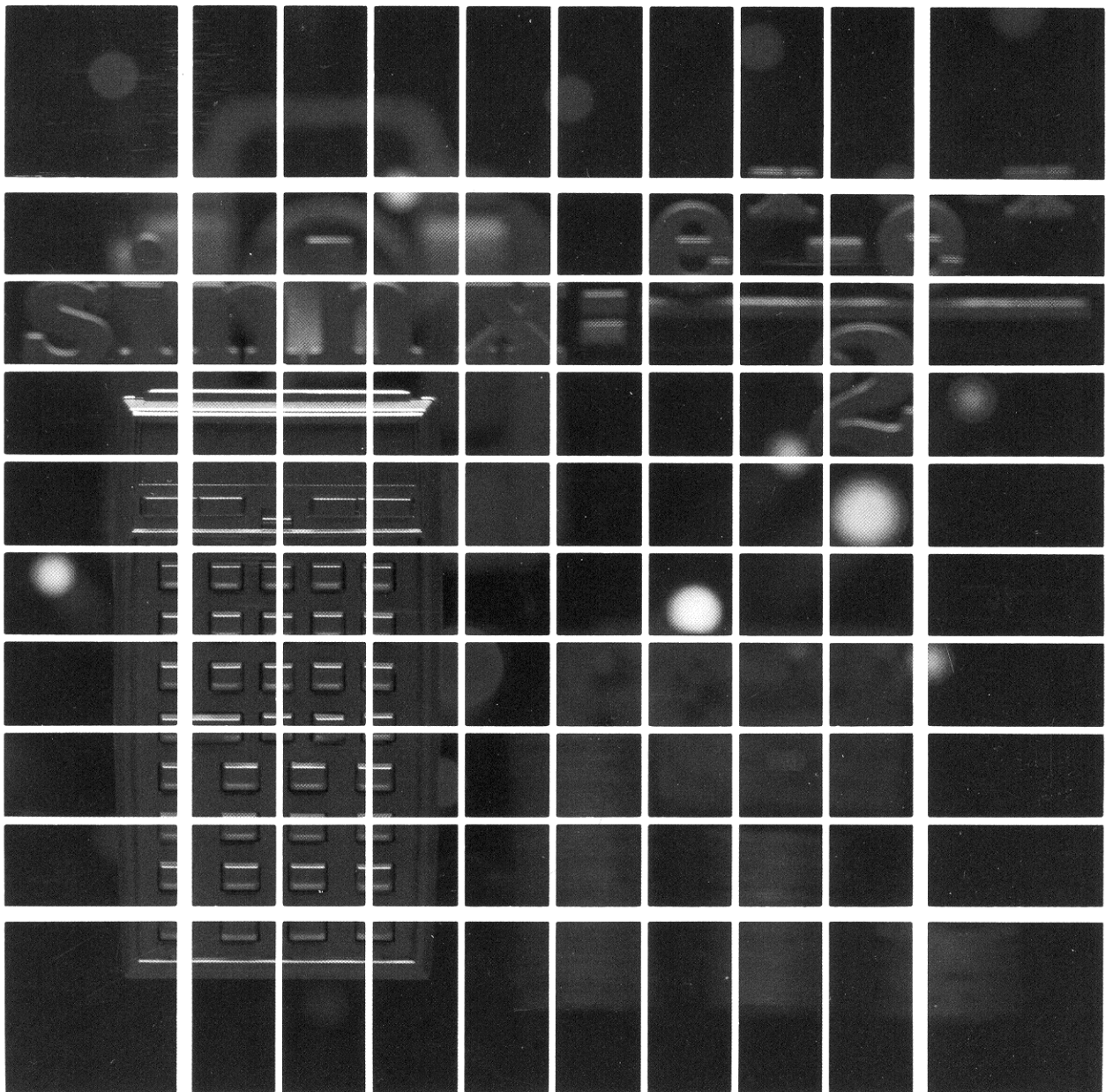


HEWLETT-PACKARD

HP-41

USERS' LIBRARY SOLUTIONS  
**Fluid Dynamics**

Includes barcode for easy software entry.



#### **NOTICE**

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## INTRODUCTION

This HP-41C Solutions book was written to help you get the most from your calculator. The programs were chosen to provide useful calculations for many of the common problems encountered.

They will provide you with immediate capabilities in your everyday calculations and you will find them useful as guides to programming techniques for writing your own customized software. The comments on each program listing describe the approach used to reach the solution and help you follow the programmer's logic as you become and expert on your HP calculator.

### KEYING A PROGRAM INTO THE HP-41C

There are several things that you should keep in mind while you are keying in programs from the program listings provided in this book. The output from the HP 82143A printer provides a convenient way of listing and an easily understood method of keying in programs without showing every keystroke. This type of output is what appears in this handbook. Once you understand the procedure for keying programs in from the printed listings, you will find this method simple and fast. Here is the procedure:

- At the end of each program listing is a listing of status information required to properly execute that program. Included is the SIZE allocation required. Before you begin keying in the program, press **XEQ** **ALPHA** **SIZE** **ALPHA** and specify the allocation (three digits; e.g., 10 should be specified as 010).

Also included in the status information is the display format and status of flags important to the program. To ensure proper execution, check to see that the display status of the HP-41C is set as specified and check to see that all applicable flags are set or clear as specified.

- Set the HP-41C to PRGM mode (press the **PRGM** key) and press **■** **GTO** **■** **■** to prepare the calculator for the new program.
- Begin keying in the program. Following is a list of hints that will help you when you key in your programs from the program listings in this handbook.
  - When you see " (quote marks) around a character or group of characters in the program listing, those characters are ALPHA. To key them in, simply press **ALPHA**, key in the characters, then press **ALPHA** again. So "SAMPLE" would be keyed in as **ALPHA** "SAMPLE" **ALPHA**.
  - The diamond in front of each LBL instruction is only a visual aid to help you locate labels in the program listings. When you key in a program, ignore the diamond.
  - The printer indication of divide sign is /. When you see / in the program listing, press **÷**.
  - The printer indication of the multiply sign is  $\times$ . When you see  $\times$  in the program listing, press **×**.
  - The I character in the program listing is an indication of the **APPEND** function. When you see I, press **■** **APPEND** in ALPHA mode (press **■** and the K key).
  - All operations requiring register addresses accept those addresses in these forms:

nn (a two-digit number)

IND nn (INDIRECT: **■**, followed by a two-digit number)

X, Y, Z, T, or L (a STACK address: **■** followed by X, Y, Z, T, or L)

IND X, Y, Z, T or L (INDIRECT stack: **■** **■** followed by X, Y, Z, T, or L)

Indirect addresses are specified by pressing **■** and then the indirect address. Stack addresses are specified by pressing **■** followed by X, Y, Z, T, or L. Indirect stack addresses are specified by pressing **■** **■** and X, Y, Z, T, or L.

#### Printer Listing

```

01 LBL "SAM
PLE"
02 "THIS IS
A "
03 "I SAMPLE
"
04 AVIEW
05 6
06 ENTER
07 -2
08 /
09 ABS
10 STO IND
L
11 "R3="
12 ARCL 03
13 AVIEW
14 RTN

```

#### Keystrokes

```

 $\blacksquare$  LBL ALPHA SAMPLE ALPHA
ALPHA THIS IS A ALPHA
ALPHA  $\blacksquare$  APPEND SAMPLE
 $\blacksquare$  AVIEW ALPHA
6
ENTER
2 CHS
÷
XEQ ALPHA ABS ALPHA
STO  $\blacksquare$  ■ L
ALPHA R3=  $\blacksquare$  ARCL 03
 $\blacksquare$  AVIEW
ALPHA
 $\blacksquare$  RTN

```

#### Display

```

01 LBLT SAMPLE
02T THIS IS A
03T I SAMPLE
04 AVIEW
05 6
06 ENTER ↗
07 -2
08 /
09 ABS
10 STO IND L
11T R3=
12 ARCL 03
13 AVIEW
14 RTN

```

## FLUID DYNAMICS AND HYDRAULICS

1. CONDUIT FLOW..... 1  
Solves a variety of problems involving viscous conduit flow.
2. FLOW WITH A FREE SURFACE..... 10  
Solves flow problems using Manning flow formulae.
3. PIPE SLIDE-RULE..... 18  
Given surface coefficient (n) and any three of the following: 1) Flow 2) Slope 3) Pipe diameter 4) Depth %, the fourth is computed. Also computes velocity.
4. FORCES AT BENDS AND FITTINGS..... 26  
Solves for force due to a change in velocity of a fluid at a bend or fitting.
5. VALVE SIZING..... 32  
Solves Valve Coefficient (Cv) for valves used in Liquid, Gas, Vapor and Steam.
- \*6. PIPE NETWORK ANALYSIS..... 39  
Solves equivalent length of a pipe using the Hazen-Williams equation. This allows for analysis of a water distribution system using the Hardy-Cross method.
7. RESTRICTION METERING ORIFICE CALCULATIONS..... 53  
Solves for orifice bore and differential pressure across an orifice with flange taps for gas flow.
8. ENERGY EQUATION FOR STEADY FLOW..... 61  
Given any eight of nine terms of the Energy Equation, the ninth is computed.
9. COMPRESSIBLE FLOW IN VARIABLE AREA DUCTS..... 67  
Solves the area ratio mach number relationship for isentropic flow of a perfect gas in a variable area duct.
10. FLOOD ROUTING AND HYDROGRAPHS..... 75  
Solves for a unit hydrograph or a soil conservation service hydrograph given peak time and flow.

\* Requires at least one additional memory module.



## CONDUIT FLOW

This program solves for the average velocity, or the pressure drop for viscous, incompressible flow in conduits.

Equations:

$$v^2 = \frac{\Delta P / \rho}{2 \left( f \frac{L}{D} + \frac{K_T}{4} \right)}$$

For laminar flow ( $Re < 2300$ )

$$f = 16/Re.$$

For turbulent flow ( $Re > 2300$ )

$$\frac{1}{\sqrt{f}} = 1.737 \ln \frac{D}{\epsilon} + 2.28 - 1.737 \ln \left( 4.67 \frac{D}{\epsilon Re \sqrt{f}} + 1 \right)$$

is solved by Newton's method.

$$\frac{1}{\sqrt{f_0}} = 1.737 \ln \frac{D}{\epsilon} + 2.28$$

is used as an initial guess in the iteration.

where:  $Re$  is the Reynolds number, defined as  $\rho D v / \mu$ ;

$D$  is the pipe diameter;

$\epsilon$  is the dimension of irregularities in the conduit surface (see table 2);

$f$  is the Fanning friction factor for conduit flow;

$\Delta P$  is the pressure drop along the conduit;

$\rho$  is the density of the fluid;

$\mu$  is the viscosity of the fluid;

$\nu$  is the kinematic viscosity of the fluid and  $\mu = \rho \nu$ ;

$L$  is the conduit length;

$v$  is the average fluid velocity;

$K_T$  is the total of the applicable fitting coefficients in table 1.

Table 1  
Fitting Coefficients

| Fitting                                     | K                       |
|---------------------------------------------|-------------------------|
| Globe valve, wide open                      | 7.5—10                  |
| Angle valve, wide open                      | 3.8                     |
| Gate valve, wide open                       | 0.15—0.19               |
| Gate valve, 3/4 open                        | 0.85                    |
| Gate valve, 1/2 open                        | 4.4                     |
| Gate valve, 1/4 open                        | 20                      |
| 90° elbow                                   | 0.4—0.9                 |
| Standard 45° elbow                          | 0.35—0.42               |
| Tee, through side outlet                    | 1.5                     |
| Tee, straight through                       | .4                      |
| 180° bend                                   | 1.6                     |
| Entrance to circular pipe                   | 0.25—0.50               |
| Sudden expansion                            | $(1-A_{up}/A_{dn})^2$ * |
| Acceleration from $v=0$ to $v=v_{entrance}$ | 1.0                     |

\* $A_{up}$  is the upstream area and  $A_{dn}$  is the downstream area.

Table 2  
Surface Irregularities

| Material                         | $\epsilon$ (feet)                            | $\epsilon$ (meters)                          |
|----------------------------------|----------------------------------------------|----------------------------------------------|
| Drawn or Smooth Tubing           | $5.0 \times 10^{-6}$                         | $1.5 \times 10^{-6}$                         |
| Commercial Steel or Wrought Iron | $1.5 \times 10^{-4}$                         | $4.6 \times 10^{-5}$                         |
| Asphalted Cast Iron              | $4.0 \times 10^{-4}$                         | $1.2 \times 10^{-4}$                         |
| Galvanized Iron                  | $5.0 \times 10^{-4}$                         | $1.5 \times 10^{-4}$                         |
| Cast Iron                        | $8.3 \times 10^{-4}$                         | $2.5 \times 10^{-4}$                         |
| Wood Stave                       | $6.0 \times 10^{-4}$ to $3.0 \times 10^{-3}$ | $1.8 \times 10^{-4}$ to $9.1 \times 10^{-4}$ |
| Concrete                         | $1.0 \times 10^{-3}$ to $1.0 \times 10^{-2}$ | $3.0 \times 10^{-4}$ to $3.0 \times 10^{-3}$ |
| Riveted Steel                    | $3.0 \times 10^{-3}$ to $3.0 \times 10^{-2}$ | $9.1 \times 10^{-4}$ to $9.1 \times 10^{-3}$ |

Reference:

Welty, Wicks, Wilson, *Fundamentals of Momentum, Heat and Mass Transfer*, John Wiley and Sons, Inc., 1969.

Remarks:

The correlation gives meaningless results in the region  $2300 < Re < 4000$ .

The solution requires an iterative procedure. The time for solution will range from 10 seconds for  $\Delta P$ , to several minutes for  $v$ . The display setting is used to determine when the solution for  $v$  is adequately accurate. Time for solution of  $v$  is roughly proportional to the number of significant digits in the display setting.

If the conduit is not circular, an equivalent diameter may be calculated using the formula below:

$$D_{eq} = 4 \frac{\text{cross sectional area}}{\text{wetted perimeter}}$$

Unitary consistency must be maintained.

Example:

A heat exchanger has 20, 3 meter tube passes (60 m of pipe) with 180 degrees bends connecting each pair of tubes (from table 1,  $K_T = 10 \times 1.6$ ). The fluid is water ( $\nu = 9.3 \times 10^{-7} \text{ m}^2/\text{s}$ ,  $\rho = 10^3 \text{ kg/m}^3$ ). The surface roughness is  $3 \times 10^{-4} \text{ m}$  and the diameter is  $2.54 \times 10^{-2} \text{ m}$ . If the fluid velocity is 3.05 m/s, what is the pressure loss? What is the Reynolds number? What is the Fanning friction factor?

Keystrokes:

[XEQ] [ALPHA] SIZE [ALPHA] 015

[////] [ENG] 3

[XEQ] [ALPHA] CONDUIT [ALPHA]

9.3 [EEX] [CHS] 7 [ENTER↑]

[EEX] 3 [X] [R/S]

[EEX] 3 [R/S]

3 [EEX] [CHS] 4 [R/S]

60 [R/S]

2.54 [EEX] [CHS] 2 [R/S]

16 [R/S]

3.05 [R/S]

[R/S]

[R/S]

[R/S]

Display:

U=?

RHO=?

E=?

L=?

D=?

KT=?

V=?

DP=?

DP=521.9E3

Re=83.30E3

F=10.18E-3

[illegible]

# Program Listings

|                      |              |           |                        |
|----------------------|--------------|-----------|------------------------|
| 01*LBL "CON<br>DUIT" |              | 51 X<>Y   |                        |
| 02 "U=?"             |              | 52 X≠Y?   |                        |
| 03 PROMPT            |              | 53 GTO 03 |                        |
| 04 STO 09            |              | 54 "V="   |                        |
| 05 "RHO=?"           | Input        | 55 RCL 02 |                        |
| 06 PROMPT            |              | 56 GTO 10 |                        |
| 07 STO 10            |              | 57*LBL 09 |                        |
| 08 ST/ 09            |              | 58 RCL 10 |                        |
| 09 "E=?"             |              | 59 RCL 13 |                        |
| 10 PROMPT            |              | 60 RCL 14 | Calculate<br>constants |
| 11 STO 14            |              | 61 /      |                        |
| 12 "L=?"             |              | 62 STO 06 |                        |
| 13 PROMPT            |              | 63 LN     |                        |
| 14 STO 03            |              | 64 1.737  |                        |
| 15 "D=?"             |              | 65 STO 07 |                        |
| 16 PROMPT            |              | 66 *      |                        |
| 17 STO 13            |              | 67 2.28   |                        |
| 18 "KT=?"            |              | 68 +      |                        |
| 19 PROMPT            |              | 69 STO 12 |                        |
| 20 4                 |              | 70 STO 05 |                        |
| 21 /                 |              | 71 FS? 00 |                        |
| 22 STO 08            |              | 72 GTO 07 |                        |
| 23*LBL "CHA<br>NGE"  |              | 73*LBL 08 |                        |
| 24 CF 22             |              | 74 16     |                        |
| 25 "V=?"             |              | 75 RCL 02 |                        |
| 26 PROMPT            |              | 76 RCL 13 | Is flow<br>turbulent?  |
| 27 SF 00             |              | 77 *      |                        |
| 28 FS? 22            |              | 78 RCL 09 |                        |
| 29 CF 00             |              | 79 /      |                        |
| 30 STO 02            |              | 80 STO 01 |                        |
| 31 "DP=?"            |              | 81 2300   |                        |
| 32 PROMPT            |              | 82 X<=Y?  |                        |
| 33 STO 04            |              | 83 GTO 02 |                        |
| 34 XEQ 09            | lst V        | 84 RDN    |                        |
| 35 FS? 00            |              | 85 /      |                        |
| 36 GTO 03            |              | 86 SQRT   |                        |
| 37 RCL 02            |              | 87 1/X    |                        |
| 38 X↑2               |              | 88 STO 05 |                        |
| 39 *                 | Calculate ΔP | 89 GTO 07 |                        |
| 40 RCL 10            |              | 90*LBL 02 |                        |
| 41 *                 |              | 91 RCL 12 |                        |
| 42 STO 04            |              | 92 RCL 05 |                        |
| 43 "DP="             |              | 93 -      |                        |
| 44 GTO 10            |              | 94 4.67   |                        |
| 45*LBL 03            |              | 95 RCL 06 |                        |
| 46 RND               |              | 96 *      |                        |
| 47 STO 00            |              | 97 RCL 01 |                        |
| 48 XEQ 08            |              | 98 /      |                        |
| 49 RND               |              | 99 RCL 05 |                        |
| 50 RCL 00            |              | 100 *     |                        |
|                      |              | 101 1     |                        |
|                      |              | 102 +     |                        |

# Program Listings

```

103 STO 11
104 LN
105 RCL 07
106 *
107 -
108 RCL 11
109 1/X
110 CHS
111 1
112 +
113 RCL 07
114 *
115 RCL 05
116 /
117 1
118 +
119 /
120 ST+ 05
121 RCL 05
122 /
123 ABS
124 E-3
125 X<=Y?
126 GTO 02
127 LBL 07
128 RCL 05
129 1/X
130 X↑2
131 RCL 03
132 *
133 RCL 13
134 /
135 RCL 08
136 +
137 2
138 *
139 RCL 04
140 RCL 10
141 /
142 X<>Y
143 FS? 00
144 GTO 00
145 RTN
146 LBL 00
147 /
148 SQRT
149 STO 02
150 RTN
151 LBL 10
152 ARCL X
153 PROMPT
154 "Re="

```

```

155 ARCL 01
156 PROMPT
157 "F="
158 RCL 05
159 1/X
160 X↑2
161 ARCL X
162 PROMPT
163 RTN
164 .END.

```

00

70

80

90

Output

00



## FLOW WITH A FREE SURFACE

This program solves algebraic manipulations of the following two equations for any of the five variables in each:

Manning flow formula:

$$S = \frac{(nQ)^2}{2.2082 \, r^{4/3} \times a^2} \quad (1)$$

$$Q = \frac{K}{n} D^{8/3} \times S^{1/2} \quad (2)$$

Where

S = slope of the bottom, dimensionless

n = roughness coefficient

r = hydraulic radius ft.

Q = discharge rate ft<sup>3</sup>/sec

a = crosssection area ft<sup>2</sup>/sec

K = discharge factor dimensionless

and

D = hydraulic diameter

References: Civil Engineering Handbook, Leonard Church Urquhart (ed.), McGraw-Hill Book Company, 4th Ed.  
HP-67/HP-97 Users' Library program #00269D.



Example: 1. Find Q for  $S = .001$ ,  $N = .013$ ,  $R = 5/12$ , and  $A = 5.0$

2. Find K for  $S = .001$ ,  $n = .014$ ,  $Q = 200$ , and  $D = 4$

Solution:

Keystrokes:

[USER]

[XEQ] [ALPHA] SIZE [ALPHA] 007

[XEQ] [ALPHA] FSFLO [ALPHA]

[A]

.001 [R/S]

.013 [R/S]

[R/S]

5 [ENT] 12 [ $\div$ ] [R/S]

5 [R/S]

[B]

.001 [R/S]

.014 [R/S]

200 [R/S]

4 [R/S]

[R/S]

Display:

(Set USER mode)

LBL A OR B ?

S ?

N ?

Q ?

R ?

A ?

Q=10.0826

S ?

N ?

Q ?

D ?

K ?

K=2.1962

# User Instructions

|      |                                           |       |             | SIZE: 007     |
|------|-------------------------------------------|-------|-------------|---------------|
| STEP | INSTRUCTIONS                              | INPUT | FUNCTION    | DISPLAY       |
| 1    | Load the program and set USER mode        |       | [USER]      |               |
| 2    | Initialize the program                    |       | [XEQ] FSFLO | LBL A OR B ?  |
| 3    | For Manning Flow formula, press →         |       | [A]         | S ?           |
|      | and input 4 of the following:             | S     | [R/S]       | N ?           |
|      | When prompted for the unknown variable,   | N     | [R/S]       | Q ?           |
|      | press [R/S] (make no input). The unknown  | Q     | [R/S]       | R ?           |
|      | is then automatically calculated.         | R     | [R/S]       | A ?           |
|      |                                           | A     | [R/S]       | S=( )         |
|      |                                           |       |             | -or-<br>N=( ) |
|      |                                           |       |             | -or-<br>Q=( ) |
|      |                                           |       |             | -or-<br>R=( ) |
|      |                                           |       |             | -or-<br>A=( ) |
| 4    | For discharge factor formula, press →     |       | [B]         | S ?           |
|      | and input 4 of the following:             |       | [R/S]       | N ?           |
|      | When prompted for the unknown variable,   |       | [R/S]       | Q ?           |
|      | press [R/S] (make no input). The          |       | [R/S]       | D ?           |
|      | unknown is then automatically calculated. |       | [R/S]       | K ?           |
|      |                                           |       | [R/S]       | S=( )         |
|      |                                           |       |             | -or-<br>N=( ) |
|      |                                           |       |             | -or-<br>Q=( ) |
|      |                                           |       |             | -or-<br>D=( ) |
|      |                                           |       |             | -or-<br>K=( ) |
|      |                                           |       |             |               |
|      |                                           |       |             |               |
|      |                                           |       |             |               |
|      |                                           |       |             |               |
|      |                                           |       |             |               |

# Program Listings

|                                                                                                                                                                                                                                                                                                                                                 |                          |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                 |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------|
| 01*LBL "FSF<br>L0"<br>02 "LBL A 0<br>R B?"<br>03 PROMPT<br>04*LBL A<br>05 1.1<br>06 STO 00<br>07 CF 22<br>08 "S ?"<br>09 XEQ 11<br>10 "N ?"<br>11 XEQ 11<br>12 "Q ?"<br>13 XEQ 11<br>14 "R ?"<br>15 XEQ 11<br>16 "A ?"<br>17 XEQ 11<br>18 RCL 04<br>19 4<br>20 ENTER↑<br>21 3<br>22 /<br>23 Y↑X<br>24 2.2082<br>25 *<br>26 STO 04<br>27 GTO IND | Equation 1               | 48 RCL 02<br>49 RCL 03<br>50 *<br>51 X↑2<br>52 RCL 01<br>53 /<br>54 RTN<br>55*LBL 15<br>56 RCL 05<br>57 X↑2<br>58 RCL 04<br>59 *<br>60 RTN<br>61*LBL 02<br>62 XEQ 15<br>63 RCL 01<br>64 *<br>65 SQRT<br>66 RCL 03<br>67 /<br>68 "N"<br>69 XEQ 12<br>70*LBL 03<br>71 XEQ 15<br>72 RCL 01<br>73 *<br>74 SQRT<br>75 RCL 02<br>76 /<br>77 "Q"<br>78 XEQ 12<br>79*LBL 05<br>80 XEQ 16<br>81 RCL 04<br>82 /<br>83 SQRT<br>84 "A"<br>85 XEQ 12<br>86*LBL 04<br>87 XEQ 16<br>88 RCL 05<br>89 X↑2<br>90 /<br>91 2.2082<br>92 /<br>93 3<br>94 ENTER↑<br>95 4<br>96 /<br>97 Y↑X<br>98 "R" | Calculate<br>$\frac{(NQ)^2}{S}$ |
| 06<br>28*LBL 01<br>29 XEQ 16<br>30 RCL 01<br>31 *<br>32 XEQ 15<br>33 /<br>34 "S"<br>35*LBL 12<br>36 "I="                                                                                                                                                                                                                                        | Prompt and<br>store data |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Calculate<br>denominator        |
| 37 ARCL X<br>38 PROMPT<br>39*LBL 11<br>40 PROMPT<br>41 STO IND                                                                                                                                                                                                                                                                                  |                          |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Calculate N                     |
| 00<br>42 RCL 00<br>43 FC?C 22<br>44 STO 06<br>45 ISG 00<br>46 RTN<br>47*LBL 16                                                                                                                                                                                                                                                                  |                          |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Calculate Q                     |
|                                                                                                                                                                                                                                                                                                                                                 | Calculate S              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Calculate A                     |
|                                                                                                                                                                                                                                                                                                                                                 | Display routine          |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Calculate R                     |
|                                                                                                                                                                                                                                                                                                                                                 | Input storage<br>routine |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                 |

# Program Listings

|             |                |            |             |
|-------------|----------------|------------|-------------|
| 99 XEQ 12   |                | 149 RCL 02 | Calculate K |
| 100♦LBL B   | Equation 2     | 150 RCL 03 |             |
| 101 1.1     |                | 151 RCL 01 |             |
| 102 STO 00  |                | 152 /      |             |
| 103 CF 22   |                | 153 *      |             |
| 104 "S ?"   |                | 154 RCL 04 |             |
| 105 XEQ 11  | Prompt and     | 155 /      |             |
| 106 "N ?"   | store date     | 156 "K"    |             |
| 107 XEQ 11  |                | 157 XEQ 12 |             |
| 108 "Q ?"   |                | 158♦LBL 07 | Calculate N |
| 109 XEQ 11  |                | 159 RCL 05 |             |
| 110 "D ?"   |                | 160 RCL 04 |             |
| 111 XEQ 11  |                | 161 *      |             |
| 112 "K ?"   |                | 162 RCL 03 |             |
| 113 XEQ 11  |                | 163 RCL 01 |             |
| 114 5       | adjust pointer | 164 /      |             |
| 115 ST+ 06  |                | 165 /      |             |
| 116 RCL 01  |                | 166 "N"    |             |
| 117 SQRT    |                | 167 XEQ 12 |             |
| 118 STO 01  |                | 168♦LBL 09 | Calculate D |
| 119 RCL 04  |                | 169 RCL 03 |             |
| 120 8       |                | 170 RCL 01 |             |
| 121 ENTER↑  |                | 171 /      |             |
| 122 3       |                | 172 RCL 02 |             |
| 123 /       |                | 173 *      |             |
| 124 Y↑X     | $D^{8/3}$      | 174 RCL 05 |             |
| 125 STO 04  |                | 175 /      |             |
| 126 GTO IND |                | 176 3      |             |
| 06          |                | 177 ENTER↑ |             |
| 127♦LBL 08  |                | 178 8      |             |
| 128 RCL 05  | Calculate Q    | 179 /      |             |
| 129 RCL 02  |                | 180 Y↑X    |             |
| 130 /       |                | 181 "D"    |             |
| 131 RCL 04  |                | 182 XEQ 12 |             |
| 132 *       |                | 183 .END.  |             |
| 133 RCL 01  |                |            |             |
| 134 *       |                |            |             |
| 135 "Q"     |                |            |             |
| 136 XEQ 12  |                |            |             |
| 137♦LBL 06  |                |            |             |
| 138 RCL 03  | Calculate S    | 90         |             |
| 139 RCL 05  |                |            |             |
| 140 RCL 02  |                |            |             |
| 141 /       |                |            |             |
| 142 RCL 04  |                |            |             |
| 143 *       |                |            |             |
| 144 /       |                |            |             |
| 145 X↑2     |                |            |             |
| 146 "S"     |                |            |             |
| 147 XEQ 12  |                |            |             |
| 148♦LBL 10  |                | 00         |             |

[illegible]

## PIPE SLIDE-RULE

The program computes the unknown, when given the surface coefficient (n) and any three of the following: 1) Flow (Q); 2) Slope (S); 3) Pipe diameter (D); 4) Depth % (D/d). Also computes Velocity (V). When solving for Pipe diameter, the program automatically rounds up to a standard size of 6", 8", 12", 15", 18", 21", 24", etc.--pipe. Depth percentage (D/d) is found by Newton's method of iteration. In the case of depth percentages between approximately 82% and 100%, two roots or values are appropriate.

Reference: HP-67/97 Users' Library program #00281D by C. B. Coleman.

Example: Find D/d and V given the following:

|               |                        |
|---------------|------------------------|
| n = .013      | s = .001 (1ft/1000ft)* |
| Q = 850.3 CFS | D = 144 (inches)       |

Solution:

Keystrokes:

Display:

|                                   |            |
|-----------------------------------|------------|
| [///] [FIX] 2                     |            |
| [XEQ] [ALPHA] SIZE [ALPHA] 013    |            |
| [XEQ] [ALPHA] PSR [ALPHA] [A]     | N ?        |
| .013 [R/S]                        | S ?        |
| .001 [R/S]                        | Q ?        |
| 850.3 [R/S]                       | D ?        |
| 144 [R/S]                         | D/d ?      |
| [R/S]                             | D/d=81.96  |
| [R/S] (second solution)           | D/d=100.00 |
| [B]                               | Q ?        |
| 850.3 [R/S]                       | D ?        |
| 144 [R/S]                         | D/d ?      |
| 81.96 [R/S]                       | V=8.57     |
| etc. (for second solution V=7.52) |            |

\*Note that slope is given as rise/run, not %. A 30% slope would be entered as .30.

[illegible]

# Program Listings

|             |                |            |                           |
|-------------|----------------|------------|---------------------------|
| 01*LBL "PSR |                | 47 PROMPT  |                           |
| 02 SF 21    | Initialize     | 48 STO IND | Common Input Routine      |
| 03 SF 27    |                | 04         |                           |
| 04 RAD      |                | 49 RCL 04  |                           |
| 05 STOP     |                | 50 FC?C 22 |                           |
| 06*LBL B    | Solve for V    | 51 STO 03  |                           |
| 07 SF 06    |                | 52 ISG 04  |                           |
| 08 10       |                | 53 CLD     |                           |
| 09 STO 04   |                | 54 RTN     |                           |
| 10 XEQ 05   | Input Routine  | 55*LBL 10  | Solve for Q               |
| 11 XEQ 02   |                | 56 SF 05   |                           |
| 12 ENTER↑   |                | 57 XEQ 02  |                           |
| 13 SIN      |                | 58 XEQ 15  |                           |
| 14 -        |                | 59 "Q"     | Output Q                  |
| 15 1/X      |                | 60 GTO 14  |                           |
| 16 RCL 10   | Calculate V    | 61*LBL 09  |                           |
| 17 *        |                | 62 1       |                           |
| 18 RCL 11   |                | 63 STO 09  | Solve for S               |
| 19 X↑2      |                | 64 XEQ 20  |                           |
| 20 /        |                | 65 X↑2     |                           |
| 21 1152     |                | 66 100     |                           |
| 22 *        |                | 67 /       |                           |
| 23 "V"      |                | 68 "S"     | Output S                  |
| 24 GTO 14   | Output Routine | 69 GTO 14  |                           |
| 25*LBL A    |                | 70*LBL 11  |                           |
| 26 CF 06    |                | 71 1       |                           |
| 27 8        |                | 72 STO 11  |                           |
| 28 STO 04   |                | 73 XEQ 20  |                           |
| 29 "N"      |                | 74 .375    |                           |
| 30 XEQ 00   |                | 75 Y↑X     |                           |
| 31 "S"      | Input Knowns   | 76 6       |                           |
| 32 XEQ 00   |                | 77 X<>Y    |                           |
| 33*LBL 05   |                | 78 X<=Y?   |                           |
| 34 "Q"      |                | 79 GTO 04  |                           |
| 35 XEQ 00   |                | 80 8       | Solve for D               |
| 36 "D"      |                | 81 X<>Y    |                           |
| 37 XEQ 00   |                | 82 X<=Y?   |                           |
| 38 "D/d"    |                | 83 GTO 04  | Rounding to Standard Size |
| 39 XEQ 00   |                | 84 12      |                           |
| 40 FS?C 06  |                | 85 X<>Y    |                           |
| 41 RTN      |                | 86 X<=Y?   |                           |
| 42 100      |                | 87 GTO 04  |                           |
| 43 ST* 09   |                | 88 3       |                           |
| 44 GTO IND  |                | 89 /       |                           |
| 03          |                | 90 .999    |                           |
| 45*LBL 00   |                | 91 +       |                           |
| 46 "┐ ?"    |                | 92 INT     |                           |
|             |                | 93 3       |                           |



# Program Listings

|                          |                |                           |
|--------------------------|----------------|---------------------------|
| 94 *                     |                | 142 $X \uparrow 2$        |
| 95 $X \langle \rangle Y$ |                | 143 /                     |
| 96 $\downarrow$ LBL 04   |                | 144 3                     |
| 97 $X \langle \rangle Y$ |                | 145 $1/X$                 |
| 98 "D"                   | Output D       | 146 $Y \uparrow X$        |
| 99 GTO 14                |                | 147 RCL 05                |
| 100 $\downarrow$ LBL 02  |                | 148 *                     |
| 101 RCL 12               | Common Routine | 149 FS?C 05               |
| 102 50                   |                | 150 RTN                   |
| 103 /                    |                | 151 RCL 10                |
| 104 1                    |                | 152 -                     |
| 105 -                    |                | 153 STO 00                |
| 106 CHS                  |                | 154 RCL 01                |
| 107 ACOS                 |                | 155 RCL 12                |
| 108 ST+ X                |                | 156 STO 01                |
| 109 STO 12               |                | 157 -                     |
| 110 RTN                  |                | 158 RCL 02                |
| 111 $\downarrow$ LBL 12  | Solve for D/d  | 159 RCL 00                |
| 112 PI                   |                | 160 STO 02                |
| 113 STO 12               |                | 161 -                     |
| 114 4                    |                | 162 /                     |
| 115 STO 01               |                | 163 *                     |
| 116 CHS                  |                | 164 CHS                   |
| 117 STO 02               |                | 165 ST+ 12                |
| 118 $\downarrow$ LBL 15  |                | 166 RCL 12                |
| 119 RCL 11               | Common         | 167 /                     |
| 120 8                    | Iteration      | 168 RND                   |
| 121 ENTER $\uparrow$     | Routine        | 169 $X \neq 0?$           |
| 122 3                    |                | 170 GTO 01                |
| 123 /                    |                | 171 7                     |
| 124 $Y \uparrow X$       |                | 172 RCL 12                |
| 125 RCL 09               |                | 173 $X > Y?$              |
| 126 SQRT                 |                | 174 GTO 17                |
| 127 *                    |                | 175 2                     |
| 128 RCL 08               |                | 176 /                     |
| 129 /                    |                | 177 COS                   |
| 130 320                  |                | 178 1                     |
| 131 $X \uparrow 2$       |                | 179 -                     |
| 132 /                    |                | 180 2                     |
| 133 STO 05               |                | 181 /                     |
| 134 $\downarrow$ LBL 01  |                | 182 CHS                   |
| 135 RCL 12               |                | 183 1 E2                  |
| 136 ENTER $\uparrow$     |                | 184 *                     |
| 137 SIN                  |                | 185 STO 06                |
| 138 -                    |                | 186 .8196                 |
| 139 5                    |                | 187 $X \langle \rangle Y$ |
| 140 $Y \uparrow X$       |                | 188 "D/d"                 |
| 141 RCL 12               |                | 189 $X \leq Y?$           |

# Program Listings

```

190 GTO 14
191 FC? 07
192 XEQ 14
193 FS?C 07
194 GTO 14
195 SF 07
196 RCL 12
197 STO 07
198 PI
199 ST+ X
200 STO 01
201 CHS
202 STO 02
203 6
204 STO 12
205 GTO 15
206♦LBL 20
207 SF 05
208 XEQ 02
209 XEQ 15
210 RCL 10
211 /
212 1/X
213 RTN
214♦LBL 14
215 "I="
216 ARCL X
217 AVIEW
218 END

```

Output D/d

Output Routine

51

60

70

80

90

00

40

50

[illegible]

# FORCES AT BENDS AND FITTINGS

When the velocity of a flowing fluid is changed in magnitude or direction, such as at a bend or fitting, a force must act upon the fluid to cause the change. This program considers only the systems where the pipe itself is pressure-tight, but where accelerating forces must be resisted by external means to prevent movement of the piping, increased stress in the pipe walls, or both. The equations are:

$$F_x = \frac{QW}{g} (V_{2x} - V_{1x}), \quad F_y = \frac{QW}{g} (V_{2y} - V_{1y})$$

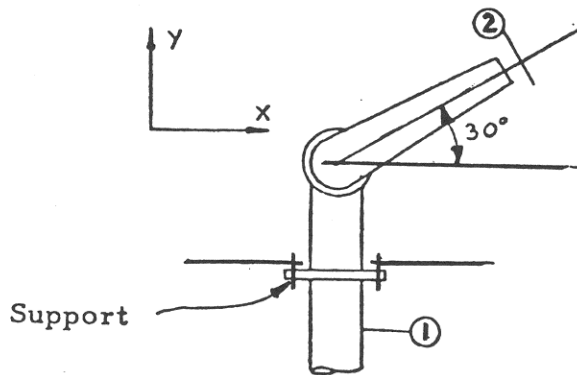
$$\vec{F} = \vec{F}_x + \vec{F}_y, \quad \vec{R} = -\vec{F}$$

where  $\vec{F}$  = accelerating force on water, lbs  
 $Q$  = rate of flow, ft<sup>3</sup>/sec  
 $W$  = specific weight, lbs/ft<sup>3</sup>  
 $g$  = acceleration of gravity, ft/sec<sup>2</sup>  
 $V_2$  = velocity leaving fittings, ft/sec  
 $V_1$  = velocity entering fitting, ft/sec  
 $\vec{R}$  = reaction of water on fitting, lbs

Subscripts: x for x direction and y for y direction

References: Fluid Mechanics and Hydraulics, by Ronald V. Giles, Schaums Outline Series, McGraw-Hill Book Company, New York, 1962.  
 Hp-67/HP-97 Users' Library program #00268D

Example:



$$Q = 2 \text{ ft.}^3/\text{sec.}$$

$$A_1 = 0.2 \text{ ft.}^2$$

$$A_2 = 0.016 \text{ ft.}^2$$

Find the forces on the water deck gun due to the changes in velocity and direction.

$$V_{x_1} = 0$$

$$V_{x_2} = V \cos \theta; \theta = 30^\circ, V = \frac{2}{.016} \left( \frac{Q}{A_2} \right).$$

$$V_{y_1} = 2/.2 \quad (Q/A_1)$$

$$V_{y_2} = V \sin \theta; \theta = 30^\circ, V = \frac{2}{.016} \left( \frac{Q}{A_2} \right).$$

Solution:

Keystrokes:

[XEQ] [ALPHA] SIZE [ALPHA] 002

[XEQ] [ALPHA] FORCE [ALPHA]

62.4 [R/S]

2 [R/S]

0 [R/S]

108.25 [R/S]

10 [R/S]

62.5 [R/S]

[R/S]

[R/S]

[R/S]

Display:

W ?

Q ?

V,X1 ?

V,X2 ?

V,Y1 ?

V,Y2 ?

F,X=419.940.0

F,Y=203.6490.0

F=466.7425.9

R=466.74-154.1

[illegible]

# Program Listings

|             |                 |    |  |
|-------------|-----------------|----|--|
| 01♦LBL "FOR |                 | 51 |  |
| CE"         |                 |    |  |
| 02 "W ?"    |                 |    |  |
| 03 PROMPT   |                 |    |  |
| 04 "Q ?"    |                 |    |  |
| 05 PROMPT   |                 |    |  |
| 06 *        |                 |    |  |
| 07 32.1739  | $\frac{WQ}{g}$  |    |  |
| 08 /        |                 |    |  |
| 09 STO 00   |                 | 60 |  |
| 10 STO 01   |                 |    |  |
| 11 "V,X1 ?" |                 |    |  |
| 12 PROMPT   |                 |    |  |
| 13 "V,X2 ?" |                 |    |  |
| 14 PROMPT   |                 |    |  |
| 15 -        |                 |    |  |
| 16 CHS      |                 |    |  |
| 17 ST* 00   | $F_x$           |    |  |
| 18 "V,Y1 ?" |                 |    |  |
| 19 PROMPT   |                 |    |  |
| 20 "V,Y2 ?" |                 | 70 |  |
| 21 PROMPT   |                 |    |  |
| 22 -        |                 |    |  |
| 23 CHS      |                 |    |  |
| 24 ST* 01   | $F_y$           |    |  |
| 25 0        |                 |    |  |
| 26 RCL 00   |                 |    |  |
| 27 "F,X"    |                 |    |  |
| 28 XEQ 08   |                 |    |  |
| 29 90       |                 |    |  |
| 30 RCL 01   |                 | 80 |  |
| 31 "F,Y"    |                 |    |  |
| 32 XEQ 08   |                 |    |  |
| 33 RCL 00   |                 |    |  |
| 34 R-P      |                 |    |  |
| 35 "F"      |                 |    |  |
| 36 XEQ 08   |                 |    |  |
| 37 RCL 01   |                 |    |  |
| 38 CHS      |                 |    |  |
| 39 RCL 00   |                 |    |  |
| 40 CHS      |                 | 90 |  |
| 41 R-P      |                 |    |  |
| 42 "R"      |                 |    |  |
| 43♦LBL 08   | -----           |    |  |
| 44 "I="     | Display routine |    |  |
| 45 ARCL X   |                 |    |  |
| 46 "I<"     |                 |    |  |
| 47 ARCL Y   |                 |    |  |
| 48 PROMPT   |                 |    |  |
| 49 RTN      |                 |    |  |
| 50 .END.    |                 | 00 |  |

| DATA REGISTERS |          |    |  | STATUS      |               |               |                 |
|----------------|----------|----|--|-------------|---------------|---------------|-----------------|
| 00             | QW/g, FX | 50 |  | SIZE 002    | TOT. REG. 019 | USER MODE     |                 |
|                | QW/g, FY |    |  | ENG         | FIX 1         | SCI           | ON OFF x        |
|                |          |    |  | DEG x       | RAD           | GRAD          |                 |
| 05             |          | 55 |  | FLAGS       |               |               |                 |
|                |          |    |  | #           | INIT S/C      | SET INDICATES | CLEAR INDICATES |
|                |          |    |  |             |               |               |                 |
| 10             |          | 60 |  |             |               |               |                 |
|                |          |    |  |             |               |               |                 |
|                |          |    |  |             |               |               |                 |
| 15             |          | 65 |  |             |               |               |                 |
|                |          |    |  |             |               |               |                 |
|                |          |    |  |             |               |               |                 |
| 20             |          | 70 |  |             |               |               |                 |
|                |          |    |  |             |               |               |                 |
|                |          |    |  |             |               |               |                 |
| 25             |          | 75 |  |             |               |               |                 |
|                |          |    |  |             |               |               |                 |
|                |          |    |  |             |               |               |                 |
| 30             |          | 80 |  |             |               |               |                 |
|                |          |    |  |             |               |               |                 |
|                |          |    |  |             |               |               |                 |
| 35             |          | 85 |  |             |               |               |                 |
|                |          |    |  |             |               |               |                 |
|                |          |    |  |             |               |               |                 |
| 40             |          | 90 |  | ASSIGNMENTS |               |               |                 |
|                |          |    |  | FUNCTION    | KEY           | FUNCTION      | KEY             |
|                |          |    |  |             |               |               |                 |
|                |          |    |  |             |               |               |                 |
| 45             |          | 95 |  |             |               |               |                 |
|                |          |    |  |             |               |               |                 |
|                |          |    |  |             |               |               |                 |



## VALVE SIZING

This program calculates the valve coefficient  $C_v$ .

Valve for Liquid flow:

$$C_v = Q \sqrt{\frac{G}{(P_1 - P_2)}}$$

Valve for Gas flow, if  $P_2 \geq \frac{P_1}{2}$  :

$$C_v = \frac{Q \sqrt{G T_a}}{1360 \sqrt{(P_1 - P_2) P_2}}$$

Valve for Gas flow, if  $P_2 < \frac{P_1}{2}$  :

$$C_v = \frac{Q \sqrt{G T_a}}{1360 (P_1/2)}$$

Valve for Vapor flow, if  $P_2 \geq \frac{P_1}{2}$  :

$$C_v = \frac{Q}{63.4} \sqrt{\frac{V_s}{(P_1 - P_2)}}$$

Valve for Vapor flow, if  $P_2 < \frac{P_1}{2}$  :

$$C_v = \frac{Q}{63.4} \sqrt{\frac{V_s}{(P_1/2)}}$$

Valve for Steam flow, if  $P_2 \geq \frac{P_1}{2}$  :

$$C_v = \frac{Q (1 + 0.0007 T_s)}{3 \sqrt{(P_1 - P_2) P_2}}$$

Valve for Steam flow, if  $P_2 < \frac{P_1}{2}$  :

$$C_v = \frac{Q (1 + 0.0007 T_s)}{3 (P_1/2)}$$

References: HP-67/HP-97 Users' Library program #02200D by Paul Crowder.  
 "Process Instruments and Control Handbook" by D. M. Constadine,  
 pub. McGraw-Hill, 1957.

Example: Calculate CV for a gas valve:

Inlet pressure - 135 psig  
Outlet pressure - 115 psig  
Sp. Gr. @ flow - 1.0

Flow temp. - 10°F  
Flow rate - 9000 CFH

Solution:

Keystrokes:

[XEQ] [ALPHA] SIZE [ALPHA] 004  
[XEQ] CV  
[ALPHA] G [ALPHA] [R/S]  
9000 [R/S]  
149.7 [R/S]  
129.7 [R/S]  
1 [R/S]  
10 [R/S]

Display:

L,G,V, OR S ?  
Q ?  
P1 ?  
P2 ?  
G ?  
T ?  
CV = 2.82

[illegible]

# Program Listings

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                                                                                                          |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|
| <pre> 01*LBL "CV" 02 CF 01 03 "L,G,V, OR S?" 04 PROMPT 05 ASTO Y 06 "L" 07 ASTO X 08 X=Y? 09 GTO 01 10 "G" 11 ASTO X 12 X=Y? 13 GTO 02 14 "V" 15 ASTO X 16 X=Y? 17 GTO 03 18 XEQ 05 19 "TS ?" 20 PROMPT 21 .0007 22 * 23 1 24 + 25 3 26 / 27 RCL 00 28 * 29 XEQ 06 30 FS?C 01 31 GTO 08 32*LBL 10 33 RCL 01 34 RCL 02 35 * 36 SQRT 37 / 38 XEQ 09 39*LBL 08 40 RCL 01 41 / 42*LBL 09 43 "CV=" 44 ARCL X 45 PROMPT 46*LBL 03 47 XEQ 05 48 RCL 00 49 63.4 50 / </pre> | <p>Select equation</p> <hr/> <p>Calculate<br/>CV for steam</p> <hr/> $P_2 \geq \frac{P_1}{2}$ <hr/> $P_2 < \frac{P_1}{2}$ <hr/> <p>Display<br/>routine</p> <hr/> <p>Calculate<br/>CV for vapor</p> | <pre> 51 XEQ 06 52 "VS ?" 53 PROMPT 54 RCL 01 55 / 56 SQRT 57 * 58 CF 01 59 XEQ 09 60*LBL 02 61 XEQ 05 62 RCL 00 63 1360 64 / 65 "G ?" 66 PROMPT 67 "T ?" 68 PROMPT 69 460 70 + 71 * 72 SQRT 73 * 74 XEQ 06 75 FS?C 01 76 GTO 08 77 GTO 10 78*LBL 01 79 XEQ 05 80 "G ?" 81 PROMPT 82 RCL 01 83 RCL 02 84 - 85 / 86 SQRT 87 RCL 00 88 * 89 XEQ 09 90*LBL 05 91 "Q ?" 92 PROMPT 93 STO 00 94 "P1 ?" 95 PROMPT 96 STO 01 97 "P2 ?" 98 PROMPT 99 STO 02 100 RTN 101*LBL 06 </pre> | <hr/> <p>Calculate<br/>CV for gas</p> <hr/> <p>absolute temp.</p> <hr/> <p>Calculate<br/>CV for liquid</p> <hr/> <p>Prompt and<br/>store input</p> <hr/> |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|

# Program Listings

|     |        |                                    |    |  |
|-----|--------|------------------------------------|----|--|
| 102 | STO 03 | test $P_1, P_2$<br>$\frac{P_1}{2}$ | 51 |  |
| 103 | RCL 02 |                                    |    |  |
| 104 | RCL 01 |                                    |    |  |
| 105 | 2      |                                    |    |  |
| 106 | /      |                                    |    |  |
| 107 | X>Y?   |                                    |    |  |
| 108 | GTO 07 |                                    |    |  |
| 109 | RCL 02 |                                    |    |  |
| 110 | ST- 01 |                                    |    |  |
| 111 | RCL 03 |                                    |    |  |
| 112 | RTN    | $P_2 \geq \frac{P_1}{2}$           | 60 |  |
| 113 | LBL 07 | $P_2 < \frac{P_1}{2}$              |    |  |
| 114 | STO 01 |                                    |    |  |
| 115 | SF 01  |                                    |    |  |
| 116 | RCL 03 |                                    |    |  |
| 117 | RTN    |                                    |    |  |
| 118 | .END.  |                                    |    |  |
|     |        |                                    |    |  |
|     |        |                                    |    |  |
| 20  |        |                                    | 70 |  |
|     |        |                                    |    |  |
|     |        |                                    |    |  |
|     |        |                                    |    |  |
|     |        |                                    |    |  |
|     |        |                                    |    |  |
| 30  |        |                                    | 80 |  |
|     |        |                                    |    |  |
|     |        |                                    |    |  |
|     |        |                                    |    |  |
|     |        |                                    |    |  |
|     |        |                                    |    |  |
| 40  |        |                                    | 90 |  |
|     |        |                                    |    |  |
|     |        |                                    |    |  |
|     |        |                                    |    |  |
|     |        |                                    |    |  |
|     |        |                                    |    |  |
| 50  |        |                                    | 00 |  |



## PIPE NETWORK ANALYSIS

(Requires at least one additional memory module)

The first portion of the program computes the equivalent length of a pipe by use of the Hazen-Williams equation. This is a prerequisite to any analysis of a water distribution system by the version of the Hardy-Cross Method used herein which requires that all pipes must be of the same diameter  $d$  (normally  $d=10''$  is used) and roughness  $C$  (normally  $C=100$  is used.)

This portion of the program computes the equivalent length by the equation:

$$L_2 = L_1 \left( \frac{C_2}{C_1} \right)^{1.8519} \cdot \left( \frac{d_2}{d_1} \right)^{4.8707}$$

where the subscript 1 represents the existing pipe and the subscript 2 the equivalent pipe.

The second portion of the program computes corrected flows (4 iterations) using the Hardy-Cross method derived here:

Consider a two pipe loop; flow in one pipe  $Q_1$  and the second pipe  $Q_2$ .

- 1) Head Loss (in one pipe) =  $h = K L Q^n$  where  $K$  is a constant dependent on the diameter, roughness and length of the pipe.

$$K = \left( \frac{1.594}{C} \right)^{1.85} \cdot \frac{L}{D^{4.87}}$$

- 2) Balanced head losses ( $H_1$  and  $-H_2$ ) around loop are equal to 0

$$\Sigma H = H_1 - H_2 = 0$$

- 3) If the assumed flow split  $Q_1$  and  $-Q_2$  are each in error by the same amount  $\Delta Q$

$$\Sigma H = \Sigma K L (Q + \Delta Q)^n = 0$$

- 4) Expanding the polynomial and neglecting all but the first two terms

$$\Sigma H = \Sigma K L Q^n + \Sigma n K L \Delta Q \cdot Q^{n-1} = 0 \text{ whence } \Delta Q = \frac{-\Sigma K L Q^n}{n \Sigma K L Q^{n-1}} = \frac{-\Sigma K L Q^n}{n \Sigma K L Q^{n-1}}$$

- 5) However, since all pipes are of the same size and roughness,  $K$  cancels. Also  $n = 1.85$  ( $=1/0.54$ )

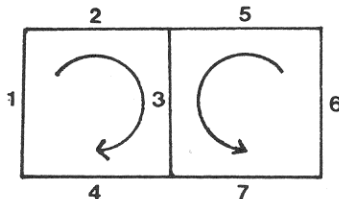
$$\Delta Q = \frac{-\Sigma L Q^{1/0.54}}{\Sigma \left( \frac{L Q^{1/0.54}}{Q(0.54)} \right)}$$

The third portion of the program enables the computation of the pressure (in psi) at any pipe junction in the distribution system given the starting pressure at a particular pipe junction (normally a point where flow enters the system from a pump or elevated tank). This portion of the program computes the head loss in feet along a particular pipe by the formula

$$h_f = L \left[ \left( \frac{3.5521Q}{C} \right)^{1.8519} \cdot d^{-4.8704} \right]$$

Notes:

1. All pipes must be assumed to carry some flow, no matter how small. No zero flows.
2. The program assumes loops comprise 4 pipes. If a loop contains 3 pipes, enter a zero for 4th pipe number.
3. Prior to running the program, sketch the pipe network and assign pipe numbers and flow directions (clockwise or counterclockwise). Adjacent loops must have opposite flow directions to keep the flow consistent in common pipes.



For example, the flow direction in pipe 3 (above) is the same for both loops. Then assign assumed flows in the direction of the arrows positive values and assumed flows opposite the arrows negative values. If the assumed flow in a particular pipe is inadvertently assumed in the wrong direction, the program will automatically correct the sign during the program iterations.

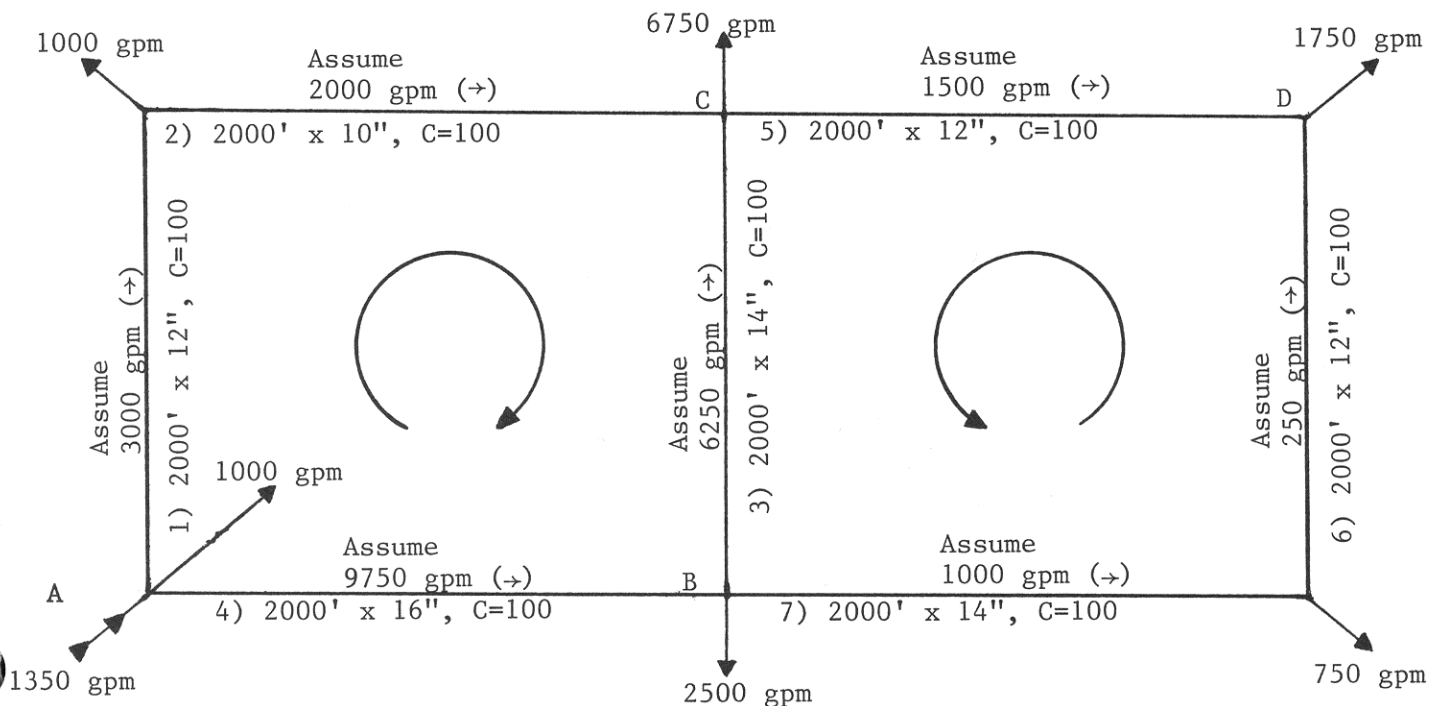
4. SIZE = No. of loops + 2 x No. of pipes + 7.
5. The annunciators in the display show the progress of the calculations (flags 1-4 correspond to iterations 1-4).

Reference: HP-67/HP-97 USERS LIBRARY  
program #02275D by Bernard Golding.



Example:

Compute the correct flows for the network below. Also, find the pressure at point D if the pressure at point A is 100 psi.



Solution:

Keystrokes:

Display:

[USER]

(Set USER mode)

[XEQ] [ALPHA] SIZE [ALPHA] 023

[XEQ] [ALPHA] NA [ALPHA]

1 [R/S]

2 [R/S]

3 [R/S]

4 [R/S]

[A]

3 [R/S]

5 [R/S]

6 [R/S]

7 [R/S]

PIPE NO. ?

PIPE NO. ?

PIPE NO. ?

PIPE NO. ?

A OR B ?

PIPE NO. ?

PIPE NO. ?

PIPE NO. ?

PIPE NO. ?

A OR B ?

|                  |                |
|------------------|----------------|
| [B]              | NO. OF PIPES ? |
| 7 [R/S]          | EQUIV. DIA. ?  |
| 10 [R/S]         | EQUIV. RUF. ?  |
| 100 [R/S]        | L,1 ?          |
| 2000 [R/S]       | d,1 ?          |
| 12 [R/S]         | C,1 ?          |
| 100 [R/S]        | Q,1 ?          |
| 3000 [R/S]       | L,2 ?          |
| 2000 [R/S]       | d,2 ?          |
| 10 [R/S]         | C,2 ?          |
| 100 [R/S]        | Q,2 ?          |
| 2000 [R/S]       | L,3 ?          |
| 2000 [R/S]       | d,3 ?          |
| 14 [R/S]         | C,3 ?          |
| 100 [R/S]        | Q,3 ?          |
| 6250 [CHS] [R/S] | L,4 ?          |
| 2000 [R/S]       | d,4 ?          |
| 16 [R/S]         | C,4 ?          |
| 100[R/S]         | Q,4 ?          |
| 9750 [CHS] [R/S] | L,5 ?          |
| 2000 [R/S]       | d,5 ?          |
| 12 [R/S]         | C,5 ?          |
| 100 [R/S]        | Q,5 ?          |
| 1500 [CHS] [R/S] | L,6 ?          |
| 2000 [R/S]       | d,6 ?          |
| 12 [R/S]         | C,6 ?          |
| 100 [R/S]        | Q,6 ?          |
| 250 [R/S]        | L,7 ?          |
| 2000 [R/S]       | d,7 ?          |
| 14 [R/S]         | C,7 ?          |
| 100 [R/S]        | Q,7 ?          |
| 1000 [R/S]       | Q,1=3404       |
| [R/S]            | Q,2=2404       |
| [R/S]            | Q,3=-4134      |
| [R/S]            | Q,4=-9346      |

|           |               |
|-----------|---------------|
| [R/S]     | Q,5=212       |
| [R/S]     | Q,6=1962      |
| [R/S]     | Q,7=2712      |
| [C]       | EQUIV. DIA. ? |
| 10 [R/S]  | EQUIV. RUF. ? |
| 100 [R/S] | dP,1=34.55    |
| [R/S]     | dP,2=44.09    |
| [R/S]     | dP,3=23.37    |
| [R/S]     | dP,4=55.24    |
| [R/S]     | dP,5=0.20     |
| [R/S]     | dP,6=12.45    |
| [R/S]     | dP,7=10.71    |

Since the pressure drops in the direction of the flow (and increases moving upstream), the pressure at point D =  $100.00 - 55.24 - 23.37 + .20 = 21.59\text{psi}$ .

# User Instructions

SIZE: 007+

| STEP | INSTRUCTIONS                                       | INPUT     | FUNCTION | DISPLAY        |
|------|----------------------------------------------------|-----------|----------|----------------|
| 1    | Load the program and set USER mode                 |           | [USER]   |                |
| 2    | Initialize the program                             |           | [XEQ] NA | PIPE NO. ?     |
| 3    | Input 4 pipe numbers for each loop.                | N         | [R/S]    | PIPE NO. ?     |
|      | Enter a zero for pipe number when there            | N         | [R/S]    | PIPE NO. ?     |
|      | are less than 4 pipes in a loop.                   | N         | [R/S]    | PIPE NO. ?     |
|      |                                                    | N         | [R/S]    | A OR B ?       |
| 4    | For another pipe loop, press                       |           | [A]      | PIPE NO. ?     |
|      | and go to step 3                                   |           |          |                |
| 5    | When all pipe loops are in, press                  |           | [B]      | NO. OF PIPES ? |
| 6    | Input: the number of pipes;                        | n         | [R/S]    | EQUIV. DIA. ?  |
|      | equivalent diameter;                               | d         | [R/S]    | EQUIV. RUF. ?  |
|      | and equivalent roughness                           | C         | [R/S]    | L,1 ?          |
| 7    | Input: pipe length;                                | L,x       | [R/S]    | d,x ?          |
|      | pipe diameter;                                     | d,x       | [R/S]    | C,x ?          |
|      | pipe roughness;                                    | C,x       | [R/S]    | Q,x ?          |
|      | and assumed flow.                                  | $\pm Q,x$ | [R/S]    | L,x+1 ?        |
|      |                                                    |           |          | or<br>Q,1=C    |
| 8    | If a mistake is made in putting L,d, or C,         |           |          |                |
|      | press                                              |           | [GTO] 03 |                |
|      | and go to step 7                                   |           | [R/S]    | L,x ?          |
| 9    | Perform step 7 until the data for all pipes        |           |          |                |
|      | is input, at which time the program com-           |           |          |                |
|      | putes corrected flows. If a printer is in          |           |          |                |
|      | the system, the $\Delta Q$ 's will be printed that |           |          |                |
|      | the user may watch convergence.                    |           |          |                |
| 10   | To see the corrected flows, press                  |           | [R/S]    | Q,x=( )        |
| 11   | Repeat step 9 until x=n.                           |           |          |                |

[illegible]

# Program Listings

|             |                          |             |                                                     |
|-------------|--------------------------|-------------|-----------------------------------------------------|
| 01*LBL "NA" | Initialize               | DIA. ?"     |                                                     |
| 02 FIX 0    |                          | 47 PROMPT   |                                                     |
| 03 CF 29    | Set up control registers | 48 STO 02   | Compute equivalent lengths, L and store L's and Q's |
| 04 CF 01    |                          | 49 "EQUIV.  |                                                     |
| 05 CF 02    |                          | RUF. ?"     |                                                     |
| 06 CF 03    |                          | 50 PROMPT   |                                                     |
| 07 CF 04    |                          | 51 STO 04   |                                                     |
| 08 6.3      |                          | 52*LBL 03   |                                                     |
| 09 STO 03   |                          | 53 "L,"     |                                                     |
| 10*LBL A    |                          | 54 XEQ 04   |                                                     |
| 11 ISG 03   |                          | 55 RCL 02   |                                                     |
| 12 RCL 03   |                          | 56 "d,"     |                                                     |
| 13 STO 00   |                          | 57 XEQ 04   |                                                     |
| 14 .01      |                          | 58 /        |                                                     |
| 15 STO 04   |                          | 59 2.63     |                                                     |
| 16 0        |                          | 60 ENTER↑   |                                                     |
| 17 STO IND  |                          | 61 .54      |                                                     |
| 03          |                          | 62 /        |                                                     |
| 18*LBL 01   | 4th pipe?<br>no          | 63 Y↑X      |                                                     |
| 19 "PIPE NO |                          | 64 *        |                                                     |
| ?"          |                          | 65 RCL 04   |                                                     |
| 20 PROMPT   |                          | 66 "C,"     |                                                     |
| 21 RCL 04   |                          | 67 XEQ 04   |                                                     |
| 22 *        |                          | 68 /        |                                                     |
| 23 ST+ IND  |                          | 69 .54      |                                                     |
| 03          |                          | 70 1/X      |                                                     |
| 24 .01      |                          | 71 Y↑X      |                                                     |
| 25 ST* 04   |                          | 72 *        |                                                     |
| 26 RCL 04   |                          | 73 STO IND  |                                                     |
| 27 1 E-9    |                          | 03          |                                                     |
| 28 X<=Y?    |                          | 74 RCL 06   |                                                     |
| 29 GTO 01   |                          | 75 RCL 03   |                                                     |
| 30 "A OR B  |                          | 76 +        |                                                     |
| ?"          |                          | 77 "Q,"     |                                                     |
| 31 PROMPT   | Prompt and store data    | 78 XEQ 04   |                                                     |
| 32*LBL B    |                          | 79 STO IND  |                                                     |
| 33 RCL 03   |                          | Y           |                                                     |
| 34 INT      |                          | 80 ISG 01   |                                                     |
| 35 STO 03   |                          | 81 ISG 03   |                                                     |
| 36 "NO. OF  |                          | 82 GTO 03   |                                                     |
| PIPES?"     |                          | 83 .004     |                                                     |
| 37 PROMPT   |                          | 84 STO 02   |                                                     |
| 38 STO 06   |                          | 85*LBL 05   |                                                     |
| 39 +        |                          | 86 CF IND 0 |                                                     |
| 40 1 E3     |                          | 2           |                                                     |
| 41 /        |                          | 87 ISG 02   | iteration counter done, display results             |
| 42 ST+ 03   |                          | 88 GTO 06   |                                                     |
| 43 ISG 03   |                          | 89 RCL 00   |                                                     |
| 44 1.3      |                          | 90 RCL 06   |                                                     |
| 45 STO 01   |                          | 91 +        |                                                     |
| 46 "EQUIV.  |                          | 92 1        |                                                     |

# Program Listings

```

93 +
94 STO 01
95 1
96*LBL 02
97 "Q,"
98 ARCL X
99 "I="
100 ARCL IND
01
101 PROMPT
102 1
103 +
104 ISG 01
105 GTO 02
106*LBL 06
107 SF IND 0
2
108 RCL 00
109 6
110 -
111 INT
112 6
113 +
114 1 E3
115 /
116 7
117 +
118 STO 05
119*LBL 07
120 0
121 STO 03
122 STO 04
123 RCL IND
05
124 STO 01
125*LBL 10
126 XEQ 09
127 RCL 00
128 +
129 ENTER↑
130 ENTER↑
131 RCL 06
132 +
133 RCL IND
X
134 ABS
135 .54
136 1/X
137 Y↑X
138 RCL IND
Y

```

set annunciator

clear E's

move control  
reg. into working  
control reg.

compute  $\Delta Q$

```

139 SIGN
140 *
141 RCL IND
Z
142 *
143 ST+ 04
144 .54
145 /
146 RCL IND
Y
147 /
148 ABS
149 ST+ 03
150 GTO 10
151*LBL 04
152 ARCL 01
153 "I ?"
154 PROMPT
155 RTN
156*LBL 09
157 100
158 ST* 01
159 RCL 01
160 INT
161 ST- 01
162 X=0?
163 RTN
164 RCL 04
165 RCL 03
166 /
167 FS? 55
168 PRX
169 INT
170 STO 03
171 RCL IND
05
172 STO 01
173*LBL 11
174 100
175 ST* 01
176 RCL 01
177 INT
178 ST- 01
179 X=0?
180 GTO 08
181 RCL 00
182 RCL 06
183 +
184 +
185 RCL 03
186 ST- IND
Y

```

input prompting

extract pipe  
numbers

done?  
no

print  $\Delta Q$  so user  
can watch con-  
vergence

adjust Q's by  
adding  $\Delta Q$

done?  
yes

# Program Listings

|                        |                                                      |            |  |
|------------------------|------------------------------------------------------|------------|--|
| 187 GTO 11             |                                                      | 234 FIX 2  |  |
| 188♦LBL 08             |                                                      | 235 ARCL X |  |
| 189 ISG 05             |                                                      | 236 PROMPT |  |
| 190 GTO 07             |                                                      | 237 ISG 01 |  |
| 191 GTO 05             |                                                      | 238 GTO 12 |  |
| 192♦LBL C              |                                                      | 239 .END.  |  |
| 193 "EQUIV.<br>DIA. ?" | do next loop<br>iterate<br>compute pressure<br>drops |            |  |
| 194 PROMPT             |                                                      |            |  |
| 195 STO 02             | usually 10                                           | 60         |  |
| 196 "EQUIV.<br>RUF. ?" |                                                      |            |  |
| 197 PROMPT             |                                                      |            |  |
| 198 STO 04             | usually 100                                          |            |  |
| 199 1.1                |                                                      |            |  |
| 200 STO 01             |                                                      |            |  |
| 201♦LBL 12             |                                                      |            |  |
| 202 RCL 01             |                                                      |            |  |
| 203 RCL 00             | pipe no., n                                          |            |  |
| 204 +                  |                                                      |            |  |
| 205 ENTER↑             |                                                      | 70         |  |
| 206 ENTER↑             |                                                      |            |  |
| 207 RCL 06             |                                                      |            |  |
| 208 +                  |                                                      |            |  |
| 209 RCL IND            | $Q_n$                                                |            |  |
| Y                      |                                                      |            |  |
| 210 RCL IND            | $L_n$                                                |            |  |
| Y                      |                                                      |            |  |
| 211 ABS                |                                                      |            |  |
| 212 3.5521             |                                                      |            |  |
| 213 *                  |                                                      | 80         |  |
| 214 RCL 04             |                                                      |            |  |
| 215 /                  |                                                      |            |  |
| 216 .54                |                                                      |            |  |
| 217 1/X                |                                                      |            |  |
| 218 Y↑X                |                                                      |            |  |
| 219 *                  |                                                      |            |  |
| 220 RCL 02             |                                                      |            |  |
| 221 2.63               |                                                      |            |  |
| 222 ENTER↑             |                                                      |            |  |
| 223 .54                |                                                      | 90         |  |
| 224 /                  |                                                      |            |  |
| 225 CHS                |                                                      |            |  |
| 226 Y↑X                |                                                      |            |  |
| 227 *                  |                                                      |            |  |
| 228 .4335              |                                                      |            |  |
| 229 *                  |                                                      |            |  |
| 230 "dP, "             | $\Delta$ pressure                                    |            |  |
| 231 FIX 0              |                                                      |            |  |
| 232 ARCL 01            | display                                              |            |  |
| 233 "I="               | result                                               | 00         |  |



[illegible]

## RESTRICTION METERING ORIFICE CALCULATIONS

This program solves for orifice bore and for differential pressure across an orifice with flange taps for gas flow.

Equations:

$$C = \frac{Q \text{ NORM}}{7727} \sqrt{\frac{T_F}{P_F} G}$$

$$Y_P = 1 - [0.333 + 1.145 (\beta^2 + 0.7\beta^5 + 12\beta^{13})] \frac{\Delta P}{P_f k}$$

$$S_P = \frac{C}{Y_P \sqrt{h}} , \quad h = 27.7 \Delta P$$

$$S_P = .58925\beta^2 + 0.2725\beta^3 - 0.825\beta^4 + 1.75\beta^5$$

$$d = \beta D$$

$$S_f = 0.598\beta^2 + 0.01\beta^3 + 0.00001947\beta^2 (10\beta)^{4.425}$$

$$Y_F = 1 - \left[ \frac{0.41 + 0.35\beta^4}{27.7 P_f k} \right] h_{\text{normF}} \quad h_{\text{normF}} = (C/S_f)^2 / Y_F^2$$

$$h_{\text{max}} = h_{\text{normF}} [Q_{\text{max}} / Q_{\text{normF}}]^2$$

Note: If differential pressure across orifice is too high, the second part of the program will not converge.

References: L. K. Spink, Principles and Practices of Flow Meter Engineering, 9th Ed., page 167, Plimpton Press, 1967.  
 R. G. Cunningham, Orifice Meters with Supercritical Compressible Flow, pages 625-638, ASTM, July 1951.  
 HP-67/HP-97 Users' Library program #02448D by Larry Richardson.

Example: An orifice is to be sized to control the flow of nitrogen in a 1.939" ID line to 3330 SCFH. A flow transmitter is to be connected to flange taps for an alarm. The temperature is 100°F (560°R), pressure upstream is 8.3 psig (23 psia) pressure downstream is 4.69 psig (P=3.61 psi). Meter maximum is to be 4500 SCFH.

$$G = \frac{MW_{\text{nitrogen}}}{MW_{\text{air}}} \sim 28/28.95 \sim 0.967$$

$$K_{\text{nitrogen}} = 1.4$$

Solution:

Keystrokes:

[XEQ] [ALPHA] SIZE [ALPHA] 011  
 [XEQ] [ALPHA] ORF [ALPHA]  
 3330 [R/S]  
 560 [R/S]  
 .967 [R/S]  
 23 [R/S]  
 3.61 [R/S]  
 1.4 [R/S]  
 1.939 [R/S]  
 [R/S]  
 4500 [R/S]

Display:

Q ?  
 T ?  
 G ?  
 P ?  
 dP ?  
 K ?  
 D ?  
 d=.585 (" bore)  
 QMAX ?  
 HM=209. (" water column)

[illegible]

# Program Listings

|             |                  |            |                     |
|-------------|------------------|------------|---------------------|
| 01♦LBL "ORF |                  | 51 RCL 10  |                     |
| 02 "Q ?"    |                  | 52 X↑2     |                     |
| 03 PROMPT   |                  | 53 +       |                     |
| 04 "T ?"    | Prompt and store | 54 1.145   |                     |
| 05 PROMPT   | data             | 55 *       |                     |
| 06 "G ?"    |                  | 56 .333    |                     |
| 07 PROMPT   |                  | 57 +       |                     |
| 08 "P ?"    |                  | 58 RCL 01  |                     |
| 09 PROMPT   |                  | 59 *       |                     |
| 10 STO 00   |                  | 60 RCL 00  |                     |
| 11 /        |                  | 61 /       | $Y_p$               |
| 12 *        |                  | 62 -       |                     |
| 13 SQRT     |                  | 63 RCL 09  |                     |
| 14 X<>Y     |                  | 64 X<>Y    |                     |
| 15 STO 03   |                  | 65 /       |                     |
| 16 *        |                  | 66 STO 04  | Calculate $S_p$     |
| 17 STO 09   |                  | 67 .5      |                     |
| 18 "dP ?"   |                  | 68 STO 05  | $\beta$             |
| 19 PROMPT   |                  | 69 STO 06  |                     |
| 20 FIX 3    |                  | 70♦LBL 01  |                     |
| 21 STO 01   |                  | 71 RCL 05  |                     |
| 22 27.7     |                  | 72 RCL 05  |                     |
| 23 *        |                  | 73 RCL 05  |                     |
| 24 SQRT     |                  | 74 1.75    |                     |
| 25 ST/ 09   |                  | 75 *       |                     |
| 26 "K ?"    |                  | 76 .825    |                     |
| 27 PROMPT   |                  | 77 -       |                     |
| 28 ST* 00   |                  | 78 *       |                     |
| 29 "D ?"    |                  | 79 .2725   |                     |
| 30 PROMPT   |                  | 80 +       |                     |
| 31 STO 02   |                  | 81 *       |                     |
| 32 X↑2      |                  | 82 .58925  |                     |
| 33 7727     |                  | 83 +       |                     |
| 34 *        |                  | 84 *       |                     |
| 35 ST/ 09   |                  | 85 *       | $S_p$ =power series |
| 36 .5       | guess for        | 86 RCL 04  |                     |
| 37 STO 10   | $\beta$          | 87 -       |                     |
| 38♦LBL 00   |                  | 88 X=0?    |                     |
| 39 1        |                  | 89 GT0 03  |                     |
| 40 RCL 10   | Calculate d      | 90 X<0?    | iterate             |
| 41 13       |                  | 91 GT0 04  |                     |
| 42 Y↑X      |                  | 92 RCL 06  |                     |
| 43 12       |                  | 93 ST- 05  |                     |
| 44 *        |                  | 94 GT0 05  |                     |
| 45 RCL 10   |                  | 95♦LBL 04  |                     |
| 46 5        |                  | 96 RCL 06  |                     |
| 47 Y↑X      |                  | 97 ST+ 05  |                     |
| 48 .7       |                  | 98♦LBL 05  |                     |
| 49 *        |                  | 99 RCL 06  |                     |
| 50 +        |                  | 100 RCL 02 |                     |
|             |                  | 101 *      |                     |

# Program Listings

|              |                 |            |             |
|--------------|-----------------|------------|-------------|
| 102 RND      |                 | 153 X↑2    |             |
| 103 X=0?     |                 | 154 .598   |             |
| 104 GTO 03   |                 | 155 *      |             |
| 105 2        |                 | 156 RCL 02 |             |
| 106 ST/ 06   |                 | 157 3      |             |
| 107 GTO 01   |                 | 158 Y↑X    |             |
| 108♦LBL 03   |                 | 159 .01    |             |
| 109 RCL 10   |                 | 160 *      |             |
| 110 RCL 05   |                 | 161 +      |             |
| 111 -        |                 | 162 RCL 02 |             |
| 112 RCL 02   |                 | 163 6.425  |             |
| 113 *        |                 | 164 Y↑X    |             |
| 114 RND      |                 | 165 .51804 |             |
| 115 X=0?     |                 | 166 *      |             |
| 116 GTO 06   |                 | 167 +      | $S_f$       |
| 117 RCL 05   |                 | 168 RCL 10 |             |
| 118 STO 10   |                 | 169 X<>Y   |             |
| 119 GTO 00   |                 | 170 /      |             |
| 120♦LBL 06   |                 | 171 X↑2    |             |
| 121 RCL 05   | $\beta$         | 172 STO 10 |             |
| 122 RCL 02   | D               | 173 STO 07 |             |
| 123 *        | -----           | 174♦LBL 07 |             |
| 124 "d="     |                 | 175 RCL 10 |             |
| 125 ARCL X   | Display         | 176 1      |             |
| 126 PROMPT   | result          | 177 RCL 01 |             |
| 127 FIX 0    | -----           | 178 RCL 07 |             |
| 128 "QMAX ?" | Calculate $h_m$ | 179 *      |             |
| 129 PROMPT   |                 | 180 -      |             |
| 130 STO 04   |                 | 181 X↑2    |             |
| 131 RCL 01   |                 | 182 /      |             |
| 132 27.7     |                 | 183 STO 08 | $h_{normF}$ |
| 133 *        |                 | 184 RCL 07 |             |
| 134 SQRT     |                 | 185 -      |             |
| 135 RCL 09   |                 | 186 RND    |             |
| 136 *        |                 | 187 X=0?   |             |
| 137 STO 10   | C               | 188 GTO 08 |             |
| 138 RCL 05   | $\beta$         | 189 RCL 08 |             |
| 139 4        |                 | 190 STO 07 |             |
| 140 Y↑X      |                 | 191 GTO 07 |             |
| 141 .35      |                 | 192♦LBL 08 |             |
| 142 *        |                 | 193 RCL 04 | $Q_{max}$   |
| 143 .41      |                 | 194 RCL 03 |             |
| 144 +        |                 | 195 /      |             |
| 145 RCL 00   |                 | 196 X↑2    |             |
| 146 /        |                 | 197 RCL 08 |             |
| 147 27.7     |                 | 198 *      |             |
| 148 /        |                 | 199 "HM="  |             |
| 149 STO 01   | [ ] $Y_F$       | 200 ARCL X | Display     |
| 150 RCL 05   |                 | 201 PROMPT | result      |
| 151 STO 02   |                 | 202 .END.  | -----       |
| 152 RCL 02   | $\beta$         |            |             |

[illegible]

## ENERGY EQUATION FOR STEADY FLOW

Given any eight of the nine terms in the equation below, the program calculates the unknown term.

Energy Equation:

$$\frac{P_1}{W} + Z_1 + \frac{V_1^2}{2g} + H_P = \frac{P_2}{W} + Z_2 + \frac{V_2^2}{2g} + H_T + H_L$$

where

$H$  = total dynamic head, ft.

$H_P$  = head added by pump, ft.

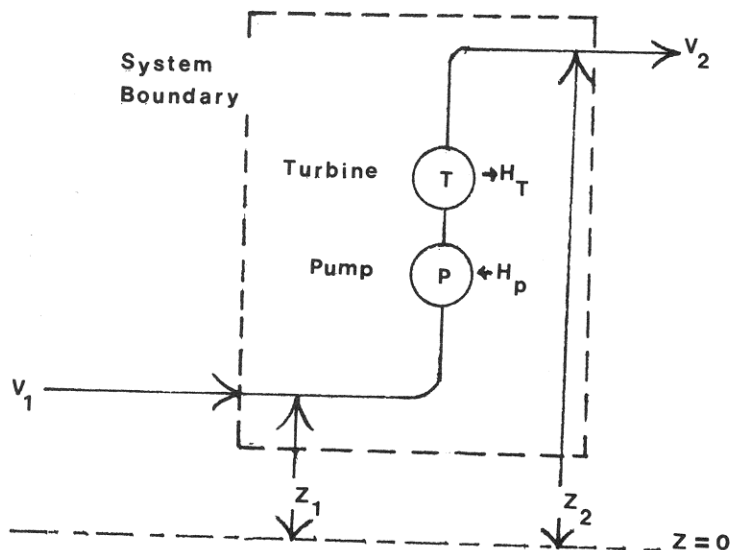
$H_T$  = head extracted by turbine, ft.

$H_L$  = head loss due to friction, ft.

$\frac{V^2}{2g}$  = velocity head, ft.

$\frac{P}{W}$  = pressure head, ft.

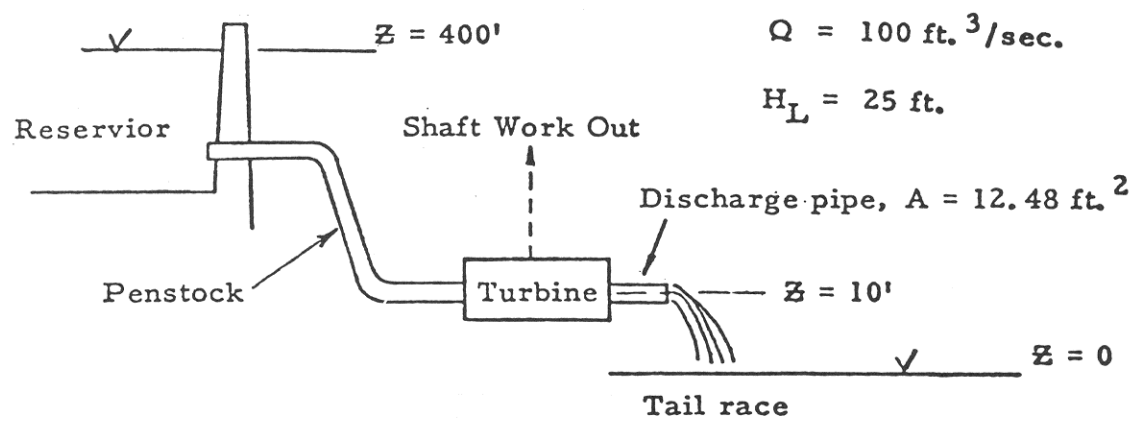
$Z$  = potential head, ft.



References: HP-67/HP-97 Users' Library program #00267D  
Fluid Mechanics and Hydraulics, by Ronald V. Giles, Schaums  
Outline Series, McGraw-Hill Book Company, New York, 1962.



Example:



Find the head extracted by the turbine.

Solution:

Keystrokes:

```
[XEQ] [ALPHA] SIZE [ALPHA] 013
[XEQ] [ALPHA] ENRG [ALPHA]
0 [R/S]
400 [R/S]
0 [R/S]
0 [R/S]
0 [R/S]
10 [R/S]
100 [ENT] 12.48 [÷] [x^2] 64.4 [÷] [R/S]
[R/S]
25 [R/S]
```

Display:

```
P1 HEAD ?
Z1 HEAD ?
V1 HEAD ?
HP HEAD ?
P2 HEAD ?
Z2 HEAD ?
V2 HEAD ?
HT HEAD ?
HL HEAD ?
HT HEAD=364.00
```

## 6

6

# Program Listings

|                   |                          |            |                  |
|-------------------|--------------------------|------------|------------------|
| 01♦LBL "ENR<br>G" | Initialize               | 47 CF 01   | RHS or LHS?      |
| 02 CF 02          |                          | 48 RCL 00  |                  |
| 03 SF 01          |                          | 49 5       |                  |
| 04 1.1            |                          | 50 X<=Y?   |                  |
| 05 STO 00         |                          | 51 SF 02   |                  |
| 06 CF 22          |                          | 52♦LBL 10  |                  |
| 07 "P1"           |                          | 53 ISG 00  |                  |
| 08 XEQ 15         | Prompt and<br>store data | 54 RTN     |                  |
| 09 "Z1"           |                          | 55♦LBL 16  | Calculate<br>RHS |
| 10 XEQ 15         |                          | 56 5.009   |                  |
| 11 "V1"           |                          | 57 STO 00  |                  |
| 12 XEQ 15         |                          | 58 0       |                  |
| 13 "HP"           |                          | 59♦LBL 17  |                  |
| 14 XEQ 15         |                          | 60 RCL IND |                  |
| 15 "P2"           |                          | 00         |                  |
| 16 XEQ 15         |                          | 61 +       |                  |
| 17 "Z2"           |                          | 62 ISG 00  |                  |
| 18 XEQ 15         |                          | 63 GTO 17  |                  |
| 19 "V2"           |                          | 64 STO 11  |                  |
| 20 XEQ 15         |                          | 65 RTN     |                  |
| 21 "HT"           |                          | 66♦LBL 18  | Calculate<br>LHS |
| 22 XEQ 15         |                          | 67 1.004   |                  |
| 23 "HL"           |                          | 68 STO 00  |                  |
| 24 XEQ 15         |                          | 69 0       |                  |
| 25 XEQ 16         |                          | 70 GTO 17  |                  |
| 26 RCL 11         | Compute<br>unknown       | 71 .END.   |                  |
| 27 STO 12         |                          |            |                  |
| 28 XEQ 18         |                          |            |                  |
| 29 RCL 12         |                          |            |                  |
| 30 FC? 02         |                          | 80         |                  |
| 31 X<>Y           |                          |            |                  |
| 32 -              |                          |            |                  |
| 33 CLA            |                          |            |                  |
| 34 ARCL 10        | Display<br>result        |            |                  |
| 35 "F HEAD=       |                          |            |                  |
| "                 |                          |            |                  |
| 36 ARCL X         |                          |            |                  |
| 37 PROMPT         |                          |            |                  |
| 38♦LBL 15         |                          |            |                  |
| 39 FS? 01         | Input storage            | 90         |                  |
| 40 ASTO 10        |                          |            |                  |
| 41 "F HEAD        |                          |            |                  |
| ?"                |                          |            |                  |
| 42 PROMPT         |                          |            |                  |
| 43 STO IND        |                          |            |                  |
| 00                |                          |            |                  |
| 44 FS?C 22        |                          |            |                  |
| 45 GTO 10         |                          |            |                  |
| 46 ST- IND        |                          |            |                  |
| 00                | Zero results             | 00         |                  |

## REGISTERS, STATUS, FLAGS, ASSIGNMENTS

[illegible]

## COMPRESSIBLE FLOW IN VARIABLE AREA DUCTS

This program solves the area ratio mach number relationship for isentropic flow of a perfect gas in a variable area duct. The program will find M given A/A\* or A/A\* given M, or T/To, P/Po or M given any one of these three quantities. The zero subscript refers to stagnation conditions.

Equations:

$$A/A^* = \frac{1}{M} \left( \frac{1 + \frac{k-1}{2} M^2}{\frac{k+1}{2}} \right)^{\frac{k+1}{2(h-1)}}$$

$$P/P_o = \left( 1 + \frac{k-1}{2} M^2 \right)^{\frac{-k}{h-1}}$$

$$T/T_o = \left( 1 + \frac{k-1}{2} M^2 \right)^{-1}$$

where

T = temperature

P = pressure

A = cross-sectional area of ducts at which M occurs

M = Mach number

A\* = throat area of duct

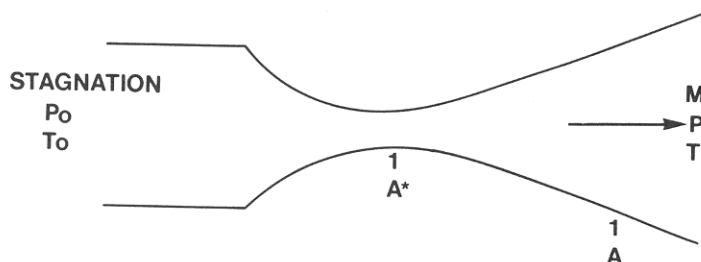
and

$$k = \frac{C_p}{C_n}, \quad \begin{array}{l} C_p = \text{specific heat at constant pressure} \\ C_n = \text{specific heat at constant volume} \end{array}$$

Notes: The equations apply only to a perfect gas with constant specific heats. An initial guess for M must be supplied for the first equation given above if the area ratio A/A\* is the known quantity. If the guess for M is < 1 then the program converges to a Mach number < 1. If the guess for M is > 1 then the program converges to a solution for M > 1.

References: HP-65 Users' Library program #00780A by Harry Townes.

Example:



For  $K = 1.4$  and  $A/A^* = 1.5$ , find the two possible Mach numbers,  $T/T_0$  and  $P/P_0$ .

Solution:

Keystrokes:

[USER]

[XEQ] [ALPHA] SIZE [ALPHA] 009

[XEQ] [ALPHA] COMFLO [ALPHA]

[A]

1.4 [R/S]

1.5 [R/S]

.5 [R/S]

[A]

1.4 [R/S]

1.5 [R/S]

1.5 [R/S]

[B]

1.4 [R/S]

.4303 [R/S]

[R/S]

[B]

1.4 [R/S]

1.8541 [R/S]

[R/S]

Display:

(Set USER mode)

LBL A OR B ?

K ?

$A/A^*$  ?

GUESS FOR M ?

$M=0.4303$

K ?

$A/A^*$  ?

GUESS FOR M ?

$M=1.8541$

K ?

M ?

$T/T_0=0.9643$

$P/P_0=0.8805$

K ?

M ?

$T/T_0=0.5926$

$P/P_0=0.1602$

# User Instructions

SIZE: 009

| STEP | INSTRUCTIONS                                   | INPUT   | FUNCTION     | DISPLAY               |
|------|------------------------------------------------|---------|--------------|-----------------------|
| 1    | Load the program and set USER mode             |         | [USER]       |                       |
| 2    | Initialize the program                         |         | [XEQ] COMFLO | LBL A OR B ?          |
| 3    | To find $A/A^*$ or M given the other           |         |              |                       |
|      | quantity, press $\rightarrow$                  |         | [A]          | K ?                   |
| 3a   | Input K                                        | K       | [R/S]        | $A/A^*$ ?             |
| 3b   | Input $A/A^*$ (note 1)                         | $A/A^*$ | [R/S]        | M ?                   |
|      |                                                |         |              | -or-<br>GUESS FOR M ? |
| 3c   | Input M or a guess for M                       | M       | [R/S]        | $A/A^*=(\quad)$       |
|      | If the guess for M is $< 1$ then the result-   |         |              | -or-<br>M=( )         |
|      | ing M is $< 1$ . If the guess is $> 1$ then    |         |              |                       |
|      | the result is $> 1$ . The equation has two     |         |              |                       |
|      | roots when $A/A^*$ is the known value.         |         |              |                       |
| 4    | To find $T/T_o$ , $P/P_o$ , or M given any one |         |              |                       |
|      | of these three quantities, press $\rightarrow$ |         | [B]          | K ?                   |
| 4a   | Input K                                        | K       | [R/S]        | M ?                   |
| 4b   | Input M and find $T/T_o$ and $P/P_o$ (note 1)  | M       | [R/S]        | $T/T_o=(\quad)$       |
|      |                                                |         | [R/S]        | $P/P_o=(\quad)$       |
| 4c   | Input $T/T_o$ and find M (note 1)              | $T/T_o$ | [R/S]        | M=( )                 |
| 4d   | Input $P/P_o$ and find M                       | $P/P_o$ | [R/S]        | M=( )                 |
|      |                                                |         |              |                       |
|      | Note 1: When prompted for an unknown           |         |              |                       |
|      | quantity, press [R/S] (make no                 |         |              |                       |
|      | input).                                        |         |              |                       |
|      |                                                |         |              |                       |
|      |                                                |         |              |                       |
|      |                                                |         |              |                       |
|      |                                                |         |              |                       |

# Program Listings

|                       |                    |             |                            |
|-----------------------|--------------------|-------------|----------------------------|
| 01*LBL "COM<br>FLO"   |                    | 49 RCL 05   |                            |
| 02 "LBL A 0<br>R B ?" |                    | 50 -        | Calculate M<br>iteratively |
| 03 PROMPT             |                    | 51 STO 08   |                            |
| 04*LBL A              | A/A* vs. M         | 52 RCL 07   |                            |
| 05 CF 01              |                    | 53 CHS      |                            |
| 06 "K ?"              |                    | 54 RCL 01   |                            |
| 07 PROMPT             |                    | 55 X↑2      |                            |
| 08 1                  |                    | 56 /        |                            |
| 09 +                  |                    | 57 RCL 06   |                            |
| 10 2                  |                    | 58 RCL 02   |                            |
| 11 /                  |                    | 59 1        |                            |
| 12 STO 03             |                    | 60 -        |                            |
| 13 RCL 03             |                    | 61 Y↑X      |                            |
| 14 1                  |                    | 62 +        |                            |
| 15 -                  |                    | 63 RCL 08   |                            |
| 16 STO 04             |                    | 64 X<>Y     |                            |
| 17 /                  |                    | 65 /        |                            |
| 18 2                  |                    | 66 ST- 01   |                            |
| 19 /                  |                    | 67 ABS      |                            |
| 20 STO 02             |                    | 68 RCL 01   |                            |
| 21 CF 22              |                    | 69 /        |                            |
| 22 "A/A* ?"           |                    | 70 1 E-3    |                            |
| 23 PROMPT             |                    | 71 X<=Y?    |                            |
| 24 FS? 22             | Input made?<br>yes | 72 GTO 01   |                            |
| 25 SF 01              |                    | 73 RCL 01   |                            |
| 26 STO 05             |                    | 74 GTO 09   |                            |
| 27 "GUESS F<br>OR M?" |                    | 75*LBL 02   |                            |
| 28 FC? 22             |                    | 76 "A/A*"   |                            |
| 29 "M ?"              |                    | 77 GTO 03   |                            |
| 30 PROMPT             |                    | 78*LBL B    | T/To, P/Po, vs. M          |
| 31 STO 01             |                    | 79 "K ?"    |                            |
| 32*LBL 01             |                    | 80 PROMPT   |                            |
| 33 RCL 01             | Calculate A/A*     | 81 STO 00   |                            |
| 34 X↑2                |                    | 82 1        |                            |
| 35 RCL 04             |                    | 83 -        |                            |
| 36 *                  |                    | 84 ST/ 00   |                            |
| 37 1                  |                    | 85 2        |                            |
| 38 +                  |                    | 86 /        |                            |
| 39 RCL 03             |                    | 87 STO 02   |                            |
| 40 /                  |                    | 88 CF 22    |                            |
| 41 STO 06             |                    | 89 "M ?"    |                            |
| 42 RCL 02             |                    | 90 PROMPT   |                            |
| 43 Y↑X                |                    | 91 FS? 22   | M input?<br>yes            |
| 44 STO 07             |                    | 92 GTO 04   |                            |
| 45 RCL 01             |                    | 93 "T/Ta ?" |                            |
| 46 /                  | A/A*               | 94 PROMPT   |                            |
| 47 FC? 01             |                    | 95 FS? 22   |                            |
| 48 GTO 02             |                    | 96 GTO 05   |                            |
|                       |                    | 97 "P/Pa ?" |                            |
|                       |                    | 98 PROMPT   |                            |
|                       |                    | 99 RCL 00   |                            |



# Program Listings

|            |                                    |    |  |
|------------|------------------------------------|----|--|
| 100 CHS    | Calculate M<br>given P/Po          | 51 |  |
| 101 1/X    |                                    |    |  |
| 102 Y↑X    |                                    |    |  |
| 103 1      |                                    |    |  |
| 104 -      |                                    |    |  |
| 105 RCL 02 |                                    |    |  |
| 106 /      |                                    |    |  |
| 107 SQRT   |                                    |    |  |
| 108♦LBL 09 |                                    |    |  |
| 109 "M"    |                                    | 60 |  |
| 110♦LBL 03 | -----<br>Display<br>routine        |    |  |
| 111 "I="   |                                    |    |  |
| 112 ARCL X |                                    |    |  |
| 113 PROMPT |                                    |    |  |
| 114 RTN    | -----<br>Calculate T/To            |    |  |
| 115♦LBL 04 |                                    |    |  |
| 116 X↑2    |                                    |    |  |
| 117 *      |                                    |    |  |
| 118 1      |                                    |    |  |
| 119 +      |                                    | 70 |  |
| 120 STO 01 |                                    |    |  |
| 121 1/X    |                                    |    |  |
| 122 "T/Ta" |                                    |    |  |
| 123 XEQ 03 | -----<br>Calculate P/Po            |    |  |
| 124 RCL 01 |                                    |    |  |
| 125 RCL 00 |                                    |    |  |
| 126 Y↑X    |                                    |    |  |
| 127 1/X    |                                    |    |  |
| 128 "P/Pa" |                                    |    |  |
| 129 XEQ 03 |                                    |    |  |
| 130♦LBL 05 |                                    | 80 |  |
| 131 1/X    | -----<br>Calculate M<br>given T/To |    |  |
| 132 1      |                                    |    |  |
| 133 -      |                                    |    |  |
| 134 RCL 02 |                                    |    |  |
| 135 /      |                                    |    |  |
| 136 SQRT   |                                    |    |  |
| 137 GTO 09 |                                    |    |  |
| 138 .END.  |                                    |    |  |
| 40         |                                    | 90 |  |
|            |                                    |    |  |
|            |                                    |    |  |
|            |                                    |    |  |
|            |                                    |    |  |
|            |                                    |    |  |
|            |                                    |    |  |
|            |                                    |    |  |
|            |                                    |    |  |
|            |                                    |    |  |
| 50         |                                    | 00 |  |

| DATA REGISTERS |                         |    |  | STATUS                                                           |     |                         |                |
|----------------|-------------------------|----|--|------------------------------------------------------------------|-----|-------------------------|----------------|
| 00             | K/(K-1)                 | 50 |  | SIZE                                                             | 009 | TOT. REG.               | 052            |
|                | Used                    |    |  | ENG                                                              |     | FIX                     | 4              |
|                | (K+1)/2(K-1) or (K-1)/2 |    |  | DEG                                                              | x   | RAD                     |                |
|                | (K-1)/2                 |    |  | SCI                                                              |     | GRAD                    |                |
|                | (K-L)/2                 |    |  | <div> <div>USER MODE</div> <div>ON x OFF</div> </div>            |     |                         |                |
| 05             | A/A*                    | 55 |  | <div> <div>INIT</div> <div>S/C</div> </div>                      |     |                         |                |
|                | Used                    |    |  | <div> <div>SET INDICATES</div> <div>CLEAR INDICATES</div> </div> |     |                         |                |
|                | Used                    |    |  | 01                                                               | C   | calculate M             | calculate A/A* |
|                | Used                    |    |  | 22                                                               | C   | refer to owner's manual |                |
| 10             |                         | 60 |  |                                                                  |     |                         |                |
|                |                         |    |  |                                                                  |     |                         |                |
|                |                         |    |  |                                                                  |     |                         |                |
| 15             |                         | 65 |  |                                                                  |     |                         |                |
|                |                         |    |  |                                                                  |     |                         |                |
|                |                         |    |  |                                                                  |     |                         |                |
| 20             |                         | 70 |  |                                                                  |     |                         |                |
|                |                         |    |  |                                                                  |     |                         |                |
|                |                         |    |  |                                                                  |     |                         |                |
| 25             |                         | 75 |  |                                                                  |     |                         |                |
|                |                         |    |  |                                                                  |     |                         |                |
|                |                         |    |  |                                                                  |     |                         |                |
| 30             |                         | 80 |  |                                                                  |     |                         |                |
|                |                         |    |  |                                                                  |     |                         |                |
|                |                         |    |  |                                                                  |     |                         |                |
| 35             |                         | 85 |  |                                                                  |     |                         |                |
|                |                         |    |  |                                                                  |     |                         |                |
|                |                         |    |  |                                                                  |     |                         |                |
|                |                         |    |  | <div> <div>ASSIGNMENTS</div> </div>                              |     |                         |                |
|                |                         |    |  | FUNCTION                                                         |     | KEY                     |                |
| 40             |                         | 90 |  | FUNCTION                                                         |     | KEY                     |                |
|                |                         |    |  | FUNCTION                                                         |     | KEY                     |                |
|                |                         |    |  | FUNCTION                                                         |     | KEY                     |                |
|                |                         |    |  | FUNCTION                                                         |     | KEY                     |                |
| 45             |                         | 95 |  | FUNCTION                                                         |     | KEY                     |                |
|                |                         |    |  | FUNCTION                                                         |     | KEY                     |                |
|                |                         |    |  | FUNCTION                                                         |     | KEY                     |                |
|                |                         |    |  | FUNCTION                                                         |     | KEY                     |                |

## FLOOD ROUTING AND HYDROGRAPHS

This program calculates either a unit hydrograph or a soil conservation service hydrograph from a given peak time (time of concentration) and peak flow. Any time interval can be selected. The program will also route a given hydrograph through a given dam calculating an outflow hydrograph from given storage conditions and a given outflow structure.

Equations:

### Flood routing

$$I_n + I_{n+1} + \frac{2 S_n}{\Delta t} - O = \frac{2 S_{n+1}}{\Delta t} + O_{n+1}$$

where:

I = inflow;

S = storage;

$\Delta t$  = time interval;

O = outflow;

n = cycle number.

### UNIT HYDROGRAPH

$$y = 1.45x^{1.67}, 0.5 > x > 0$$

$$y = 1.16 + \ln x, 0.9 > x > 0.5$$

$$y = \sin(e^{x-1} \cdot 90), 1.2 > x > 0.9$$

$$y = 1.93 - .83 x, 1.6 > x > 1.2$$

$$y = 7.49e^{-1.63x}, x > 1.6$$

SCS HYDROGRAPH

$$y = 1.7 x^2, 0.7 > x > 0$$

$$y = 1.06 + .8 \ln x, 1. > x > 0.7$$

$$y = 1.9 - .83x, 1.8 > x > 1.0$$

$$y = 5.7e^{-1.44x}, x > 1.8$$

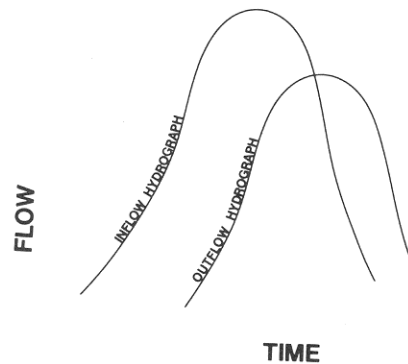
where  $x$  = time/time of peak

and  $y$  = flow/peak flow

Notes: If a subroutine is used to calculate outflow from  $[\frac{2 S}{\Delta t} + \text{outflow vs. outflow}]$  it must always produce flows greater than or equal to zero.

- References:
1. HP-67/HP-97 USER'S LIBRARY program #01442D by Lawrence Busack
  2. PENNSYLVANIA STATE UNIVERSITY, Hydrologic and Hydraulic Analysis for Small Watersheds, PENN State University, University Park, PA, 1974.
  3. U.S. Department of Interior, Bureau of Reclamation, Design of Small Dams, GPO, Washington, D.C., 1974.
  4. U.S. Department of Agriculture, Soil Conservation Service, National Engineering Handbook Section 4 - Hydrology, GPO, Washington, D.C., 1972.

Example:



A dam with a sharp crested weir spillway is located on a small stream. The spillway is 100 feet wide and has a discharge coefficient of 3.5. At the elevation of the spillway no water is stored. At an elevation of 2 feet above the spillway 100 acre-feet of water is stored and at an elevation of 4 feet above the spillway 250 acre-feet of water is stored. A flood which reaches a peak flow of 1400 cfs in 2.9 hours flows through the dam. Calculate the inflow hydrograph using the SCS curve and the outflow hydrograph. Use a 1/4 hour time interval.

Solution:

First develop the outflow vs.  $\frac{2S}{\Delta t} + \text{outflow}$  relationship at 2 feet elevation,

$$\begin{aligned}
 \text{outflow} &= (3.5) (100) (2)^{3/2} [Q=CLH^{3/2}] \\
 &= 989.95 \text{ cfs} \\
 \frac{2S}{\Delta t} + \text{outflow} &= \left[ \frac{(2) (100) \text{ AC-FT}}{.25 \text{ HRS}} \right] \left[ \frac{43560 \text{ ft}^3}{\text{AC-FT}} \right] \\
 &\quad \times \left[ \frac{1}{3600 \frac{\text{SEC}}{\text{HR}}} \right] + 989.95 \\
 &= 10669.95 \text{ cfs}
 \end{aligned}$$

Then, calculating outflow values at each elevation and  $\frac{2S}{\Delta t} + \text{outflow}$  (as above) for 4 feet and interpolating to find intermediate values, the following table is developed:

| <u>ELEVATION</u> | <u>OUTFLOW</u> | <u><math>\frac{2S}{\Delta t} + \text{OUTFLOW}</math></u> |
|------------------|----------------|----------------------------------------------------------|
| 0                | 0              | 0                                                        |
| 1/2              | 123.74         | 2543.74                                                  |
| 1                | 350.00         | 5190.00                                                  |
| 1 1/2            | 642.99         | 7902.99                                                  |
| 2                | 989.95         | 10669.95                                                 |
| 2 1/2            | 1383.50        | 14693.50                                                 |
| 3                | 1818.65        | 18758.65                                                 |
| 3 1/2            | 2291.77        | 22861.77                                                 |
| 4                | 2800.00        | 27000.00                                                 |

Using a curve-fitting program to yield an analytical expression for the above table,

$$\text{OUTFLOW} \approx 0.11 \left[ \frac{2S}{\Delta t} + \text{outflow} \right] - 200$$

This equation is programmed in subroutine 09.

The hydrographs (inflow and outflow) are then calculated. The keystrokes which follow reflect a printer in the system.

KEYSTROKES:

DISPLAY:

[USER]

(set USER mode)

[XEQ] [ALPHA] SIZE [ALPHA] 009

[XEQ] [ALPHA] HYDRO [ALPHA]

TIME INTVL. ?

.25 [R/S]

TIME, PEAK Q ?

2.90 [R/S]

PEAK Q ?

1400 [R/S]

A,B, OR C ?

[C]

A OR B ?

[B]

T=0.00

IN=0.00

T=0.25

IN=17.69

OUT=0.00

•  
•  
•

(increment T)

T=1.25

IN=442.18

OUT=0.00

T=1.50

IN=636.74

OUT=86.00

etc.

•  
•  
•

(increment T)

# User Instructions

|      |                                                                  |        |            | SIZE: 009      |
|------|------------------------------------------------------------------|--------|------------|----------------|
| STEP | INSTRUCTIONS                                                     | INPUT  | FUNCTION   | DISPLAY        |
| 1    | Load the program and set USER mode                               |        | [USER]     |                |
| 2    | Initialize the program                                           |        | [XEQ]HYDRO | TIME INTVL. ?  |
| 3    | Input: time interval;                                            | i      | [R/S]      | TIME, PEAK Q ? |
|      | time of peak flow;                                               | t peak | [R/S]      | PEAK Q ?       |
|      | and peak flow.                                                   | Q peak | [R/S]      | A, B, OR C ?   |
| 4    | To do flood routing, press                                       |        | [C]        | A OR B ?       |
| 5    | For a unit hydrograph, press                                     |        | [A]        | T=( )          |
| 6    | find inflow                                                      |        | [R/S]*     | IN=( )         |
| 7    | flood routing only, find outflow                                 |        | [R/S]*     | OUT=( )        |
| 8    | Increment T and go to step 6                                     |        | [R/S]*     | T=( )          |
| 9    | For an SCS hydrograph, press                                     |        | [B]        | T=( )          |
| 10   | Find inflow                                                      |        | [R/S]*     | IN=( )         |
| 11   | flood routing only, find outflow                                 |        | [R/S]*     | OUT=( )        |
| 12   | Increment T and go to step 10                                    |        | [R/S]*     | T=( )          |
|      |                                                                  |        |            |                |
|      | NOTE: If an analytical expression is not                         |        |            |                |
|      | known for outflow as a function of $\frac{2S}{\Delta t} +$       |        |            |                |
|      | outflow, outflow may be read from a graph                        |        |            |                |
|      | of the function and input manually at step                       |        |            |                |
|      | 7 or 11. To do so, change line 112 from                          |        |            |                |
|      | XEQ09 to R/S. When the program stops,                            |        |            |                |
|      | enter a value for outflow which corresponds                      |        |            |                |
|      | to the value for $\frac{2S}{\Delta t} +$ outflow in the display, |        |            |                |
|      | and press [R/S] to continue.                                     |        |            |                |
|      | *These keystrokes are unnecessary if there                       |        |            |                |
|      | is a printer in the system.                                      |        |            |                |
|      |                                                                  |        |            |                |



# Program Listings

|                        |                                |           |                |
|------------------------|--------------------------------|-----------|----------------|
| 01*LBL "HYD<br>RO"     | Initialize                     | 46 X<>Y   |                |
| 02 CLRG                |                                | 47 1.8    |                |
| 03 SF 21               |                                | 48 X>Y?   |                |
| 04 CF 02               |                                | 49 GTO 02 |                |
| 05 "TIME IN<br>TVL. ?" |                                | 50 RCL 03 |                |
| 06 PROMPT              | Prompt and<br>store data       | 51 1.44   |                |
| 07 STO 01              |                                | 52 *      |                |
| 08 "TIME, P<br>EAK Q?" |                                | 53 CHS    |                |
| 09 PROMPT              |                                | 54 E↑X    |                |
| 10 STO 00              |                                | 55 5.7    |                |
| 11 "PEAK Q<br>?"       |                                | 56 *      |                |
| 12 PROMPT              |                                | 57 GTO 03 |                |
| 13 STO 04              |                                | 58*LBL 00 |                |
| 14 "A,B, OR<br>C ?"    |                                | 59 RCL 03 |                |
| 15 PROMPT              |                                | 60 X↑2    |                |
| 16*LBL A               | UNIT hydrograph                | 61 1.7    |                |
| 17 11                  |                                | 62 *      |                |
| 18 STO 08              |                                | 63 GTO 03 |                |
| 19 GTO 11              |                                | 64*LBL 01 |                |
| 20*LBL B               | SCS hydrograph                 | 65 RCL 03 |                |
| 21 12                  |                                | 66 LN     |                |
| 22 STO 08              |                                | 67 .8     |                |
| 23 GTO 12              |                                | 68 *      |                |
| 24*LBL C               | do flood routing               | 69 1.06   |                |
| 25 SF 02               |                                | 70 +      |                |
| 26 SF 03               |                                | 71 1      |                |
| 27 "A OR B<br>?"       |                                | 72 X>Y?   |                |
| 28 PROMPT              |                                | 73 X<>Y   |                |
| 29*LBL 10              |                                | 74 GTO 03 |                |
| 30 "T="                |                                | 75*LBL 02 |                |
| 31 ARCL X              | Display<br>routine             | 76 RCL 03 |                |
| 32 AVIEW               |                                | 77 .83    |                |
| 33 RTN                 |                                | 78 *      |                |
| 34*LBL 12              |                                | 79 CHS    |                |
| 35 RCL 02              | SCS hydrograph<br>calculations | 80 1.9    |                |
| 36 RCL 00              |                                | 81 +      |                |
| 37 /                   |                                | 82 1      |                |
| 38 STO 03              |                                | 83 X>Y?   |                |
| 39 .7                  |                                | 84 X<>Y   |                |
| 40 X>Y?                |                                | 85*LBL 03 |                |
| 41 GTO 00              |                                | 86 RCL 04 |                |
| 42 X<>Y                |                                | 87 *      |                |
| 43 1                   |                                | 88 RCL 02 |                |
| 44 X>Y?                |                                | 89 "T"    |                |
| 45 GTO 01              |                                | 90 XEQ 10 |                |
|                        |                                | 91 RCL 01 |                |
|                        |                                | 92 +      | increment time |
|                        |                                | 93 STO 02 |                |
|                        |                                | 94 X<>Y   |                |
|                        |                                | 95 "IN"   |                |
|                        |                                | 96 XEQ 10 |                |

# Program Listings

|             |                                    |            |  |
|-------------|------------------------------------|------------|--|
| 97 FC? 02   |                                    | 145 RCL 03 |  |
| 98 GTO IND  |                                    | 146 1.63   |  |
| 08          |                                    | 147 *      |  |
| 99 FS?C 03  |                                    | 148 CHS    |  |
| 100 GTO 13  |                                    | 149 E↑X    |  |
| 101 RCL 05  |                                    | 150 7.49   |  |
| 102 X<>Y    |                                    | 151 *      |  |
| 103 STO 05  |                                    | 152 GTO 03 |  |
| 104 +       |                                    | 153♦LBL 04 |  |
| 105 STO 06  |                                    | 154 RCL 03 |  |
| 106 RCL 07  |                                    | 155 1.67   |  |
| 107 FS?C 01 |                                    | 156 Y↑X    |  |
| 108 RCL 05  |                                    | 157 1.45   |  |
| 109 RCL 06  |                                    | 158 *      |  |
| 110 +       |                                    | 159 GTO 03 |  |
| 111 STO 07  |                                    | 160♦LBL 05 |  |
| 112 XEQ 09  | change to STOP<br>for manual input | 161 RCL 03 |  |
| 113 2       |                                    | 162 LN     |  |
| 114 *       |                                    | 163 1.16   |  |
| 115 ST- 07  |                                    | 164 +      |  |
| 116 2       |                                    | 165 GTO 03 |  |
| 117 /       |                                    | 166♦LBL 06 |  |
| 118 "OUT"   |                                    | 167 RCL 03 |  |
| 119 XEQ 10  |                                    | 168 1      |  |
| 120 GTO IND |                                    | 169 -      |  |
| 08          |                                    | 170 E↑X    |  |
| 121♦LBL 13  |                                    | 171 90     |  |
| 122 SF 01   |                                    | 172 *      |  |
| 123 STO 05  |                                    | 173 DEG    |  |
| 124 GTO IND |                                    | 174 SIN    |  |
| 08          |                                    | 175 GTO 03 |  |
| 125♦LBL 11  | UNIT hydrograph<br>calculations    | 176♦LBL 07 |  |
| 126 RCL 02  |                                    | 177 RCL 03 |  |
| 127 RCL 00  |                                    | 178 .83    |  |
| 128 /       |                                    | 179 *      |  |
| 129 STO 03  |                                    | 180 CHS    |  |
| 130 .5      |                                    | 181 1.93   |  |
| 131 X>Y?    |                                    | 182 +      |  |
| 132 GTO 04  |                                    | 183 GTO 03 |  |
| 133 X<>Y    |                                    | 184♦LBL 09 |  |
| 134 .9      |                                    | 185 .11    |  |
| 135 X>Y?    |                                    | 186 *      |  |
| 136 GTO 05  |                                    | 187 200    |  |
| 137 X<>Y    |                                    | 188 -      |  |
| 138 1.2     |                                    | 189 X<0?   |  |
| 139 X>Y?    |                                    | 190 0      |  |
| 140 GTO 06  |                                    | 191 RTN    |  |
| 141 X<>Y    |                                    | 192 .END.  |  |
| 142 1.6     |                                    |            |  |
| 143 X>Y?    |                                    |            |  |
| 144 GTO 07  |                                    |            |  |
|             |                                    | 00         |  |

} calculate out-  
flow peculiar  
to the sample  
problem

## REGISTERS, STATUS, FLAGS, ASSIGNMENTS

| DATA REGISTERS |                |    |  | STATUS |      |                  |    |                 |  |
|----------------|----------------|----|--|--------|------|------------------|----|-----------------|--|
| 00             | Time, peak     | 50 |  | SIZE   | 009  | TOT. REG.        | 59 | USER MODE       |  |
|                | Time increment |    |  | ENG    |      | FIX              | 2  | SCI             |  |
|                | Time, total    |    |  | DEG    | X    | RAD              |    | GRAD            |  |
|                | T/T peak       |    |  | FLAGS  |      |                  |    |                 |  |
|                | Q peak         |    |  |        |      |                  |    |                 |  |
| 05             | Qi             | 55 |  |        |      |                  |    |                 |  |
|                | In+In+1        |    |  |        |      |                  |    |                 |  |
|                | 2S/Δt + 0,-0   |    |  | #      | INIT | SET INDICATES    |    | CLEAR INDICATES |  |
|                | Pointer        |    |  | 01     | C    | 1st pass through |    |                 |  |
|                |                |    |  | 02     | C    | do flood routing |    |                 |  |
|                |                |    |  | 03     | C    | 1st pass through |    |                 |  |
| 10             |                | 60 |  |        |      |                  |    |                 |  |
|                |                |    |  |        |      |                  |    |                 |  |
|                |                |    |  |        |      |                  |    |                 |  |
|                |                |    |  |        |      |                  |    |                 |  |
| 15             |                | 65 |  |        |      |                  |    |                 |  |
|                |                |    |  |        |      |                  |    |                 |  |
|                |                |    |  |        |      |                  |    |                 |  |
|                |                |    |  |        |      |                  |    |                 |  |
| 20             |                | 70 |  |        |      |                  |    |                 |  |
|                |                |    |  |        |      |                  |    |                 |  |
|                |                |    |  |        |      |                  |    |                 |  |
|                |                |    |  |        |      |                  |    |                 |  |
| 25             |                | 75 |  |        |      |                  |    |                 |  |
|                |                |    |  |        |      |                  |    |                 |  |
|                |                |    |  |        |      |                  |    |                 |  |
|                |                |    |  |        |      |                  |    |                 |  |
| 30             |                | 80 |  |        |      |                  |    |                 |  |
|                |                |    |  |        |      |                  |    |                 |  |
|                |                |    |  |        |      |                  |    |                 |  |
|                |                |    |  |        |      |                  |    |                 |  |
| 35             |                | 85 |  |        |      |                  |    |                 |  |
|                |                |    |  |        |      |                  |    |                 |  |
|                |                |    |  |        |      |                  |    |                 |  |
|                |                |    |  |        |      |                  |    |                 |  |
|                |                |    |  |        |      |                  |    |                 |  |
| 40             |                | 90 |  |        |      |                  |    |                 |  |
|                |                |    |  |        |      |                  |    |                 |  |
|                |                |    |  |        |      |                  |    |                 |  |
|                |                |    |  |        |      |                  |    |                 |  |
| 45             |                | 95 |  |        |      |                  |    |                 |  |
|                |                |    |  |        |      |                  |    |                 |  |
|                |                |    |  |        |      |                  |    |                 |  |
|                |                |    |  |        |      |                  |    |                 |  |

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