section 4.

```

PROGRAM #76.006
2- DIMENSIONAL
TETHER CABLE
14000.000 -Balloon Alt.,ft.MSL
4000.000 -Surface Alt.,ft.MSL
3.142 -7 for Internal Cd
0.280 -Diam.of Cable,in.
25.000 -Cable WT. per 1000 ft.,lbs
500.000 -Length. K. Element,ft.
1378.000 -Total Balloon Force,lbs
79.400 -Angle of Force,deg.

ENT. WIND FIELD
1.000 -First Wind Point
14000.000 -Alt. (Balloon),ft.MSL
25.000 -Wind,knots

2.000
13000.000
25.000

3.000
10000.000
60.000

4.000
8000.000
-15.000

5.000
5000.000
-30.000

6.000 -Last Wind Point
4000.000 -Alt. (Surface),ft.MSL
-20.000 -Wind, knots

13500.532 -Alt.,Bottom-of Element
491.468 -Vert.Dist-top to bottom
491.468 -Tot.Vert Dist.to Balloon
91.976 -Horiz.Dist-top to bottom
91.976 -Tot.Horiz.Dist.to Balloon
500.000 -Cable Length
12.500 -Cable Weight
25.000 -Wind at element bottom
4405.541 -Reynolds Number
0.980 -Drag Coefficient
1.354 -Dynamic Presssure
15.480 -Element Drag
15.216 -Horiz.Drag Component
2.848 -Vert. Drag Component
78.654 -Angle of Next Element Down
1365.829 -Tension,Top of Next Element

```

```

13018.304
490.329
981.696
98.366
190.341
1000.000
25.000
25.000
4452.354
0.980
1.369
15.652
15.346
3.079
77.888
1353.694

12529.435
488.869
1470.565
104.916
295.257
1500.000
37.500
30.490
5485.769
1.043
2.058
25.035
24.477
5.253
76.706
1341.758

12042.832
486.602
1957.168
114.970
410.227
2000.000
50.000
36.167
6560.757
1.100
2.914
37.386
36.395
8.597
74.972
1330.202

```

4171.457  
42.327  
9828.543  
26.616  
5065.615  
11200.000  
280.000  
-21.715  
4173.685  
0.980  
1.015  
-1.160  
-0.982  
-0.618  
57.862  
1146.479

4129.118  
42.338  
9870.882  
26.598  
5092.213  
11250.000  
281.250  
-21.291  
4097.544  
0.980  
0.977  
-1.117  
-0.946  
-0.594  
57.884  
1145.420

4086.769  
42.349  
9913.231  
26.581  
5118.795  
11300.000  
282.500  
-20.868  
4021.086  
0.980  
0.940  
-1.075  
-0.711  
-0.572  
57.905  
1144.362

4044.411  
42.358  
9955.589  
26.566  
5145.361  
11350.000  
283.750  
-20.444  
3944.320  
0.980  
0.904  
-1.034  
-0.876  
-0.549  
57.924  
1143.303

4002.044  
42.367  
9997.956  
26.553  
5171.913  
11400.000  
285.000  
-20.020  
3867.254  
0.980  
0.868  
-0.993  
-0.841  
-0.527  
57.940  
1142.244

# CABLE APPROX. ON SURFACE

4002.044  
57.940  
1142.244  
  
9997.956  
5171.913  
11400.000  
285.000

-Altitude (~Surface)  
-C. Angle at Winch  
-C. Tension at Winch  
  
-Vert. Dist., Baln.-Winch  
-Horiz. Dist., Baln.-Winch  
-Tot. Cable Length  
-Tot. Cable Weight  
  
-Tot. Vert. Drag Comp.  
-Sum-C. Wt.+Vert. Drag  
-Tot. Horiz. Drag Comp.

READY NEXT PROB.

J.B.W. 76.006

### 3.6.8 NOTES

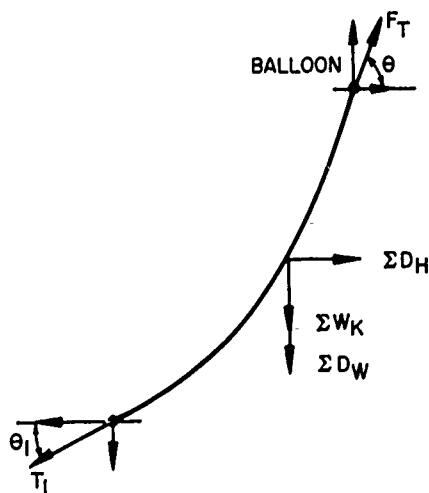
A. If incorrect data is inputted, do not press STOP END to restart program. For correct restart to clear all registers press following:

```

STOP
GO TO
    1
    3
    8
    1
CONT
    
```

B. Ditto No. 1 above if computations underway and decide that something is in error or bad problem.

C. Proof of correctness of solution can be made by summation of the vert. and horizontal forces.  $\theta_1$  and  $T_1$  are conditions at the winch in last group of program output as are  $\Sigma DH$ ,  $\Sigma W_K$ ,  $\Sigma D_W$ .



$$\text{Horizontal: } T_1 \cos \theta_1 = \Sigma D_H + F_T \cos \theta$$

$$\text{Vertical: } T_1 \sin \theta_1 + \Sigma W_K + \Sigma D_W = F_T \sin \theta$$

#### 4. EXAMPLE OF A CONVENTIONAL TETHERED BALLOON PROBLEM

##### A. Given:

1. A requirement to fly a 100-lb payload at 18,000 ft MSL (but will accept 13,000 ft MSL if necessary) in New Mexico location where the surface is 4000 ft MSL. The most severe wind profile for the season and time of day needed for the particular type of experiment is as follows:

| <u>Altitude, ft</u> | <u>Wind, knots</u> |
|---------------------|--------------------|
| 18,000              | 25                 |
| 13,000              | 25                 |
| 10,000              | 60                 |
| 8000                | -15                |
| 5000                | -30                |
| 4000                | -20                |

2. Two balloons are in the inventory which might be capable of acting as the carrier.

##### A. Lee Bridge Kite Balloon

##### B. Family-2 Balloon

|                                 |                       |                       |
|---------------------------------|-----------------------|-----------------------|
| Balloon Volume, $V_B$ :         | 30,000 CF             | 45,000 CF             |
| Ballonet Volume, $v$ :          | 8000 CF               | 13,522 CF             |
| Balloon Weight, $W_B$ :         | 725 lb                | 970 lb                |
| Instrumentation weight, $W_I$ : | 100 lb (at Conf. Pt.) | 150 lb (at Conf. Pt.) |
| Payload Weight, $W_P$ :         | 100 lb (at Conf. Pt.) | 150 lb (at Conf. Pt.) |

3. A single tether cable is desired.

Question: What is the smallest balloon capable of doing the job?

Approach: Run Program 76.001 to

- (a) Select smallest balloon
- (b) Check max. altitude capability of ballonet

Answer: See 3.1.7: 30,000 CF balloon capable of 13,906 ft MSL  
 45,000 CF balloon capable of 15,324 ft MSL  
 However, the 45,000 CF produces 347 lb lift (tension) at the ground when the balloon is at 15,324 ft MSL while the smaller balloon produces an unacceptably small 120 lb at its max altitude. Therefore, select the Family-2 45,000 CF unit. Make the max altitude 14,000 ft MSL for this project. Minimum lift at the ground (cable tension) is 464 lb under this no-wind condition. A Kevlar cable having the following properties was selected in the above computations.

Diameter: 0.28 in.  
Wt/1000 ft: 25 lb

Question: Is this preliminary selection of balloon and cable satisfactory for the loads imposed by the maximum wind field?

Approach: Run Program 76.004 for most precise balloon total force and angle at 14,000 ft (optional).  
Run Program 76.005 for balloon total force and angle at 14,000 ft and at 1000-ft increments downward to and including surface.  
Run Program 76.006 with 14,000 ft altitude output values from 76.005 and at other altitudes as judged necessary to obtain cable parameters - tension, position, etc.

Answers: See Sections 3.4.7, 3.5.7, and 3.6.7.

|                       |               |               |
|-----------------------|---------------|---------------|
| At 14,000 ft:         | <u>76.004</u> | <u>76.005</u> |
| Total Force:          | 1385 lb       | 1378 lb       |
| Angle to Horizon:     | 79.4°         | 79.4°         |
| Trim Angle of Attack: | 7.57°         | 7.49°         |

The slight disagreement is due to differences in the precision of locating the center of pressure and the impracticality of obtaining an exact trim amount of 0.0. The output of 76.005 is of acceptable precision. Its output at decreasing altitudes can be scanned, noting that when the balloon is at 10,000 ft the total force reaches a maximum level of 3500 lb at an angle of 66.9°. While the trim angle is a low 4.5° due to the 60 knot wind,\* the aerodynamic lift is 3262 lb producing a total lift of 4445 lb. This loading equals the working strength of the cable thereby suggesting that the balloon should be raised or lowered with caution during these wind conditions. Note that the ballonnet is 0.9 full when the balloon is at the surface.

The output values of 76.005 at 14,000 ft were then used as inputs to 76.006 to determine cable conditions and location from 14,000 ft, down to the surface. The final group of figures in the 76.006 output indicate the following

|                      |                         |
|----------------------|-------------------------|
| Cable Angle:         | 57.9° above horizon     |
| Winch Tension:       | 1142 lb                 |
| Horiz. Displacement: | 5172 ft (Balloon-Winch) |
| Cable Length:        | 11,400 ft               |
| Cable Wt.            | 285 lb                  |

Intermediate groups of figures below the 14,000 ft altitude can be used to plot various cable parameters including its space position along its entire length from the balloon to the ground.

\* This decrease of trim angle with wind speed to decrease aerodynamic lift can be shown by running a series of increasing wind values in 76.004 or 76.005.

The overall conclusion would be that the 45,000 CF balloon with a 7007 break strength cable weighing 25 lb per 1000 ft is an acceptable system for the conditions specified. To determine whether it can be raised to or lowered from its maximum altitude output values for altitudes below 14,000 ft from Program 76.005 should be run in Program 76.006

##### 5. PRELIMINARY PARAMETRIC STUDIES OF THE HIGH ALTITUDE TETHERED BALLOON PROBLEM

The concept for a tethered-balloon flight to 20 km MSL first evolved from a study of minimum wind expectancy over possible tethered balloon sites. Tropical latitudes appeared to be ideal since they have the greatest number of months per year where the magnitude of the winds from the surface to 20 km could be considered acceptable for raising or lowering the balloon. Too large a wind velocity (dynamic pressure) causes excessive drag on the balloon and cable tending to cause blowdown of the system. Because of the desire to operate the first feasibility tests at the AFGL balloon test site at Holloman AFB, New Mexico, the study concentrated on the winds in this area. The July-August period has an acceptable minimum wind profile. The solid line in Figure 1 is a composite July-August 75 percent wind profile for Holloman AFB (White Sands Missile Range) and was selected as the standard for flight equipment and system design.

Based on a flight altitude of 65,616 ft MSL (20 km), a surface altitude of 4400 ft MSL, a payload of 200 lb and a cable weight of approximately 1700 lb, several natural shape balloons of varying sizes were considered as the first steps in system design. The balloon contractor then recommended a 500,000-CF and a 800,000-CF balloon.

The 500,000-CF balloon at altitude was found, by use of Program 76.006 to be too small. The program indicated that in the design wind field, the cable would become horizontal at approximately 17,000 ft MSL.

The larger 800,000-CF balloon was found to have acceptable lifting characteristics. Using the contractor's estimate of total force,  $F_T = 3073$  lb and angle of the force  $\theta = 81.6^\circ$ , a series of Program 76.006 runs were made with variations of key parameters. Results are shown in Table 3.

The three lines shown in Group 1, Table 3, illustrate the effect of cable drag coefficient variations. It can be noted that the built-in variable cylinder drag coefficient yields the same results in this particular problem as the constant drag coefficient value of 1.0 at all altitudes and wind conditions. Thereafter all computations use the internal  $C_D$  techniques.

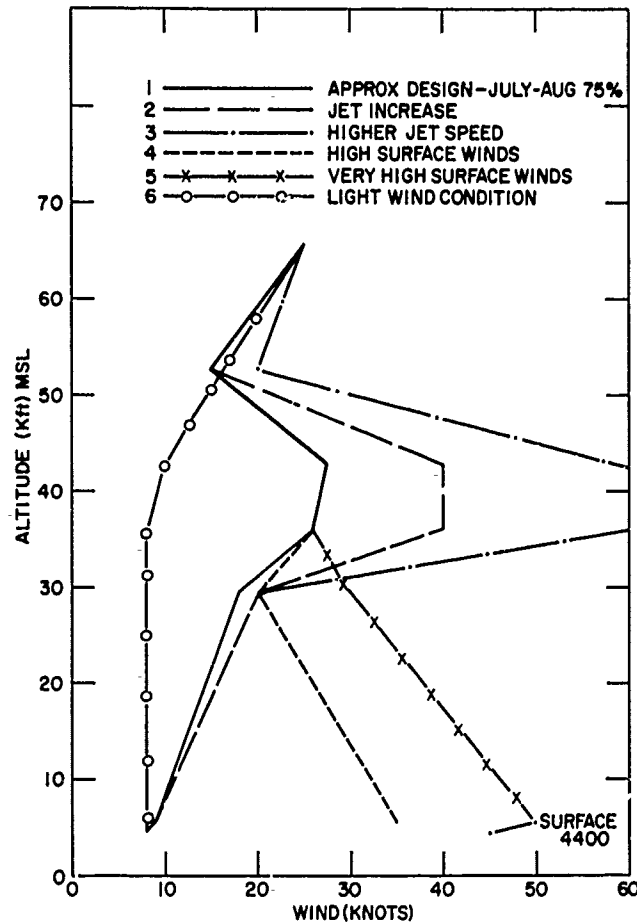


Figure 1. Wind Profiles - High Altitude Tethered Balloon

The effect of cable diameter and weights in Groups I, II, and III were investigated over a small range covering the possible characteristics of a finalized cable design. Note that the length of the cable required varies between approximately 65,000 and 68,000 ft for the 61,216-ft balloon height above the surface. The cable tension and angle at the winch remain at acceptable levels although the heaviest weight of cable investigated reduces the angle below  $40^\circ$ . The horizontal distance between the balloon and winch varies between 19,000 and 26,000 ft. This indicates a balloon elevation ("look") angle of between  $67^\circ$  and  $73^\circ$  from the winch.

Table 3. High-Altitude Tether-Cable  
(BALLOON-800,000 CF. Natural Shape, Located at 65616 Ft. MSL, 61216 Ft. Above Surface)

| Group | INPUT             |                   |       | OUTPUT         |           |                    |           |           |              |               |                |      |                                          |
|-------|-------------------|-------------------|-------|----------------|-----------|--------------------|-----------|-----------|--------------|---------------|----------------|------|------------------------------------------|
|       | BALLOON           |                   | CABLE |                | C A B L E |                    |           |           |              | Tension       |                |      |                                          |
|       | Wind Refr. Fig. 1 | F <sub>T</sub> lb | θ deg | C <sub>D</sub> | Diam. in. | Wt. per 1000 ft lb | Length ft | Weight lb | Hor. Drag lb | Vert. Drag lb | (At Winch)     |      | Horizontal Displacement Ball. - Winch ft |
|       |                   |                   |       |                |           |                    |           |           |              |               | lb             | deg  |                                          |
| I     | No. 1             | 3073              | 81.6  | 1.0            | .3        | 25                 | 65300     | 1632      | 456.4        | 152.9         | 1547           | 54.2 | 20760                                    |
|       | "                 | "                 | "     | 1.2            | "         | "                  | 66199     | 1652      | 536.6        | 192.9         | 1548           | 50.5 | 22548                                    |
|       | "                 | "                 | "     | IN *           | "         | "                  | 65300     | 1632      | 453.0        | 150.9         | 1547           | 54.3 | 20761                                    |
| II    | No. 1             | 3073              | 81.6  | IN *           | .3        | 27.5               | 65900     | 1812      | 446.2        | 156.1         | 1396           | 50.1 | 22133                                    |
|       | "                 | "                 | "     | "              | "         | 30                 | 66900     | 2007      | 438.1        | 161.4         | 1243           | 44.5 | 23961                                    |
|       | "                 | "                 | "     | "              | "         | 32                 | 68000     | 2176      | 430.1        | 165.4         | 1123           | 38.5 | 25838                                    |
| III   | No. 1             | 3073              | 81.6  | IN *           | .25       | 25                 | 64700     | 1618      | 386.4        | 120.9         | 1546           | 57.3 | 19398                                    |
|       | "                 | "                 | "     | "              | "         | 27.5               | 65200     | 1793      | 381.3        | 125.2         | 1396           | 53.5 | 20618                                    |
|       | "                 | "                 | "     | "              | "         | 30                 | 66000     | 1980      | 375.4        | 129.9         | 1243           | 48.4 | 22199                                    |
| IV    |                   |                   |       |                |           | 32                 | 67000     | 2144      | 368.8        | 134.5         | 1121           | 42.7 | 24052                                    |
|       | No. 6             | 3073              | 81.6  | IN *           | .3        | 25                 | 63000     | 1575      | 136.7        | 35.2          | 1545           | 67.7 | 14564                                    |
|       | No. 2             | "                 | "     | "              | "         | "                  | 68200     | 1705      | 661.8        | 251.4         | 1551           | 44.3 | 26724                                    |
|       | No. 3             | "                 | "     | "              | "         | "                  | 82800     | 2070      | 1043.9       | 502.8         | 1564           | 17.4 | 47555                                    |
|       | No. 4             | "                 | "     | "              | "         | "                  | 69100     | 1728      | 924.4        | 580.6         | 1560           | 28.0 | 26687                                    |
|       | No. 5             | "                 | "     | "              | "         | "                  | 86000*    | 2150*     | 1157.1*      | 910.0*        | *Did not reach | = 0  | 46713*                                   |
| V     | No. 1             | 3325              | 79.5  | IN *           | .3        | 25                 | 65800     | 1645      | 444.6        | 162.8         | 1800           | 54.2 | 22676                                    |
|       | "                 | 2979              | 81.5  | "              | "         | "                  | 65600     | 1640      | 448.6        | 154.6         | 1454           | 52.3 | 21592                                    |

\* IN - Internal Cylinder Drag Coefficient

Data in Group IV show the effects of variations in wind profiles below the balloon per Figure 1. In general, higher winds have adverse effects; increases in cable length and horizontal displacement and a decrease in cable angle at the winch. Increases in winds at lower altitudes are more pronounced in their effect due to the higher atmospheric density effect on cable drag. In one case the cable is not able to reach the ground due to the excessive cable drag for a 45 to 50 knot surface wind.

It can be also shown that a given cable density produces a constant cable tension at the winch regardless of cable length and/or wind magnitude. The chief effect of increased total cable weight is to decrease the angle of the cable at the winch. Reference to Section 3.6.8, indicates the balance of forces to show the interaction of horizontal and vertical drag with the balloon forces and winch tension.

Group V are two other possible sets of values for balloon total force and angle which appear to cover the range of uncertainty in these parameters. Further work is needed in establishing the full-scale (large Reynolds numbers) aerodynamic characteristics of natural-shaped balloons so that their characteristics can be used as inputs into Program 76.003. In this case of the high-altitude tethered balloon, the problem is made further complex by the technique required to raise the balloon from the ground. Unlike the usual tethered balloon, the design selected does not contain a ballonnet. Such a design requires the balloon to be reefed during its ascent to prevent loose uninflated sections from acting as a sail.

On the ground the top of the balloon is nearly filled with an amount of gas sufficient to expand to the full 800,000 CF volume of the balloon at 65,600 ft MSL. The excess material below this initial small bubble is gathered, during fabrication, into a small diameter bundle and secured by a number of bands along its length that are called reefing points. The reefing points are secured by squib/cutters that can be fired by radio command or by pressure sensors. As the balloon ascends, the initial bubble expands until a predetermined level of "tightness" or bottom cone angle is reached. The top reefing point is then released allowing part of the excess material to be free for additional gas expansion during further ascent. This procedure continues, one reefing point at a time, until the balloon material is completely free some distance below the maximum altitude.

Thus the aerodynamic shape and volume of the balloon is constantly changing in a combination of gradual as well as stepped phenomena. Because of the difficulty in assigning aerodynamic coefficients to such a varying body, at this time no attempt has been made to run the system at lower than the maximum altitude. The first attempt will probably involve assumptions of a smaller natural shape balloon with a small diameter cylinder attached and the system scaled for the altitude of maximum dynamic pressure in the design wind profile, (approximately 40,000 ft MSL).

## Appendix A

### Density Ratio

The ratio of atmospheric density at altitude to that at sea level is a parameter common to many kinds of balloon calculations. The usual method in calculations is to refer to some type of table which gives the ratio at discrete altitude levels. The usual reference atmosphere is the U.S. Standard Atmosphere, 1962, but the 1966 Supplements may be used if more applicable for specific locations or seasons.

The use of a table-lookup technique in conjunction with computer problem solving would be nearly unworkable. A simple relationship between altitude and density ratio is therefore needed. The altitude density ratio variation is nearly logarithmic.

Use of an equation in the quadratic form was found to give a correlation of 0.999.

$$\rho/\rho_0 = a_0 + a_1 Z + a_2 Z^2 \quad (A1)$$

Using a curve fit program, the constants were found to be:

| $Z = 0 \text{ to } 75,000 \text{ ft}$ | $Z = 0 \text{ to } 25,000 \text{ ft}$ |
|---------------------------------------|---------------------------------------|
| $\Delta Z = 5,000 \text{ ft}$         | $\Delta Z = 1000$                     |
| $a_0 = + 5.06595^{-3}$                | $a_0 = - 3.94580^{-4}$                |
| $a_1 = - 2.83164^{-5}$                | $a_1 = - 2.90568^{-5}$                |
| $a_2 = - 1.76842^{-10}$               | $a_2 = - 1.19042^{-10}$               |
| $r^2 = .99964$                        | $r^2 = .999999$                       |

It might be noted that when the altitude is zero, the density ratio is not unity.

By use of a different form:

$$\ln \rho / \rho_0 = a_0 Z + a_1 Z^2 \quad (A2)$$

or

$$\frac{\ln \rho / \rho_0}{Z} = a_0 + a_1 Z$$

and the use of a curve fit from  $Z = 0$  to 75,000 ft, the constants were found to be

$$a_0 = -2.81361 \times 10^{-5}$$

$$a_1 = -1.7772 \times 10^{-10}$$

$$r^2 = .984$$

The density ratio is 1.0 at sea-level. The lower degree of correlation was considered to be acceptable for the type of solutions used in the balloon programs. Therefore Eq. (A2) is used in all of the programs to obtain atmospheric density as defined by the U.S. Standard Atmosphere, 1962. However, Eq. (A1) can be substituted when a greater degree of correlation is required.

## Appendix B

### Symbols and Definitions

- A - Cable Frontal Area, 76.006
- $A_o$  - in  $X_{CB}$  Equation, 76.005
- $a_o$  - Constant in Density Ratio Equation (also for  $X_{CB}$ , 76.004)
- $a_1$  - Constant in Density Ratio Equation (also for  $X_{CB}$ , 76.004)
- $a_2$  - Constant in  $X_{CB}$  Equation, 76.004
- a - Lift Curve Slope
- b - Minimum Drag Coefficient  $C_{DO}$
- c -  $dC_D/d\alpha^2$
- $\bar{c}$  - Length of Balloon Envelope
- d - Cable Diameter
- $f_o, f_1, f_2$   
- Constants in  $X_{CB}$  Equation 76.005
- $g_o, g_1, g_2, g_3$   
- Constants in  $X_{CB}$  Equation, 76.005
- H - Height, Surface to Point Indicated
- $H_p$  - Height of Tritether Apex
- h - Horizontal Projected Length of One Cable Element
- j - Vertical Projected Length of One Cable Element
- K - Length of One Cable Element, 76.006
- $K = q V_B^{2/3}$
- $l$  - Length of Cable
- $l_e$  - Length of Extension Cable
- $m$  - Length,  $X_{CG} - X_{CP}$
- n - Length,  $Y_{CG} - Y_{CP}$
- r - Length  $X - X_{CP}$  ( $X = X_{CP}$  in 76.004 and 5;  
 $X_{ARC}$  in 76.003)

$s$  - Length,  $X - X^{CP}$  ( $Y = Y_{CP}$  in 76.004 and 5;  $= X_{ARC}$  in 76.003)  
 $t$  - Length,  $X_{CB} - X^{CP}$   
 $u$  - Length,  $Y_{CB} - Y^{CP}$   
 $X$ -AXIS - Centerline of Aero. Shaped Balloon,  $X = 0$  at Nose  
 $Y$ -AXIS - Normal to  $X$ -AXIS at  $X = 0$ ,  $Y = 0$  at Nose,  
 $Y$  Positive above Centerline  
 $X^{CP}$  -  $X$  Station of Confluence Point  
 $Y^{CP}$  -  $Y$  Station of Confluence Point  
 $X_{CP}$  -  $X$  Station of Center of Pressure  
 $Y_{CP}$  -  $Y$  Station of Center of Pressure  
 $X_{CB}$  -  $X$  Station of Center of Buoyancy  
 $Y_{CB}$  -  $Y$  Station of Center of Buoyancy  
 $X_{ARC}$  -  $X$  Station of Aerodynamic Reference Center  
 $Y_{ARC}$  -  $Y$  Station of Aerodynamic Reference Center  
 $x$  - Distance Between Twin-Tether Ground Anchor Points  
 $L_G$  - Gross Lift; Gas Volume  $\times$  Specific Lift of Helium  
 $L_n$  -  $Y$  Component of Gross Lift  
 $L_a$  -  $X$  Component of Gross Lift  
 $L_A$  - Aerodynamic Lift  
 $D$  - Aerodynamic Drag  
 $T$  - Total Aerodynamic Force  
 $N$  -  $Y$  Component of Total Aero Force  
 $A$  -  $X$  Component of Total Aero Force  
 $M_o$  - Aero Pitching Moment about Aero Refr. Center, 76.003  
 $C_M$  - Pitching Moment Coefficient,  $M_o / q V_B^{2/3} \bar{c}$ , 76.003  
 $C_L$  - Lift Coefficient,  $L_A / q V_B^{2/3}$   
 $C_D$  - Drag Coefficient,  $D / a V_B^{2/3}$   
 $W_B$  - Weight of Palloon  
 $W_I$  - Weight of Instruments  
 $W_P$  - Weight of Payload  
 $W_e$  - Weight of Extra Items  
 $W_c$  - Weight of Cable  
 $L$  - Total Lift,  $L_G + L_A$   
 $L_N$  - Net Lift,  $L - (W_B + W_I + W_P + W_e)$   
 $q$  - Dynamic Pressure,  $1/2 \rho V^2 = 1/2 \rho \text{Wind}^2$   
 $V_B$  - Volume of Balloon  
 $v$  - Volume of Ballonet  
 $F_T$  - Total Balloon Force at Confluence Point

$W$  - Wind (Also  $V$ )  
 $W$  - Wind Velocity Normal to Cable  
 $V_n$  - Wind Velocity Normal to Cable  
 $R$  - Reynolds Number  
 $T$  - Cable Tension  
 $Z$  - Altitude, ft, MSL

#### Greek Symbols

$\alpha$  - Balloon Angle of Attack  
 $\alpha$  - Multi-tether Cable Angle at Ground, 76.001  
 $\beta$  - Multi-tether Plane Angle at Ground, 76.001  
 $\gamma$  - Ballonet Fullness Factor  
 $\Delta$  - Increment  
 $\Sigma$  - Sum  
 $\theta$  - Angle of  $F_T$  or Cable Above Horizon  
 $\rho$  - Atmospheric Density  
 $\mu$  - Coefficient of Viscosity of Air  
 $\pi$  - To Call Special Operation

#### Subscripts

$o$  - Sea Level  
 $B$  or  $b$  - Balloon  
 $d$  - Design  
 $S$  or  $s$  - Surface