Project Report No. 102

EXPERIMENTAL STUDY OF WARM WATER FLOW INTO IMPOUNDMENTS
PART II:
TEMPERATURE AND VELOCITY INSTRUMENTATION AND DATA PROCESSING FOR THE THREE-DIMENSIONAL FLOW EXPERIMENTS

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PREFACE

Under a grant from the Department of the Interior, Federal Water Pollution Control Administration, a study was made of the hydromechanics of flow of heated water into natural lakes and reservoirs. The study was essentially experimental and confined to the immediate vicinity of the outlet. It had three phases, the results of which are presented in three project reports by the St. Anthony Falls Hydraulic Laboratory, University of Minnesota.

1. Project Report No. 101, Experimental Study of Warm Water Flow into Impoundments. Part I: Flow and Heat Exchange Near a Surface Outlet in Two-Dimensional Flow, December 1968.
2. Project Report No. 102, Experimental Study of Warm Water Flow into Impoundments. Part II: Temperature and Velocity Instrumentation and Data Processing for the Three-Dimensional Flow Experiments, December 1968.
3. Project Report No. 103, Experimental Study of Warm Water Flow into Impoundments. Part III: Temperature and Velocity Fields Near a Surface Outlet in Three-Dimensional Flow, December 1968.

The principles of the instrumentation have also been described in a separate publication entitled: The Measurement of Low Fluid Velocities with the Aid of a Tethered Sphere by Heinz Stefan and Frank R. Schiebe, published in Water Resources Research, December 1968.

EXPERIMENTAL STUDY OF WARM WATER FLOW INTO IMPOUNDMENTS
PART II: TEMPERATURE AND VELOCITY INSTRUMENTATION AND DATA PROCESSING FOR THE THREE-DIMENSIONAL FLOW EXPERIMENTS

Experimental investigations of thermal pollution problems in three-dimensional hydraulic models pose some difficult instrumentation problems. The following is a description of instruments and procedures used at the St. Anthony Falls Hydraulic Laboratory, University of Minnesota, during a study of cooling water flow from a canal into an impoundment. The study was sponsored by the Department of the Interior, FWPCA, under grant number WP00913-03.

The experimental study required the measurement of local temperatures and velocity profiles in a tank 17 ft wide, 40 ft long, and approximately 2-1/2 ft deep. The flow was stratified; velocities were essentially horizontal and of the order 0 to 0.3 ft per second. Temperatures ranged from about 50 to 100 degrees Fahrenheit. It was desired to obtain vertical profiles of velocity and temperature at various positions in the tank.

1. Velocity Probe

The probe utilized for the measurement of velocities basically consists of a small buoyant sphere tethered on a fine line [1]. The horizontal displacements of the sphere are measured. These displacements are the result of the drag and buoyancy forces of the sphere which are balanced against the tension in the tethering line. Since the drag depends on the flow velocity, the measured displacements are an indication of velocity.

The tethered sphere velocity probe consists simply of a sphere of wax or plastic material with a specific gravity slightly less than unity, fastened to a fine rayon string. One end of the string is epoxied to the end of a projecting rigid support far enough away that it does not affect the flow at the sphere. This rigid support is kept very slender as shown in Fig. 1. If such a device is placed into water at rest, the sphere tends to float due to buoyant forces, but because of the tether line it remains submerged directly above its point of support. This is the zero deflection position which corresponds to zero velocity. Flow of the water generates a drag force on both the sphere and the flexible line support, and as a consequence the ball takes a new position which depends on all forces involved. The velocity can be determined by measuring the direction and magnitude of the deflection of the sphere. A thorough analysis of the response characteristics of the device reveals that the velocity measurements obtained can be quite erroneous if too many simplifying assumptions are made. The forces on both the tethering line and the sphere must be considered. This was achieved by utilizing a numerical technique.

In order to obtain a unique relationship between the deflection and the velocity using a single probe, it is necessary to assume that vertical velocity components which would produce lift in the same direction as the buoyancy forces do not exist. In many experiments this does not represent a serious limitation. The tethered sphere experiences a buoyant force of

$$B_s = \frac{4\pi}{3} \left(\frac{D}{2}\right)^3 \rho g \, (1 - s_s) \tag{1}$$

and a horizontal drag force of

$$D_s = C_s \frac{\pi D^2}{4} \rho \frac{V^2}{2} \tag{2}$$

The symbols are defined at the end of the text. The magnitude and direction of the resultant force on the sphere are

$$K_s = K_1 = (B_s^2 + D_s^2)^{1/2} \tag{3}$$

and

$$\alpha_s = \alpha_1 = \arctan \, (B_s/D_s) \tag{4}$$

respectively. This force is acting on the upper end of the tethering line. An element of submerged line of length $\ell = z/\sin\delta$, as shown in Fig. 2, has a reduced weight of

$$G = mg = \frac{d^2\pi}{4} \ell \rho g \, (s_\ell - 1) \tag{5}$$

The dynamic form drag induced by the flow around the line element, assumed to be a cylinder, is

$$D_\ell = C_\ell \, d \, \ell \, \frac{\rho}{2} (V \sin\delta)^2 \tag{6}$$

This drag acts perpendicular to the line. Friction drag with its direction parallel to the line is equal to

$$F_\ell = C_f \pi d \ell \frac{\rho}{2} (V \cos \delta)^2 \tag{7}$$

The knowledge of all forces acting on the sphere and its flexible line support renders it possible to evaluate the deflection of the sphere and the shape of the flexible support. The problem is similar to that of finding the shape of a catenary curve. The sum of all forces acting on an element of the flexible line must be in equilibrium. No moments can be transmitted by the line. The force polygon is shown in Fig. 3. In it, K_i is the force transmitted at the upper end of the line element, and K_{i+1} is the force transmitted at the lower end. According to the force polygon, the summation of all horizontal and vertical force components yields the following equations:

$$K_i \cos \alpha_i + D_\ell \sin \delta + F_\ell \cos \delta - K_{i+1} \cos \alpha_{i+1} = 0 \tag{8}$$

$$K_i \sin \alpha_i - G - D_\ell \cos \delta + F_\ell \sin \delta - K_{i+1} \sin \alpha_{i+1} = 0 \tag{9}$$

These equations may also be written as

$$\tan \alpha_{i+1} = \frac{K_i \sin \alpha_i - G - D_\ell \sin \delta + F_\ell \sin \delta}{K_i \cos \alpha_i + D_\ell \sin \delta + F_\ell \cos \delta} \tag{8a}$$

$$K_{i+1} = \frac{1}{\cos \alpha_{i+1}} (K_i \cos \alpha_i + D_\ell \sin \delta + F_\ell \cos \delta) \tag{9a}$$

If the total length, ℓ, of the line is subdivided in n equal intervals of length $\ell = \ell/n$, the above equations can be applied n times. Starting at the sphere where $K_i = K_1$ and $\alpha_i = \alpha_1$ are given by Eqs. (3) and (4) respectively, the values of $K_{i+1} = K_2$ and $\alpha_{i+1} = \alpha_2$ may be found by the use of Eqs. (8a) and (9a). Repeated applications of the above equations will yield values K_3 and α_3 and so on. Unanswered yet is the question which δ values are to be used in this computation. Looking at the force diagram it is evident that a good approximation of δ is

$$\delta = \frac{1}{2} (\alpha_i + \alpha_{i+1}) \tag{10}$$

Numerical evaluation of the values of G, D_ℓ, and F_ℓ for a very fine line according to Eqs. (5), (6), and (7) shows that the weight of a line element and its friction drag are much less than its dynamic form drag. The force polygon (Fig. 3) for small values of G and F_ℓ is nearly isosceles and a line perpendicular to the force D_ℓ has a slope very closely approximated by Eq. (10).

The shape of the tethering line is obtained by adding line elements of length $\Delta\ell$ with their respective slope, starting at the buoyant sphere. The coordinates of a point of the tethering line are

$$x_{\ell k} = s - \frac{\ell}{n} \sum_{1}^{k} \cos \delta_i \tag{11}$$

and

$$z_{\ell k} = z_r - \frac{\ell}{n} \sum_{1}^{k} \sin \delta_i \tag{12}$$

k is the number of elements added and varies from 1 to n. The total horizontal deflection of the sphere and its height above the line attachment point are s and z_r respectively. Since the line attachment point has the coordinates $x_{\ell o} = 0$ and $z_{\ell o} = 0$,

$$s = \frac{\ell}{n} \sum_{1}^{n} \cos \delta_i \tag{13}$$

and

$$z_r = \frac{\ell}{n} \sum_{1}^{n} \sin \delta_i \tag{14}$$

Probes were developed to measure flow velocities between 0.01 and 0.3 fps in water. Several probes were constructed and calibrated. Data of probes which were actually used in experiments are listed in the following table.

TABLE 1

	Sphere Material	Diam.-ft	Spec. Grav.	Flexible Line Support Material	Diam.-ft	Length-ft	Spec. Grav.
A	Wax	.00920	.915	Rayon	.000012	.2354	1.20
B	Wax	.00970	.915	Rayon	.000012	.2417	1.20
C	Hollow Lexon	.0208	.991	Rayon	.000012	.0958	1.20
D	Polyethylen	.0155	.955	Rayon	.000012	.137	1.20
E	Butternut	.0163	.54	Rayon	.000012	.179	1.20

Specific gravities were found with the aid of a pycnometer; the diameter of the tethering line was measured with an electron microscope.

The theoretical calibration curve was calculated by using Eqs. (1) through (12). The drag coefficients C_s and C_ℓ in Eqs. (2) and (6) respectively were expressed according to Reference [2] as

$$C_s = \frac{24}{Re_D} \left(1 + \frac{3}{16} Re_D\right)^{1/2} \tag{15}$$

and

$$C_\ell = 8\pi \left(2\, Re_d - Re_d \ln Re_d\right)^{-1} \tag{16}$$

where the Reynolds numbers of the sphere and the line must satisfy the conditions $Re_D = VD/\nu < 100$ and $Re_d = Vd/\nu < 1$, respectively. Equation (15) is empirical but it can be seen that the parenthetical factor is Oseen's correction. The empirical formula permits analytical extension of Oseen's equation from Reynolds numbers of the order of 1 to the order of 100 which is desirable for the present purpose. The temperature dependence of the kinematic viscosity was taken into account, with ν given in ft^2/sec and T in $^\circ$F, by the equation

$$\nu = .00001942\,(.471101 + .014354\, T + .0000682\, T^2)^{-1} \tag{17}$$

The rayon line holding the sphere was divided into 20 elements as actual numerical calculations were carried out on a Control Data 1604 computer. The tether line against the calculated values. The deviations between the theory and experiments may be analyzed and minor changes in the input data may be made correspondingly. Figure 6, for example, would suggest that in the theory the drag on the line and the buoyancy of the sphere were slightly too small.

An examination of Eqs. (1), (2), and (4) shows that the buoyancy force depends upon the specific gravity of the sphere and the cube of the sphere diameter, and that the drag force at low Reynolds numbers depends upon approximately the first power of the sphere diameter and not on sphere specific gravity. Therefore, the sensitivity of the instrument can be increased by using smaller spheres or material with a specific gravity very close to unity.

At higher speeds buoyant spheres showed horizontal oscillations when towed in the calibration flume. Seen from the top the path of the sphere would nearly be a sine-wave instead of a straight line. The frequency of the oscillations as well as their amplitude increased when towing velocities were increased. The relationship of Strouhal to Reynolds numbers for one particular sphere is shown in Fig. 7. Actual frequencies measured were of the order of 1.4 to 2.0 cycles per second while towing velocities ranged from 0.25 to 0.47 ft per second. Maximum amplitudes were of the order of ± 3/16 in. for probe E, for example. It seems noteworthy that these results are quite different from those obtained for a free-falling sphere reported in Reference [3]. At high enough Reynolds numbers the periodic oscillations would disappear. Instead the sphere would carry out rather irregular lateral motions. It is believed that oscillations begin with the occurrence of boundary layer separation on the sphere. The lower limit for the oscillations may therefore be expected at a Reynolds number of larger than unity. In the velocity range from zero to 0.3 ft per second oscillations did not effect deflections of the buoyant sphere very much, because lateral deflections were only a few per cent of the total length of the tethering line.

Another problem encountered was the formation of tiny gas bubbles on the sphere. This phenomenon disappeared as soon as the water was degassified with the aid of a cavitating pump before discharging it into the tank.

It may be mentioned that for measurements in other types of flow, the instrument may be inverted by using a sphere slightly heavier than water. Such measurements were taken simultaneously, although at different elevations, because the tethered sphere was less deeply submerged than the tip of the thermister probe.

3. Data Acquisition

Since the experimental tank was quite large, deflections of the sphere were by necessity measured through the free surface. A telescope with a cross-hair reticule was mounted vertically on a traveling stage with two horizontal degrees of freedom. This permitted a measurement of the horizontal displacements of the optical instrument. Since the telescope could be positioned directly above the tethered sphere, it was possible to measure the displacements of the sphere with respect to the tip of the rigid support without taking into consideration the optical refractive effects of the water. Fig. 9 shows schematically how the probe was mounted. A series of measurements necessary to define a vertical velocity profile was obtained by lowering the point of support and consequently the submergence of the sphere. The depth of the sphere below the water surface and the depth of the tip of the point of support are, however, not linearly related. With the aid of potentiometers all lengths were transformed into electric signals which could be read from a digital voltmeter.

Temperatures at the tip of the thermistor probe were recorded simultaneously with the velocity components. A voltage proportional to the temperature was delivered from the recorder output of the thermistor thermometer to an x-y plotter. An auxiliary potentiometer was mounted on the plotter to facilitate obtaining a voltage output suitable to be read by the digital voltmeter. The x-y plotter in this instance was simply used as a signal conditioner.

The electronic instrumentation is shown schematically in Fig. 10. The system was designed so that ultimately the data can be recorded directly from the digital output of the digital voltmeter on magnetic tape, paper tape, or punched cards via an automatic data aquisition system. Pictures of the experimental facility and the equipment are presented in Fig. 11.

4. Data Processing

A numerical procedure was developed on the basis of the principles outlined above to calculate vertical velocity and temperature profiles. The previously mentioned digital voltmeter readings were used as input data. Recorded experimental data were checked for major errors and punched on 80 column cards (Form DD - 733727) along with sufficient identification of experiment and probe characteristics. One input card was used for every particular probe position. The vertical velocity profile was found from the displacement measurements of the sphere by successive approximation. Total sphere deflections were calculated from assumed or previously calculated velocity profiles, whereby forces acting both on the sphere and the tethering line were considered. Corrections of the velocity profile were made until all calculated and measured deflection values differed by less than five per cent.

Calculations of the total sphere deflection required an assumption concerning the anticipated velocity and temperature distribution over the distance from the tip of the probe to the sphere. The first assumption made was that the temperature and the velocity were constant over this distance. The data conversion program DACON 001 given in Appendix B furnishes results with this assumption, which may be considered as a first order approximation. The procedure is the same as the one used for the theoretical calibration, and as outlined earlier, has been experimentally verified.

The vertical distance of the tethered sphere from the thermistor was calculated from the total sphere deflection using the principle of the catanary curve as part of the program.

Results of the numerical computations carried out on a CDC 6600 were usually presented in both tabular and graphical form.

A problem arose, however, when turbulence was present in the flow. It was found that the calculated depth of the tethered sphere did not fully agree with the actually observed value when measurements were taken near the water surface. The sphere was, for instance, still submerged when according to calculations it should already have been out of the water. This may be explained by the fact that with the tethered sphere in its average position the tetherin line did not conform exactly to the catanary curve used in the calculations. Therefore the calculated vertical distance was larger than the actual value. An empirical adjustment of the calculated depth of the sphere was made by the program if the last value was found to be negative. Generally the adjustment was less than 0.02 ft.

At the end of the first order approximation calculations the temperature and the first order velocity profiles were specified by several points. As previously mentioned, the first order velocity profile was computed on the assumption that the velocity and temperature fields across the tethering line were constant. From the temperature profile and preliminary velocity profile information, a second order profile was determined in an extended program called DACON 103R which is shown in Appendix C. To make the first order results useful for the second order approximation, a curve-fitting process using the least squares method was applied. Both profiles were assumed to be describable by polynomials. A subroutine called CURFI found the unknown coefficients for the best fitting polynomial profile. The coefficient of the term with the highest power was set equal to unity. An example of the result to be expected from the curve-fitting process is presented in Fig. 12.

The second order approximation of the velocity profile was obtained by calculating the total deflection of the sphere using the measured temperature and the first order velocity profiles. The subroutine BACKWD was used for this purpose. It was similar to the first order approximation but employed velocities and temperatures depending on depth instead of constant values. The flow charts for both subroutines CURFI and BACKWD are given in Appendix C.

The flow chart for the main program DACON 103R, also contained in Appendix C, shows how the second and higher order approximations were obtained. The results were considered satisfactory when the calculated and measured total sphere deflections differed by less than five per cent of the absolute value. Some additional features of the main program should be mentioned. The input data to the main program contained essentially the depths of the combined temperature-velocity probe tip and horizontal deflections of the tethered sphere. The unknown velocity at the unknown depth of the sphere had to be found by the program.

The first order approximation yielded a set of data indicating the position of the sphere and the magnitude and direction of velocity at the sphere. Before the curve-fitting process was applied all points with velocities smaller than 0.005 fps were dropped in order to increase the accuracy of the polynomial approximation.

5. Acknowledgments

Mr. James Delker and Mr. Jerry Pommerenke built and calibrated the probes listed in Table 1. Their skillful work and contribution is gratefully acknowledged by the authors.

The entire program was carried out under the general cognizance of Professor Edward Silberman, to whom the grant was awarded by the FWPCA.

REFERENCES

[1] Stefan, H., and Schiebe, F. R., "The Measurement of Low Fluid Velocities with the Aid of a Tethered Sphere," Water Resources Research, Vol. 4, No. 6, December 1968

[2] Olson, R., Essentials of Engineering Fluid Mechanics, 2nd Ed., International Textbook Company, 1966.

[3] Shafrir, V., Horizontal Oscillations of Falling Spheres, Project Report, University of California, Los Angeles, Institute of Geophysics and Planetary Physics, February 1965.

LIST OF SYMBOLS AND UNITS

B_s = Buoyant force of sphere in lbs

C_f = Friction drag coefficient (dimensionless)

C_ℓ = Drag coefficient of line (dimensionless)

C_s = Drag coefficient of sphere (dimensionless)

d = Diameter of line in ft

D = Diameter of tethered sphere in ft

D_ℓ = Dynamic drag force on line in lbs

D_s = Dynamic drag force on sphere in lbs

F_ℓ = Friction drag force on line element of length $\Delta\ell$ in ft

g = 32.2 ft/sec^2

G = Weight of line element of length $\Delta\ell$ in lbs

ℓ = Length of tethering line in ft

$\Delta\ell$ = Length of element of line in ft

s = Total horizontal deflection of sphere in ft

s_ℓ = Specific gravity of wire or rayon line (dimensionless)

s_s = Specific gravity of sphere (dimensionless)

s, z_r = Horizontal and vertical distance between point of support and position of sphere respectively in ft

u = x-component of s in ft

v = y-component of s in ft

V = Flow velocity at position of sphere in fps

$V(z)$ = Horizontal flow velocity at a point with depth z in fps

$x_{\ell k}, z_{\ell k}$ = Horizontal and vertical coordinates of a point on the line with respect to rigid point of support in ft

δ = Inclination of line element of length $\Delta\ell$ with respect to a horizontal plane in degrees

ρ = Density of water in slugs/ft^3

LIST OF FIGURES

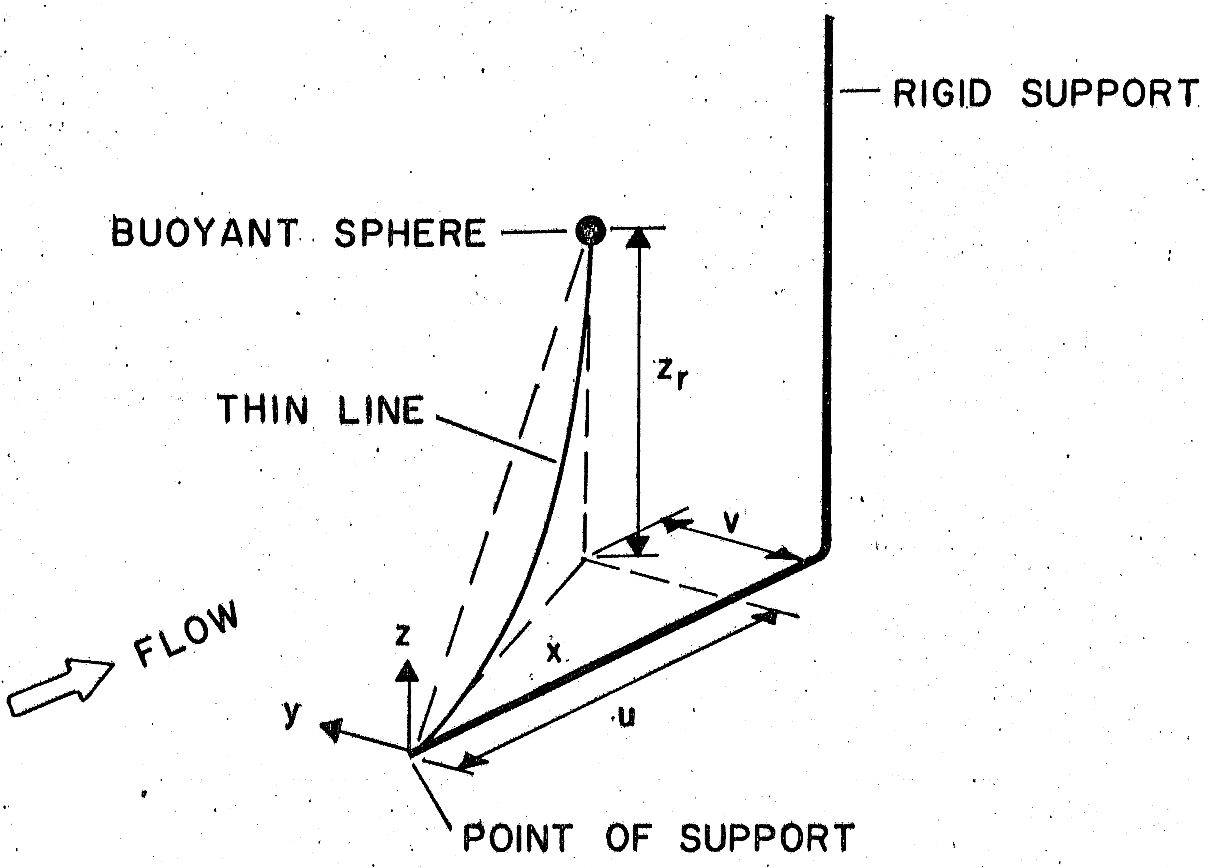


Fig. 1 Scheme of Probe

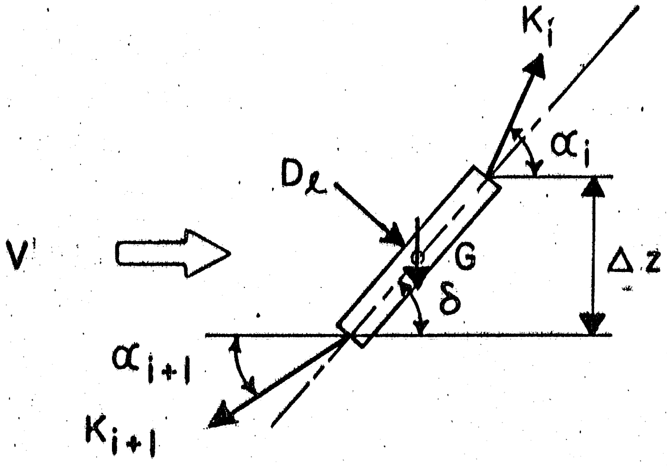


Fig.2 Forces on Line Element

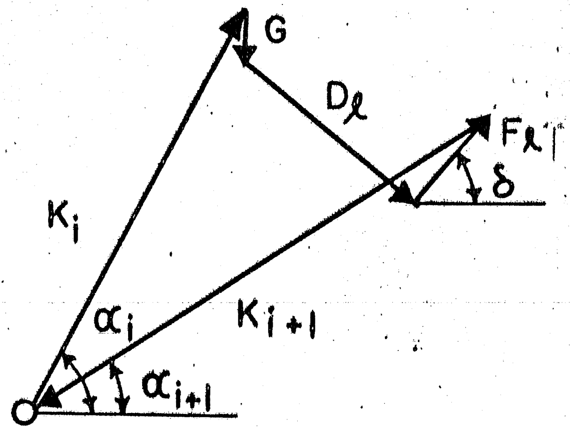


Fig. 3 Polygon of Forces Acting on Line Element

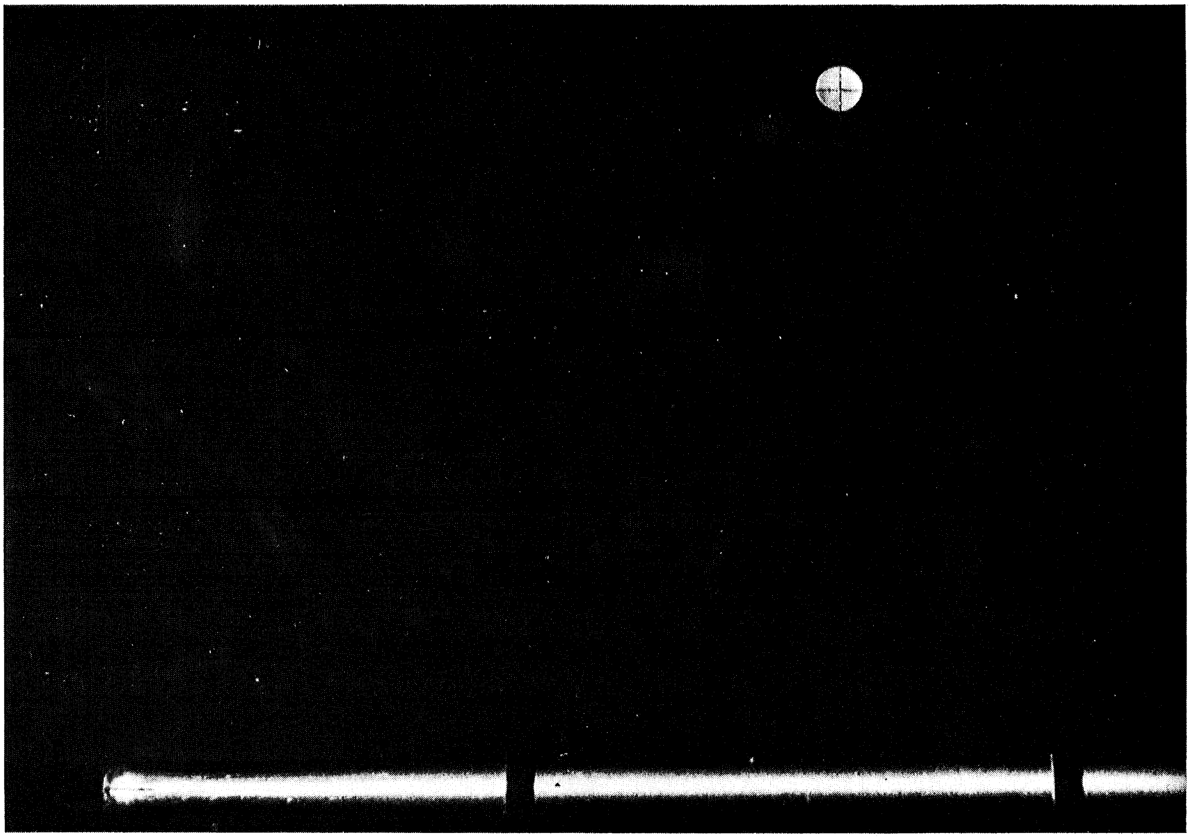
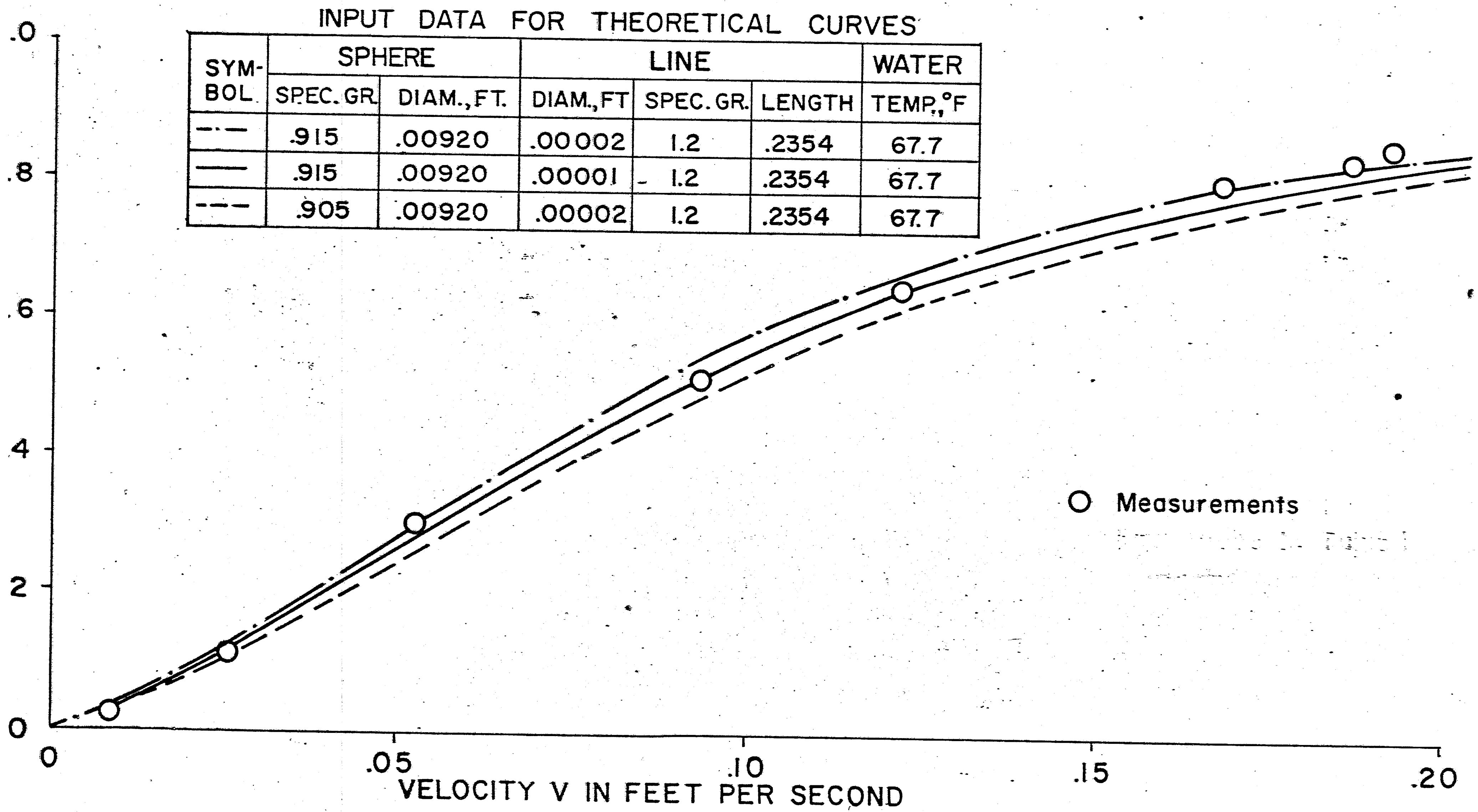


Fig. 4 Probe consisting of Buoyant Sphere, Tethering Line, and Rigid Support. Diameter of Sphere approximately 1/8 in.



INPUT DATA FOR THEORETICAL CURVES

SYMBOL	SPHERE		LINE			WATER
	SPEC. GR.	DIAM., FT.	DIAM., FT	SPEC. GR.	LENGTH	TEMP., °F
—·—	.915	.00920	.00002	1.2	.2354	67.7
——	.915	.00920	.00001	1.2	.2354	67.7
---	.905	.00920	.00002	1.2	.2354	67.7

Fig. 5 Example of Theoretical and Experimental Performance Characteristics of Tethered Sphere Probe (Probe A in Table I)

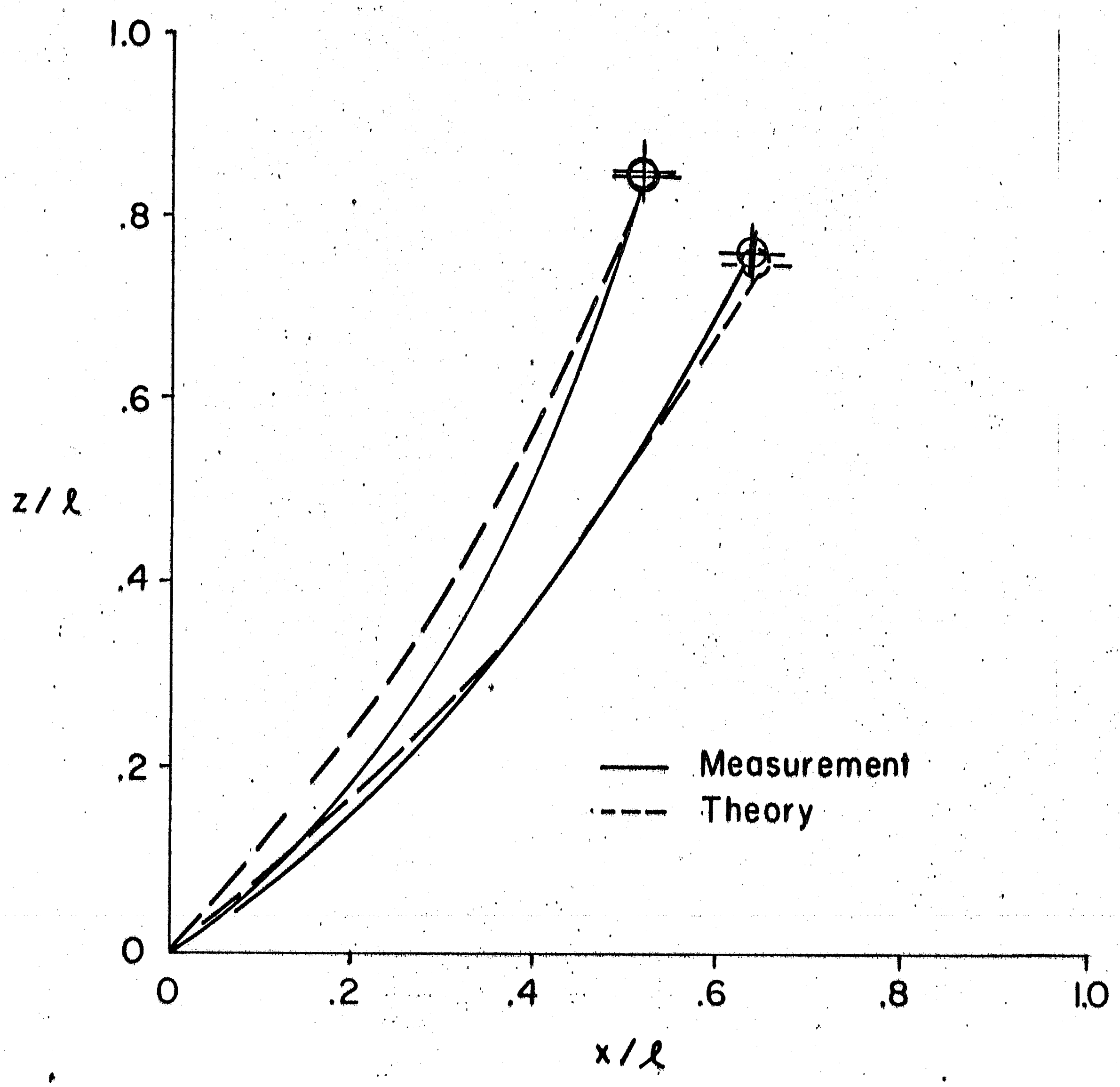


Fig. 6 Calculated and Observed Deflections of Buoyant Sphere and Tethering Line for the Second Probe in Table 1 at V = .0926 and V = .121 fps

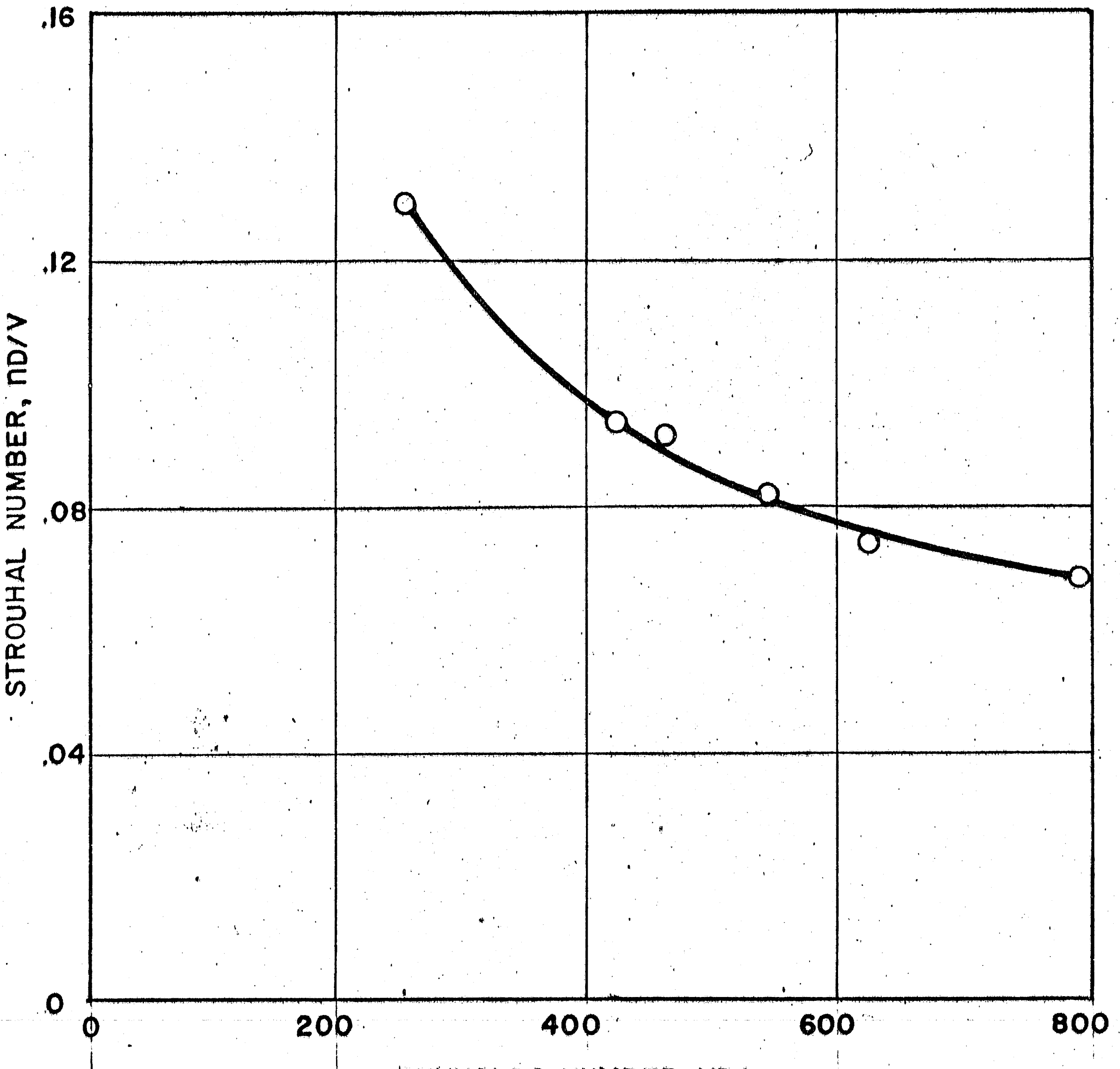


Fig. 7 Experimental Data on Tethered Sphere Oscillation for Probe E in Table 1

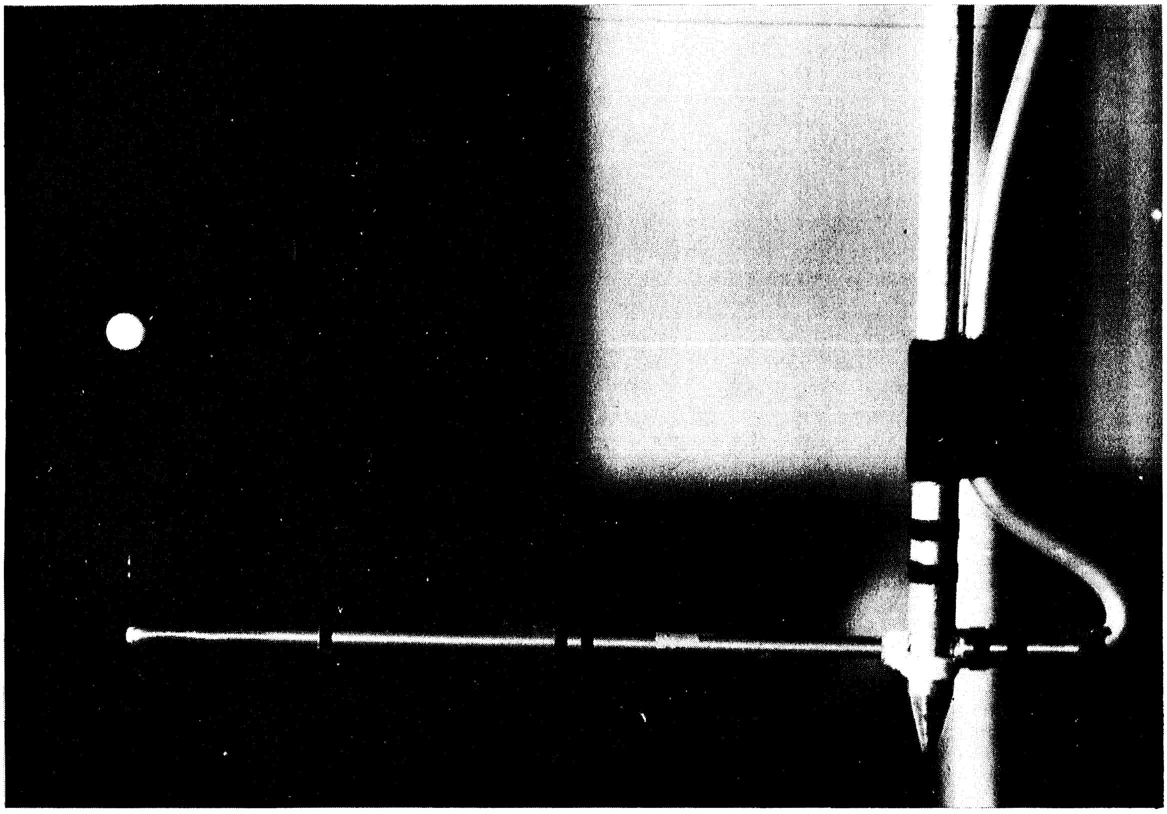


Fig. 8 Combined Velocity-Temperature Probe

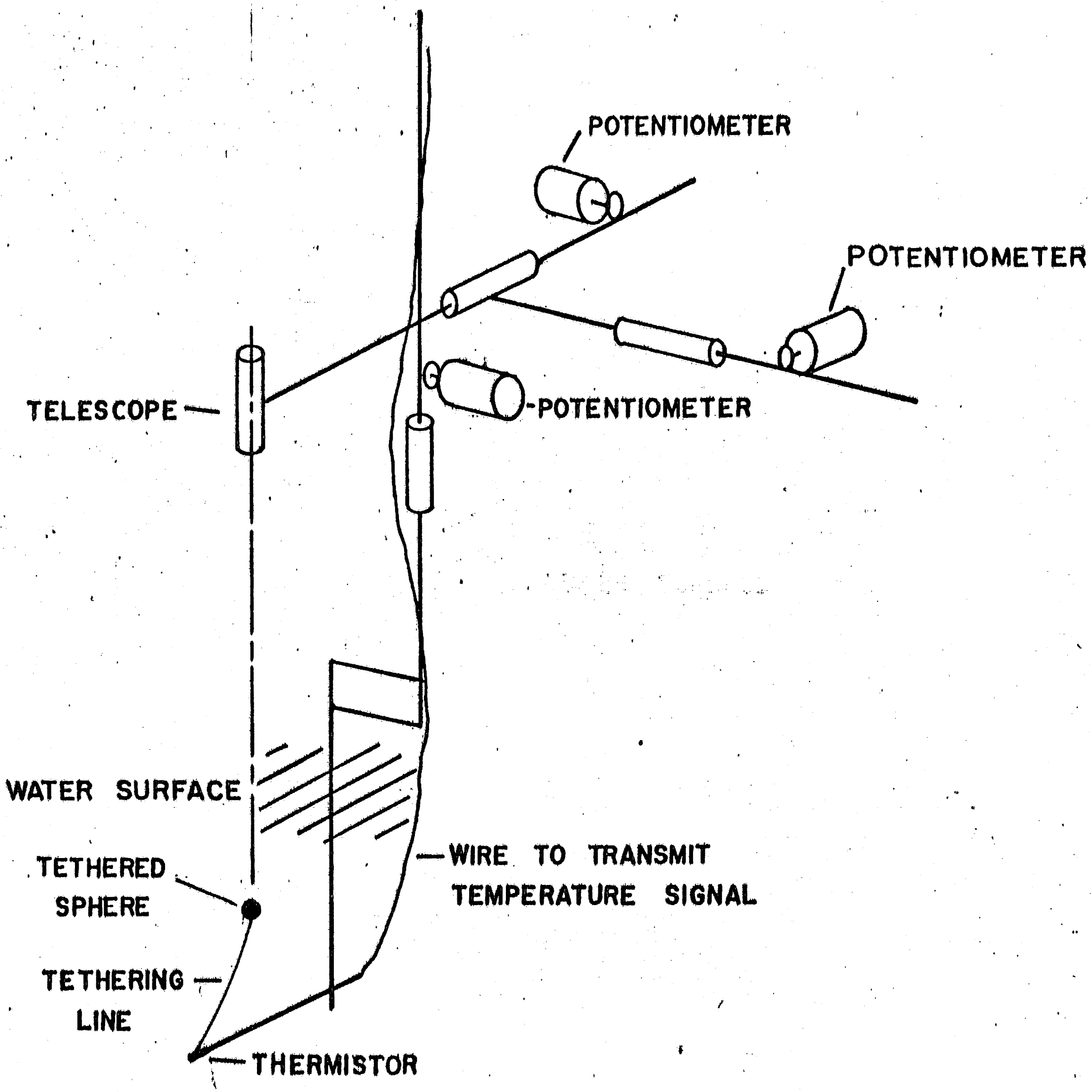


Fig. 9 Scheme of Probe Mounting

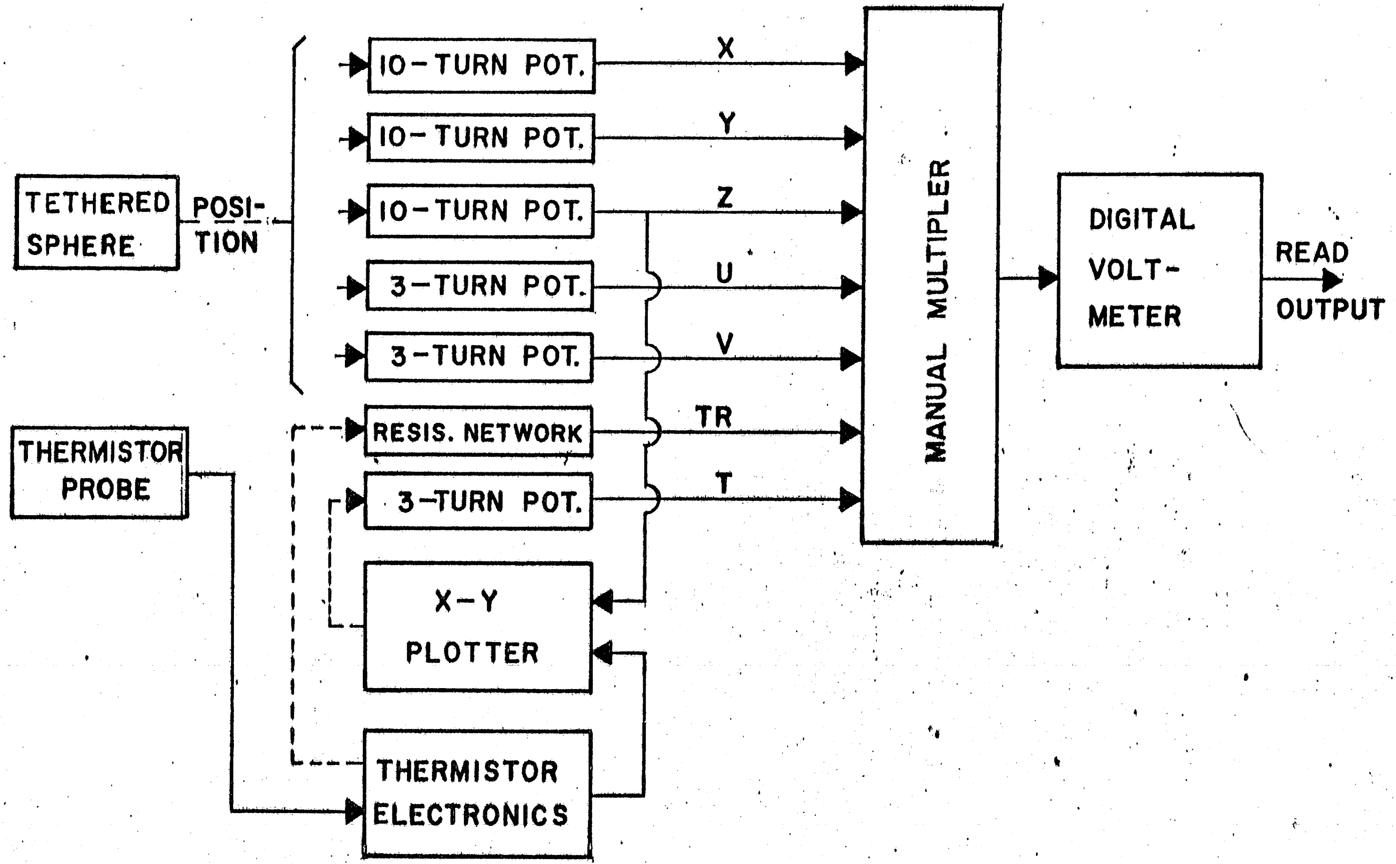
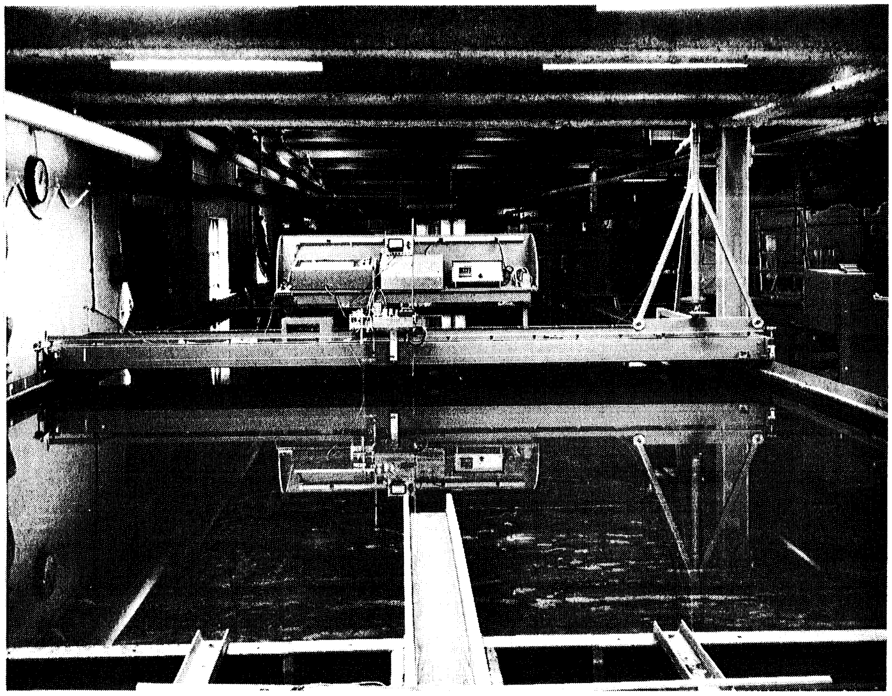
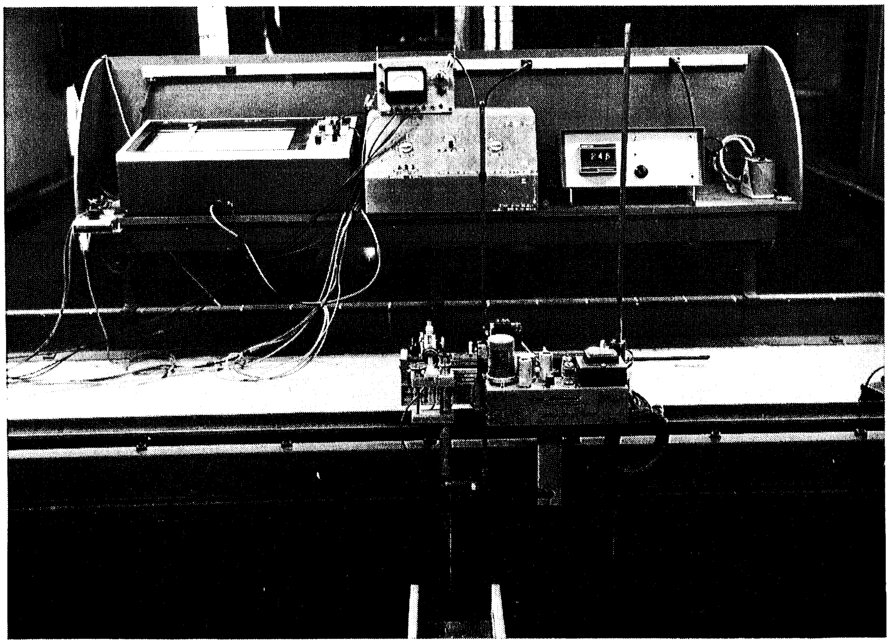


Fig. 10 Block Diagram of Electronic Equipment



a. View of Tank and Large Carriage



b. Details of Probe Assembly and Associated Equipment

Fig. 11 Equipment Used to Measure Temperature and Velocity Field in Tank

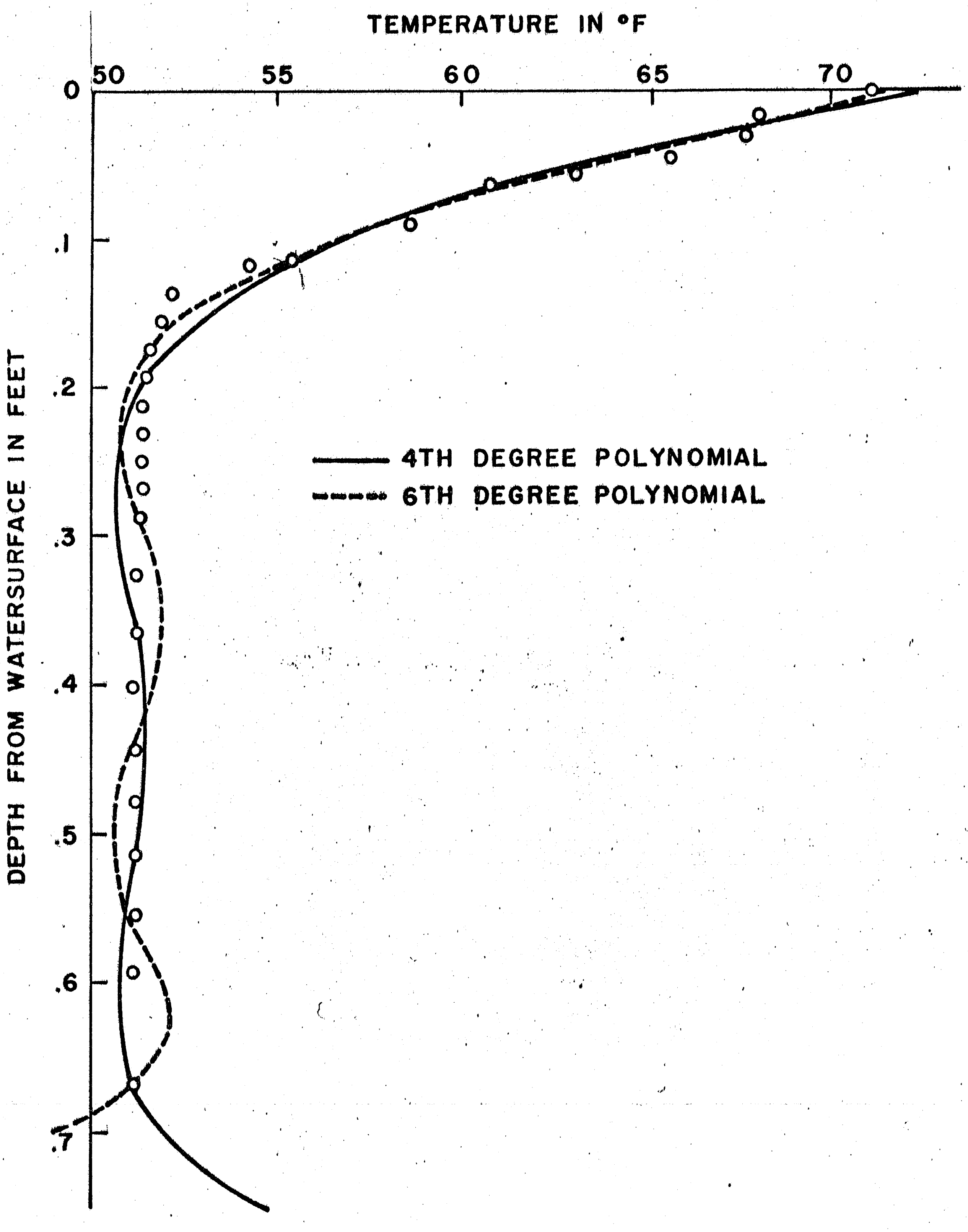


Fig. 12 Example of Temperature Data and Results of Curve-Fitting Process

Appendix A

FORTRAN PROGRAM TO CALCULATE TETHERED SPHERE DEFLECTION FOR GIVEN UNIFORM VELOCITY IN A UNIFORM VELOCITY FIELD

```
..2163716 AIS    1    60    TECAL, SEVERAL PROBES, V=.01 TO .25 FPS
      PROGRAM WATER A
C
C                                   T E C A L
C
C     THIS PROGRAM DETERMINES THE TOTAL DEFLECTION OF THE SPHERE AND
C     THE SHAPE OF THE LINE IN A STREAM OF CONSTANT AND UNIFORM VELOCITY
C     INPUT DATA
C     DIAMETER OF SPHERE D, SPECIFIC GRAVITY OF SPHERE SS,
C     DIAMETER OF LINE DW, LENGTH OF LINE L, SPECIFIC GRAVITY OF LINE SW,
C     DENSITY OF WATER RHO, LINE LENGTHINCREMENT DELTAS, WATER TEMPERATURE T
      REAL KS, KN, KN1, L, M
   60 READ 2, D, SS, DW, L, SW, RHO, DELTAS, T
    2 FORMAT (8F9.5)
      IF(D) 61,61,62
   61 GO TO 63
   62 CONTINUE
      PRINT 3, D, SS, DW, L, SW, RHO, DELTAS, T
    3 FORMAT (/,10X,22HTETHERED SPHERE METHOD, /, * DEFLECTION OF SPH
     1ERE  AND SHAPE OF LINE IN STREAM OF GIVEN UNIFORM VELOCITY*,//,
     226HINPUTDATA IN FEET AND SEC, /, 3X, 1HD, 8X, 2HSS, 8X, 2HDS, 8X,
     31HL, 8X, 2HSW, 6X, 3HRHO, 5X, 6HDELTAS, 5X, 1HT, /, 8F9.5, /)
      PRINT 40
   40 FORMAT (*SHAPE OF LINE IN RELATIVE VALUES*,/,4X,2HUR, 7X, 2HZR, /)
C     LOWER LIMIT OF VELOCITY RANGE IN FEET PER SECOND
      V=0.010
      VISC=.00001942/(.471101+.0143454*T+.00006820*T**2)
   50 RED=V*D/VISC
      BR=1.0+3.0*RED/16.0
      CS=24.0*SQRTF(BR)/RED
      DRAGS=CS*3.1415*D**2*V**2*RHO/8.0
      BUOYS=3.1415*D**3*RHO*32.2*(1.0-SS)/6.0
      SQUA=DRAGS**2+BUOYS**2
      KS=SQRTF(SQUA)
      KN=KS
      M=DW**2*3.1415*DELTAS*RHO*(SW-1.0)/4.0
      SUM=0
      U=0.
      Z=0
C     CALL DELTA(I)=ALPHA,ALPHA(I)=ALN, ALPHA(I+1)=ALN1,AL1=THE FIRST ALN
      TANAL1=BUOYS/DRAGS
      AL1=ATAN(TANAL1)
      ALN=AL1
      REW=V*DW/VISC
      CW=8*3.1415/(2*REW-REW*ALOG(REW))
   11 ALPHA=ALN
   10 DRAGW=CW*DW*DELTAS*(V*SINF(ALPHA))**2*RHO/2
      FUNV=KN*SINF(ALN)-M*32.2-DRAGW*COSF(ALPHA)
      FUNH=KN*COSF(ALN)+DRAGW*SINF(ALPHA)
      FUN=FUNV/FUNH
      ALN1=ATAN(FUN)
C     CALL K(I+1) = KN1
      SQ=FUNV**2+FUNH**2
      KN1=SQRTF(SQ)
      ALV=(ALN+ALN1)/2.0
      RAT=(ALV-ALPHA)/ALV
      IF(0.001-RAT)  5,5,6
    5 ALPHA=ALV
      GO TO 10
    6 U=U+DELTAS*COSF(ALPHA)
```

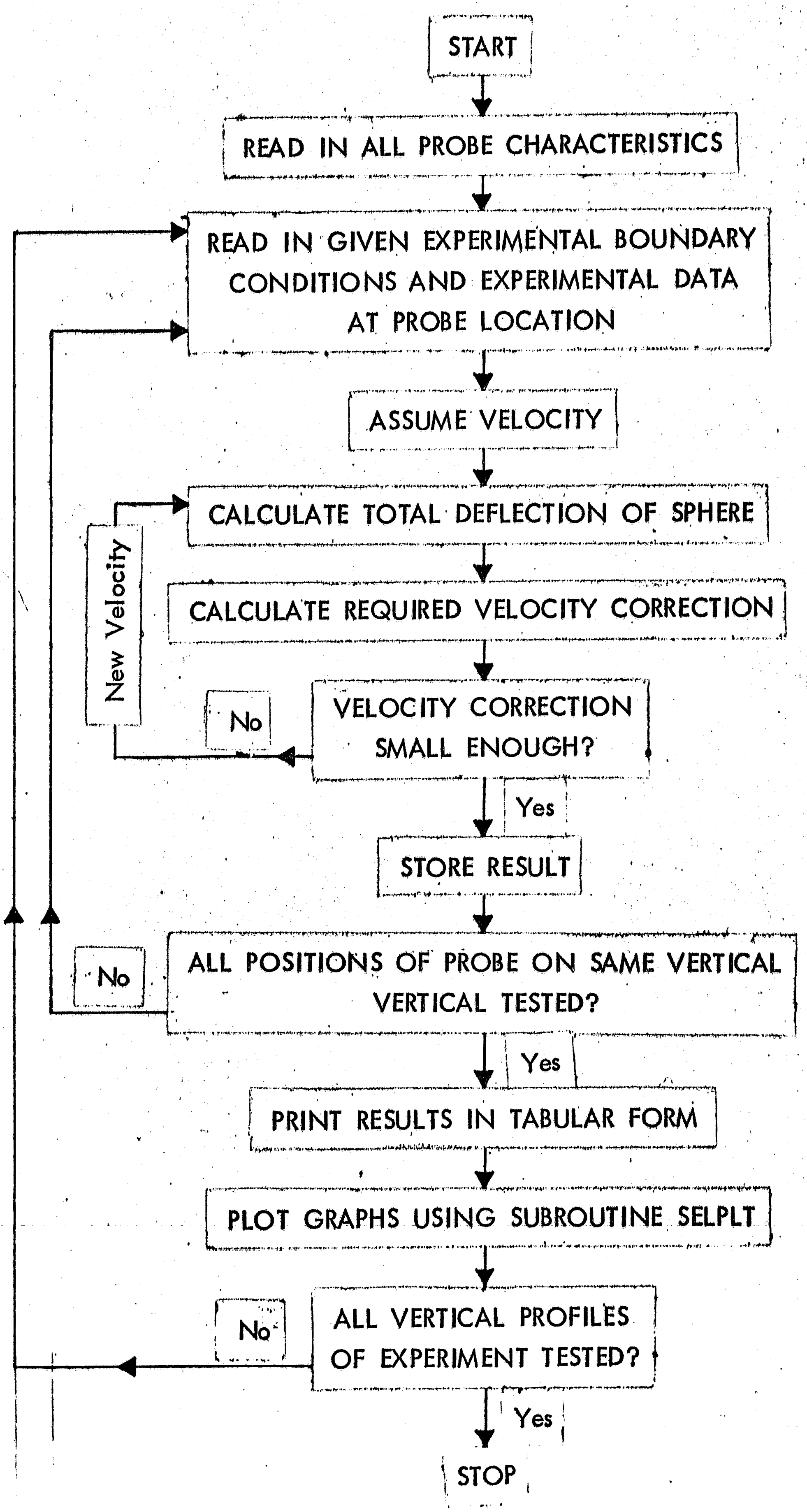
```
      Z=Z+DELTAS*SINF(ALPHA)
      UR=U/L
      ZR=Z/L
      PRINT 7, UR,ZR
    7 FORMAT (2F8.4)
      SUM= SUM + DELTAS
      IF(SUM-L) 12,13,13
   12 KN=KN1
      ALN=ALN1
      GO TO 11
   13 V=V+0.010
C     UPPER LIMIT OF VELOCITY RANGE .25 FEET PER SECOND
      IF (V-0.25) 51,51,52
   51 PRINT 15,V
   15 FORMAT (/,20X,2HV=,1F8.4,3HFPS)
      GO TO 50
   52 GO TO 60
   63 STOP
      END
      END

.01020    .95600    .00002    .15000   1.20000   1.94000    .00750 70.00000
.01560    .95600    .00002    .15000   1.20000   1.94000    .00750 70.00000
.02080    .95600    .00002    .15000   1.20000   1.94000    .00750 70.00000
.01020    .95600    .00002    .20000   1.20000   1.94000    .01000 70.00000
.01560    .95600    .00002    .20000   1.20000   1.94000    .01000 70.00000
.02080    .95600    .00002    .20000   1.20000   1.94000    .01000 70.00000
```

Appendix B

FLOW CHART AND FORTRAN PROGRAM
TO CALCULATE FIRST ORDER VELOCITY
DISTRIBUTION AND TEMPERATURE PROFILE

FLOW CHART FOR DACON 001



```
STRAFLO,P7,T100,CM110000.21036016
RUN(S,,,,,,40000)
LGO.
-
      PROGRAM STRAFLO (INPUT,OUTPUT)
C
C                                D A C O N   0 0 1
C
      DIMENSION D(10),SS(10),L(10),DW(10),SW(10),Z1A(40),TA(40),
     1ZUA(40),UA(40),VA(40),VELA(40),SA(40),SCRATCH(800)
C     THIS PROGRAM DETERMINES THE FLOW VELOCITY AT THE DEPTH OF THE
C     TETHERED SPHERE FROM ITS DEFLECTION
C     PROBE INPUT DATA FOR 10 PROBES
C     DIAMETER OF SPHERE D, SPECIFIC GRAVITY OF SPHERE SS,
C     DIAMETER OF LINE DW, LENGTH OF LINE L, SPECIFIC GRAVITY OF LINE SW,
C     ALL VALUES IN FOOT - SECOND - POUND FORCE
      TYPE REAL L
      READ 2, (D(I), I=1,10)
      READ 2, (SS(I), I=1,10)
      READ 2, (L(I), I=1,10)
      READ 2, (DW(I), I=1,10)
    2 FORMAT (10F6.0)
      READ  17, (SW(I),I=1,10)
   17 FORMAT (10F6.1)
C
C     READ WARM WATER AND COLD WATER REFERENCE TEMPERATURES
      READ 9, WAREF, COREF
    9 FORMAT (2F5.0)
      PRINT 3
    3 FORMAT(1H1,/,10X,*STRATIFIED FLOW EXPERIMENT DATA PROCESSING*,//)
C     INPUT OF EXPERIMENTAL DATA
C     NUMBER OF EXPERIMENT NRN, DENSIMETRIC FROUDE NUMBER DF,
C     ZERO DEPTH READING ZO, ZERO SPHERE DEFLECTION UO,
C     ZERO SPHERE DEFLECTION READING VO, PROBE NUMBER NB,
C     NUMBER OF POINTS ON VERTICAL LINE NP, NUMBER OF POINTS AT WHICH
C     VELOCITY WAS MEASURED NU, X-POSITION OF PROBE TIP X,
C     Y-POSTION OF PROBE TIP Y, DEFLECTION OF SPHERE IN X-DIR. U
C     DEFLECTION OF SPHERE IN Y-DIR. V, TEMPERATURE RANGE TR,
C     TEMPERATURE T
C     TW,TC IN DEGREES FAHRENHEIT
C     ZO,UO,VO,U,V,TR,T, IN FRACTIONS OF VOLT
C     X,Y IN FEET
C     TW WARM WATER TEMPERATURE AT OUTLET, TC COLD WATER TEMPERATURE IN TANK
C     READ 1 CARD AND PROCESS IT A TIME
C     STOP READING WHEN DATA CARD IS BLANC
C     THEREFORE PUT BLANC CARD AT END OF DATA DECK
   71 I=1
   51 READ 8,NRN,DF,ZO,UO,VO,NB,NP,NU,X,Y,Z,U,V,TR,T,TW,TC
    8 FORMAT(I3,4F5.0,3I3,9F5.0)
      GO TO 7
   50 READ 4,NRN,DF,ZO,UO,VO,NB,NP,NU,X,Y,Z,U,V,TR,T
    4 FORMAT(I3,4F5.0,3I3,7F5.0)
    7 IF(NRN)  10,11,10
   10 IF(I-1)  14,15,14
   15 PRINT 5
    5 FORMAT(/,4X,*RUN NO*,8X,*DF*,11X,*X*,11X,*Y*,11X,*Z*,11X,*T*,11X
     1  ,*ZU*,11X,*U*,11X,*V*,11X,*Q*,11X,*S*,/)
      PRINT 6, NRN,DF,X,Y
    6 FORMAT(6X,I3,3F12.2)
C     REAL DEPTH OF PROBE BELOW WATER SURFACE IN FEET
```

```
   14 Z1=.0379*(Z0-Z)
C     REAL TEMPERATURE IN DEGREES FAHRENHEIT
      T =-.97*TR+105.4+.333*T-3.47
C     STORE DATA IN ARRAY
      Z1A(I)=Z1
      TA(I)=T
      IF(I-NU)  12,12,13
C     REAL DEFLECTION OF SPHERE IN FEET
      IF (U  .EQ.  0.) GO TO 99
      IF (V  .EQ.  0.) GO TO 99
   12 U1=-.00374*(U-U0)
      V1=-.00374*(V-V0)
C
C     VELOCITY CALCULATION BY SUBROUTINE VELO ASSUMING UNIFORM VELOCITY
C     AND TEMPERATURE BETWEEN TIP OF PROBE AND SPHERE
      CALL VELO(U1,V1,D(NB),SS(NB),L(NB),DW(NB),SW(NB),T,ZREF,S,VEL)
C
      ZU=Z1-ZREF
      IF (VEL  .EQ.  0.) GO TO 99
      U2=VEL*U1/S
      V2=VEL*V1/S
      GO TO 16
   99 U2=0.  $  V2=0.
C     STORE RESULTS IN ARRAY
   16 ZUA(I)=ZU
      UA(I)=U2
      VA(I)=V2
      VELA(I)=VEL
      SA(I)=S
      GO TO 80
   13 ZUA(I)=0.
      UA(I)=0.
      VA(I)=0.
      VELA(I)=0.
      SA(I)=0.
   80 IF(I-NP)  70,72,70
   70 I=I+1
      GO TO 50
C     END OF DATA CONVERSION
C
C     CORRECTION OF ZU VALUES
   72 IF (ZUA(NU))  81,81,82
   81 DIFF=-ZUA(NU)+.01
      DELZU=DIFF
      DO 83  I=1,NU
   83 ZUA(I)=ZUA(I)+DELZU
C
C     LINEAR ADJUSTMENT OF TEMPERATURE PROFILE TO MATCH
C     COLD WATER AND WARM WATER INPUT REFERENCE TEMPERATURES
   82 COTAV =(TA(1)+TA(2)+TA(3))/3.0
      DISCO=(WAREF-COREF)/(TW-TC)
      DO 60 I=1,NP
   60 TA(I)=COREF+(TA(I)-COTAV)*DISCO
C     PRINTING OF RESULTS
      PRINT 78, (Z1A(I),TA(I),ZUA(I),UA(I),VA(I),VELA(I),SA(I),I=1,NP)
   78 FORMAT (45X,7F12.4,/)
C
C     PRINT TEMPERATURE AND VELOCITY PROFILES USING SUBROUTINE SCLPLT
      CALL SCLPLT (TA,Z1A,NP,60HTEMPERATURE DISTRIBUTION
     1                    ,60HWATER TEMPERATURE IN DEGREES FAHRENHEIT
```

```
     2                      ,60HDEPTH FROM WATER SURFACE IN FEET
     3                    , SCRATCH)
      CALL SCLPLT (VELA,ZUA,NU,60H  VELOCITY DISTRIBUTION
     1                          ,60HTOTAL VELOCITY Q IN FEET PER SECOND
     2                        ,60HDEPTH FROM WATER SURFACE IN FEET
     3                        , SCRATCH)
      CALL SCLPLT (UA,ZUA,NU,60HU=VELOCITY DISTRIBUTION
     1                        ,60HU=VELOCITY COMPONENT OF VELOCITY IN FEET P
     2ER SECOND             ,60HDEPTH FROM WATER SURFACE IN FEET
     3                    , SCRATCH)
      GO TO 71
   11 STOP
      END
C
C     S U B R O U T I N E   V E L O
C
      SUBROUTINE VELO(U1,V1,D,SS,L,DW,SW,T,ZREF,S,VEL)
      TYPE REAL KS,KN, KN1, L, M
      DELTAS=L/20
      RHO=1.94
      S=SQRT(U1**2+V1**2)
      IF (S   .EQ.  0.) GO TO 101
      SL=S/L
      ZS=L-S
      IF(ZS .LE. 0.) GO TO 101
C     APPROXIMATE SLOPE OF CALIBRATION CURVE. VELOCITY/SPHERE DEFLECTION
      VELCO=.25
      VEL=VELCO*SL
  199 VISC=.000019142/(.471101+.0143454*T+.0000682074*T**2)
      RED=VEL*D/VISC
      BR=1.0+3.0*RED/16.0
      CS=24.0*SQRTF(BR)/RED
      DRAGS=CS*3.1415*D**2*VEL**2*RHO/8.
      BUOYS=3.1415*D**3*RHO*32.2*(1.0-SS)/6.0
      SQUA=DRAGS**2+BUOYS**2
      KS=SQRTF(SQUA)
      KN=KS
      M=DW**2*3.1415*DELTAS*RHO*(SW-1.)/4.
      SUM=0
      UREF=0.
      ZREF=0.
      TANAL1=BUOYS/DRAGS
      AL1=ATAN(TANAL1)
      ALN=AL1
      REW=VEL*DW/VISC
      CW=8*3.1415/(2*REW-REW*ALOG(REW))
  111 ALPHA=ALN
  110 DRAGW=CW*DW*DELTAS*(VEL*SIN(ALPHA))**2*RHO/2.
      FUNV=KN*SINF(ALN)-M*32.2-DRAGW*COSF(ALPHA)
      FUNH=KN*COSF(ALN)+DRAGW*SINF(ALPHA)
      FUN=FUNV/FUNH
      ALN1=ATAN(FUN)
      SQ=FUNV**2+FUNH**2
      KN1=SQRTF(SQ)
      ALV=(ALN+ALN1)/2.0
      RAT=(ALV-ALPHA)/ALV
      IF(.001-RAT)  105,105,106
  105 ALPHA=ALV
      GO TO 110
  106 UREF=UREF+DELTAS*COS(ALPHA)
```

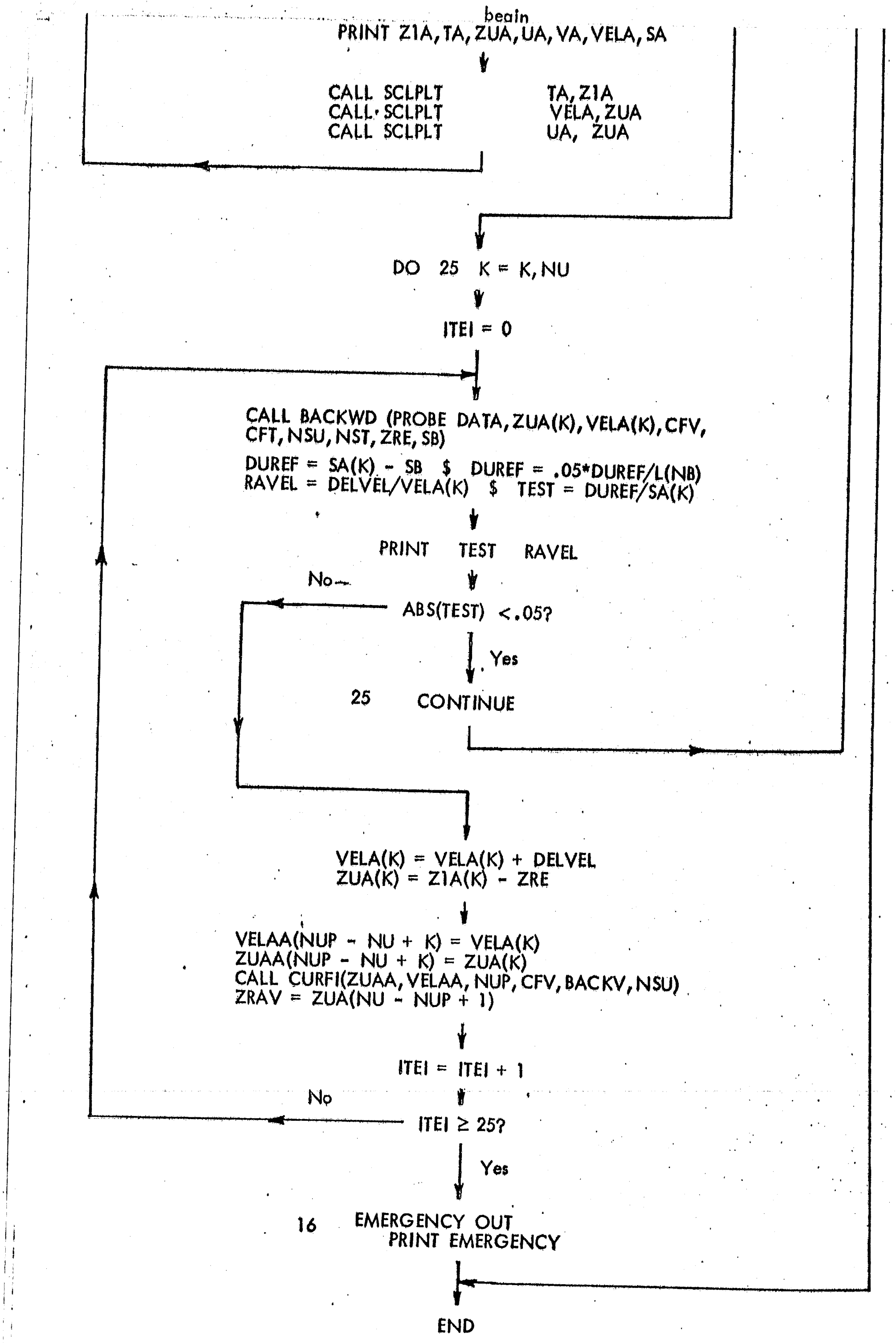
```
      ZREF=ZREF+DELTAS*SIN(ALPHA)
      SUM= SUM + DELTAS
      IF (SUM-L)  112,113,113
  112 KN=KN1
      ALN=ALN1
      GO TO 111
  113 DUREF=S-UREF
      DELVEL=VELCO*DUREF/L
      RAVEL=DELVEL/VEL
      IF (ABS(RAVEL)-.01) 115,115,116
  116 VEL=VEL+DELVEL
      GO TO 199
  101 ZREF=0.
      UREF=0.
      VEL=0.
  115 RETURN
      END

      .00920.0097
      .9150 .9200
      .2354 .2420
      .00001.00001
      1.200 1.200
92.5 73.5
217 4.16 34.5 80.5 42.1 03 22 1111.00-3.00 13.0 81.5 42.6 45.9 51.4 91.8 73.8
217 4.16 34.5 80.5 42.1 03 22 1111.00-3.00 16.0 81.5 42.6 45.9 51.4
217 4.16 34.5 80.5 42.1 03 22 1111.00-3.00 18.0 81.0 42.0 45.9 51.8
217 4.16 34.5 80.5 42.1 03 22 1111.00-3.00 20.0 81.6 41.0 45.9 52.2
217 4.16 34.5 80.5 42.1 03 22 1111.00-3.00 22.0 84.6 37.5 45.9 53.6
217 4.16 34.5 80.5 42.1 03 22 1111.00-3.00 24.0 84.6 37.6 45.9 58.0
217 4.16 34.5 80.5 42.1 03 22 1111.00-3.00 26.0 84.6 40.3 45.9 63.3
217 4.16 34.5 80.5 42.1 03 22 1111.00-3.00 27.0 84.6 42.6 30.8 24.3
217 4.16 34.5 80.5 42.1 03 22 1111.00-3.00 28.0 83.8 43.0 30.8 29.7
217 4.16 34.5 80.5 42.1 03 22 1111.00-3.00 28.5 82.6 43.8 30.8 31.0
217 4.16 34.5 80.5 42.1 03 22 1111.00-3.00 29.0 82.6 43.0 30.8 31.8
217 4.16 34.5 80.5 42.1 03 22 1111.00-3.00 29.5           30.8 32.0
217 4.16 34.5 80.5 42.1 03 22 1111.00-3.00 30.0           30.8 32.5
217 4.16 34.5 80.5 42.1 03 22 1111.00-3.00 30.5           30.8 33.1
217 4.16 34.5 80.5 42.1 03 22 1111.00-3.00 31.0           30.8 33.5
217 4.16 34.5 80.5 42.1 03 22 1111.00-3.00 31.5           30.8 34.1
217 4.16 34.5 80.5 42.1 03 22 1111.00-3.00 32.0           30.8 34.4
217 4.16 34.5 80.5 42.1 03 22 1111.00-3.00 32.5           30.8 34.6
217 4.16 34.5 80.5 42.1 03 22 1111.00-3.00 33.0           30.8 34.9
217 4.16 34.5 80.5 42.1 03 22 1111.00-3.00 33.5           30.8 35.0
217 4.16 34.5 80.5 42.1 03 22 1111.00-3.00 34.0           30.8 35.0
217 4.16 34.5 80.5 42.1 03 22 1111.00-3.00 34.5           30.8 34.9
217 4.10 34.5 80.3 42.2 03 23 1212.50 0.00 13.0 79.4 41.8 45.8 53.6 92.9 74.6
217 4.10 34.5 80.3 42.2 03 23 1212.50 0.00 16.0 79.7 42.7 45.8 53.6
217 4.10 34.5 80.3 42.2 03 23 1212.50 0.00 18.0 80.3 42.8 45.8 53.6
217 4.10 34.5 80.3 42.2 03 23 1212.50 0.00 20.0 79.3 40.5 45.8 53.9
217 4.10 34.5 80.3 42.2 03 23 1212.50 0.00 22.0 72.1 38.8 45.8 54.4
217 4.10 34.5 80.3 42.2 03 23 1212.50 0.00 24.0 64.3 35.9 45.8 56.2
217 4.10 34.5 80.3 42.2 03 23 1212.50 0.00 26.0 50.2 37.9 45.8 66.8
217 4.10 34.5 80.3 42.2 03 23 1212.50 0.00 27.0 45.7 39.7 45.8 68.3
217 4.10 34.5 80.3 42.2 03 23 1212.50 0.00 28.0 44.9 39.3 30.7 27.3
217 4.10 34.5 80.3 42.2 03 23 1212.50 0.00 28.5 44.9 41.7 30.7 30.9
217 4.10 34.5 80.3 42.2 03 23 1212.50 0.00 29.0 44.9 41.7 30.7 33.4
217 4.10 34.5 80.3 42.2 03 23 1212.50 0.00 29.5 44.9 41.7 30.7 34.7
217 4.10 34.5 80.3 42.2 03 23 1212.50 0.00 30.0           30.7 35.6
217 4.10 34.5 80.3 42.2 03 23 1212.50 0.00 30.5           30.7 35.9
```

Appendix C

FLOW CHARTS AND FORTRAN PROGRAMS
TO CALCULATE TEMPERATURE PROFILE AND
HIGHER ORDER VELOCITY PROFILES

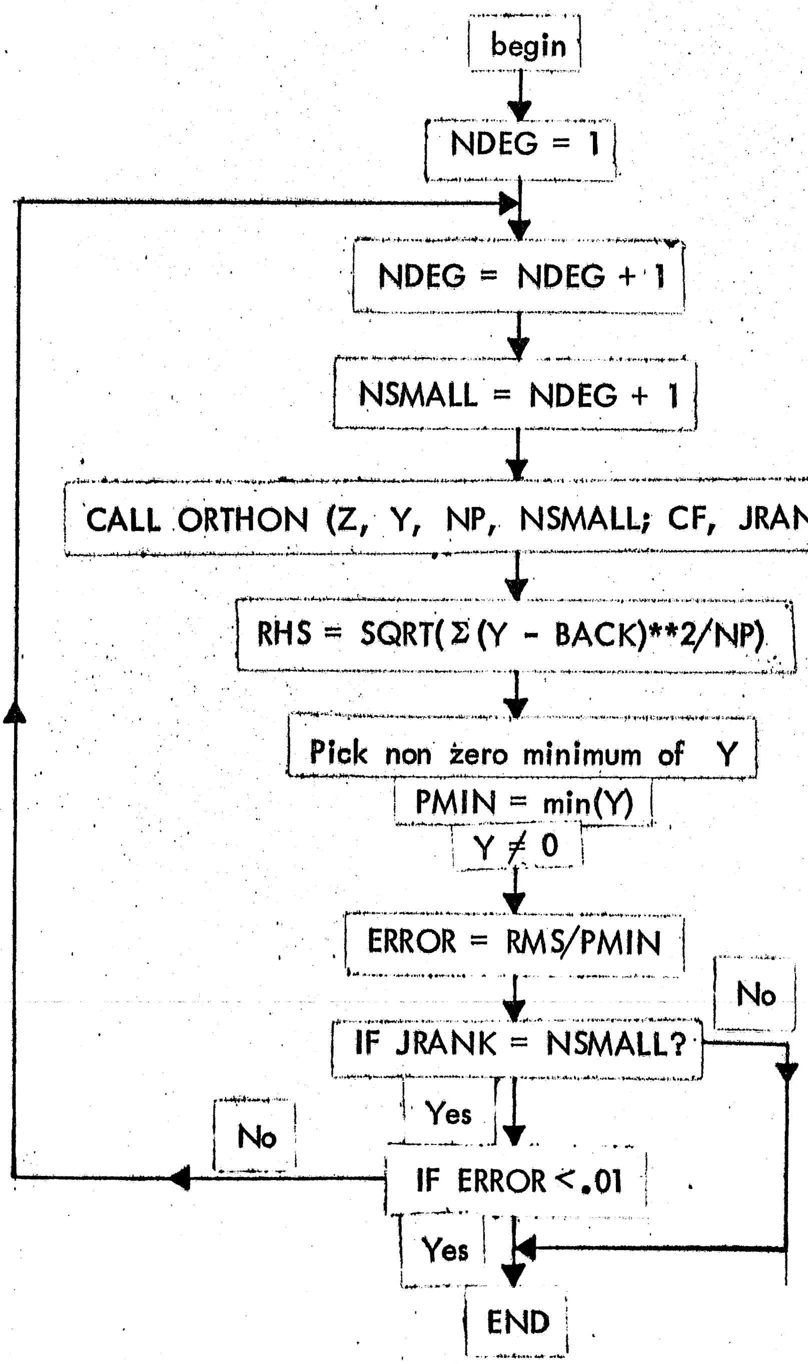
FLOW CHART OF DACON 103R



FLOW CHART OF SUBROUTINE CURFI

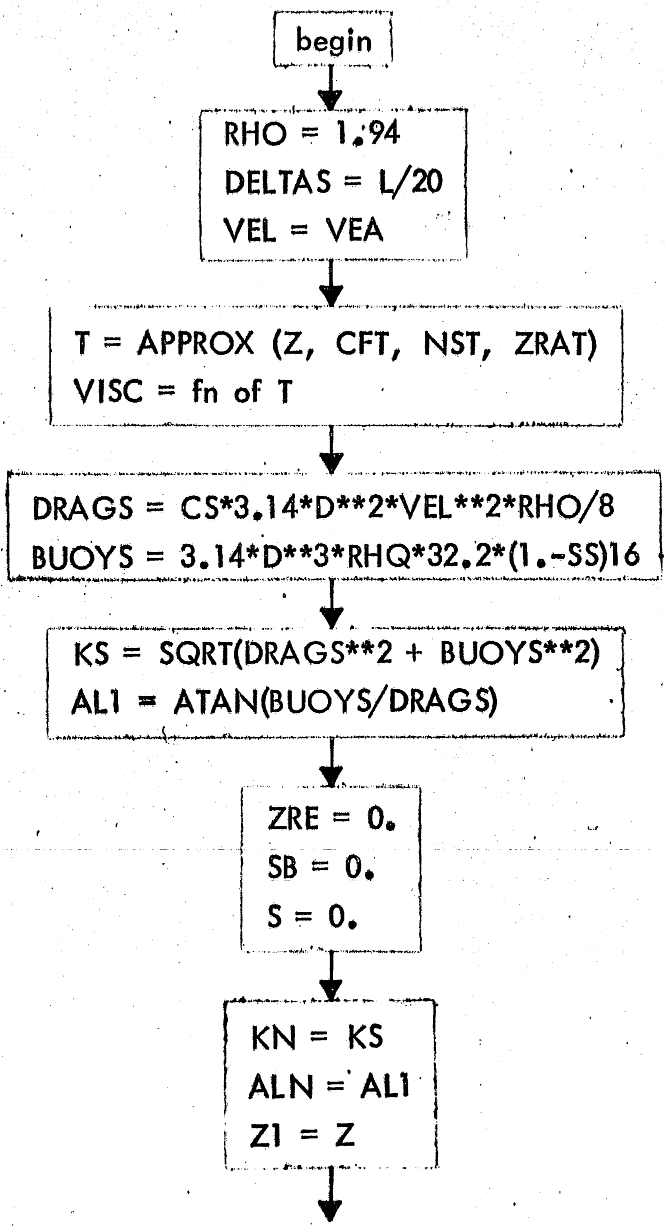
SUBROUTINE CURFI

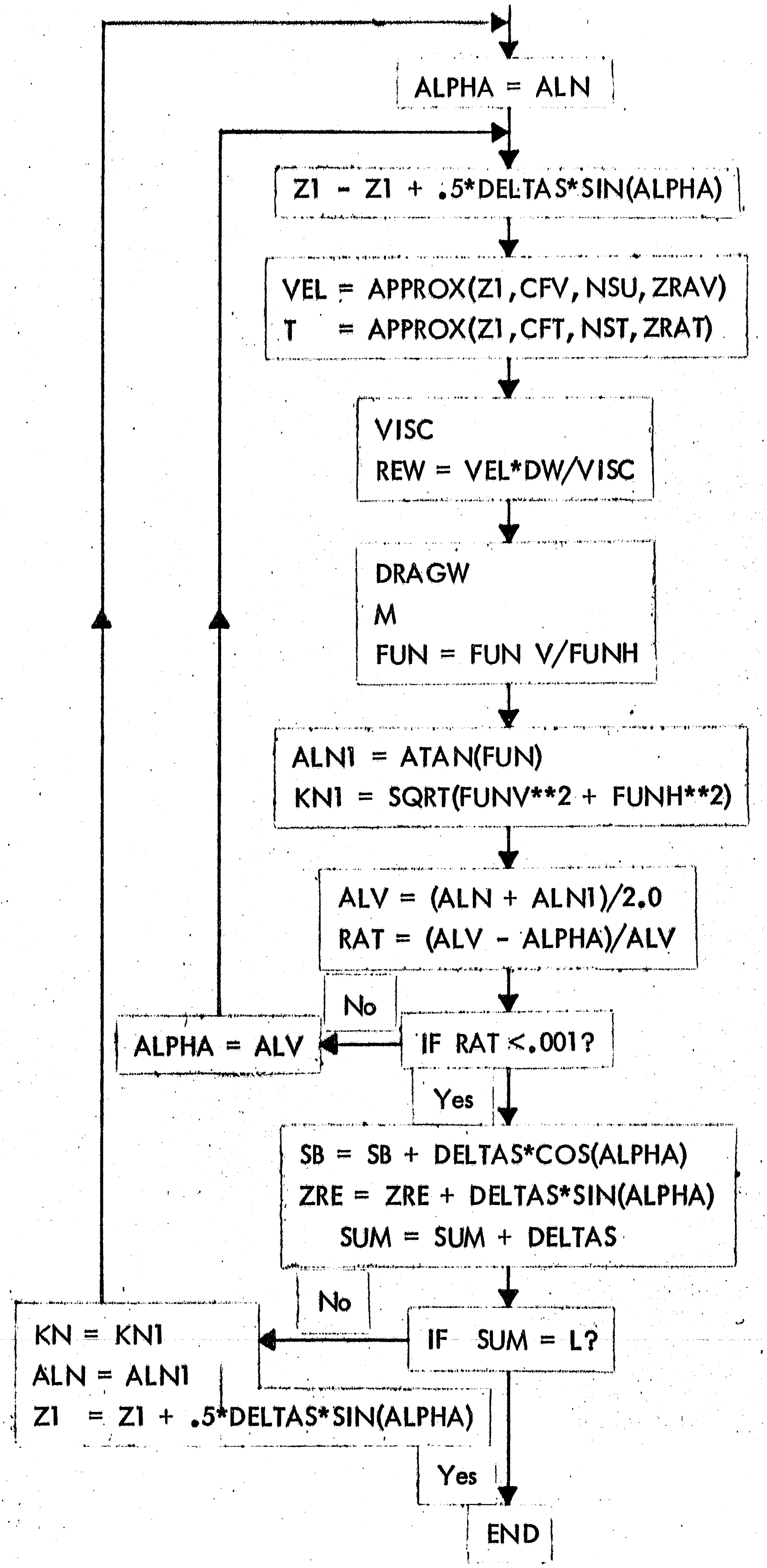
INPUT	Z	INDEP VARIABLE, ARRAY SIZE NP
	Y	OBSERVED VALUE, ARRAY SIZE NP
	NP	NUMBER OF OBSERVATION
OUTPUT	CF	COEFFICIENTS OF POLYNOMIAL, ARRAY SIZE JRANK
	JRANK	NUMBER OF INDEPENDENT POLYNOMIAL USED
	BACK	APPROXIMATED VALUE OF Y



FLOW CHART OF SUBROUTINE BACKWD

INPUT	Probe data, D, L, SS, DW, SW	
	Z	DEPTH AT A SPHERE
	VEA	VELOCITY AT Z
	CFV	COEFFS OF POLYN APPROX OF VELOCITY PROFILE
	NSU	NUMBER OF CFV
	CFT	COEFFS OF POLYN APPROX OF TEMP PROFILE
	NST	NUMBER OF CFT
OUTPUT	ZRE	VERTICAL DEFLECTION OF SPHERE
	SB	HORIZONTAL DEFLECTION OF SPHERE

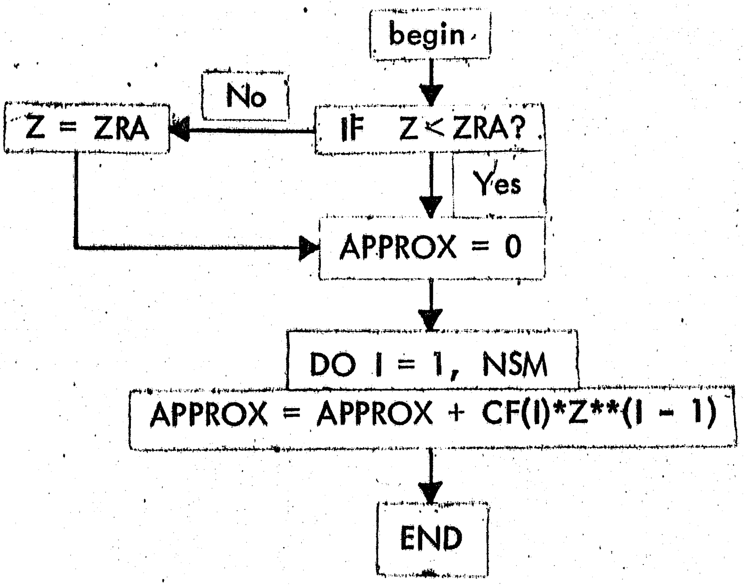




FUNCTION SUBROUTINE APPROX COMPUTES POLYNOMIAL VALUE WITH GIVEN COEFFICIENTS

FLOW CHART OF APPROX

INPUT	Z	
	CF	COEFFS OF POLYN
	NSM	NUMBER OF CF
	ZRA	IF $Z > ZRA$, APPROX = const.
OUTPUT	APPROX	



```
STRAFLO,P7,T100,CM110000,21036016
RUN(S)
LGO.
-
      PROGRAM STRAFLO (INPUT,OUTPUT)
C
C                               D A C O N   1 0 3 R
C
      DIMENSION D(10),SS(10),L(10),DW(10),SW(10),Z1A(40),TA(40),
     1ZUA(40),UA(40),VA(40),VELA(40),SA(40),SCRATCH(800)
      DIMENSION CFT(80),CFV(80),BACKT(80),BACKV(80)
      DIMENSION U1A(40),V1A(40)
      DIMENSION VELAA(40),ZUAA(40)
      COMMON ZRAV,ZRAT
C     THIS PROGRAM FINDS AND PLOTS PROFILES OF HORIZONTAL VELOCITY
C     COMPONENTS AND TEMPERATURES AS FUNCTIONS OF DEPTH. INPUT DATA ARE
C     MEASUREMENTS WITH THE COMBINED TEMPERATURE - VELOCITY PROBE.
    2 FORMAT (10F6.0)
    3 FORMAT(  ///,10X,*STRATIFIED FLOW EXPERIMENT DATA PROCESSING*,//)
    4 FORMAT(I3,4F5.0,3I3,7F5.0)
    5 FORMAT(1H1,//,4X,*RUN NO*,8X,*DF*,11X,*X*,11X,*Y*,11X,*Z*,11X,
     1*T*,11X,*ZU*,11X,*U*,11X,*V*,11X,*Q*,11X,*S*,/)
    6 FORMAT(6X,I3,3F12.2)
   51 FORMAT (///,10X,I3,*ST APPROXIMATION AND APPROXIMATED VALUES BY CU
     1RFI*,//,9X,*Z*,10X,*T*,9X,*BACKT*,10X,*ZU*,10X,*V*,9X,*BACKV*,/)
   52 FORMAT (///,10X,I3,*ND APPROXIMATION AND APPROXIMATED VALUES BY CU
     1RFI*,//,9X,*Z*,10X,*T*,9X,*BACKT*,10X,*ZU*,10X,*V*,9X,*BACKV*,/)
   53 FORMAT (///,10X,I3,*RD APPROXIMATION AND APPROXIMATED VALUES BY CU
     1RFI*,//,9X,*Z*,10X,*T*,9X,*BACKT*,10X,*ZU*,10X,*V*,9X,*BACKV*,/)
   54 FORMAT (///,10X,I3,*TH APPROXIMATION AND APPROXIMATED VALUES BY CU
     1RFI*,//,9X,*Z*,10X,*T*,9X,*BACKT*,10X,*ZU*,10X,*V*,9X,*BACKV*,/)
   93 FORMAT(5F12.4,/)
   91 FORMAT (6F12.4,/)
   92 FORMAT (3F12.4,/)
   61 FORMAT (/,10X,*TEST1=*,F10.6,/)
   62 FORMAT (/,10X,*TEST2=*,F10.6,*   RAVEL=*,F10.6)
   41 FORMAT (45X,7F12.4,/)
   43 FORMAT (45X,2F12.4,/)
   17 FORMAT ( 2X,*THIS SYSTEM DOES NOT CONVERGE*)
C     PROBE INPUT DATA FOR 10 PROBES
C     DIAMETER OF SPHERE D, SPECIFIC GRAVITY OF SPHERE SS,
C     DIAMETER OF LINE DW, LENGTH OF LINE L, SPECIFIC GRAVITY OF LINE SW,
C     ALL VALUES IN FOOT - SECOND - POUND FORCE
      TYPE REAL L
      READ 2, (D(I), I=1,10)
      READ 2, (SS(I), I=1,10)
      READ 2, (L(I), I=1,10)
      READ 2, (DW(I), I=1,10)
      READ 2,(SW(I),I=1,10)
C     PRINT HEADING
      PRINT 3
C     INPUT OF EXPERIMENTAL DATA
C     NUMBER OF EXPERIMENT NRN, DENSIMETRIC FROUDE NUMBER DF,
C     ZERO DEPTH READING ZO, ZERO SPHERE DEFLECTION READING UO,
C     ZERO SPHERE DEFLECTION READING VO, PROBE NUMBER NB,
C     NUMBER OF POINTS ON VERTICAL LINE NP, NUMBER OF POINTS AT WHICH
C     VELOCITY WAS MEASURED NU, X-POSITION OF PROBE TIP X,
C     Y-POSTION OF PROBE TIP Y, DEFLECTION OF SPHERE IN X-DIR. U
C     DEFLECTION OF SPHERE IN Y-DIR. V, TEMPERATURE RANGE TR,
C     TEMPERATURE T
```

```
C     ZO,UO,VO,U,V,TR,T, IN FRACTIONS OF VOLT
C     X,Y IN FEET
C     READ 1 CARD AND PROCESS IT A TIME
C     STOP READING WHEN DATA CARD IS BLANC
C     THEREFORE PUT BLANC CARD AT END OF DATA DECK
   71 I=1
   50 READ 4,NRN,DF,ZO,UO,VO,NB,NP,NU,X,Y,Z,U,V,TR,T
      IF(NRN)  10,11,10
C     REAL DEPTH OF PROBE TIP BELOW WATER SURFACE IN FEET
   10 Z1=.0379*(ZO-Z)
C     REAL TEMPERATURE AT PROBE TIP IN DEGREES FAHRENHEIT
      T =-.97*TR+105.4+.333*T-3.47
C     STORE DATA IN ARRAY
      Z1A(I)=Z1
      TA(I)=T
      IF(I-NU)  12,12,13
C     REAL DEFLECTION OF SPHERE IN FEET
   12 U1=-.00374*(U-UO)
      V1=-.00374*(V-VO)
C
C     VELOCITY CALCULATION BY SUBROUTINE VELO ASSUMING UNIFORM VELOCITY
C     AND TEMPERATURE BETWEEN TIP OF PROBE AND SPHERE
      CALL VELO(U1,V1,D(NB),SS(NB),L(NB),DW(NB),SW(NB),T,ZREF,S,VEL)
      ZU=Z1-ZREF
      U2=VEL*U1/S
      V2=VEL*V1/S
      ZUA(I)=ZU
      UA(I)=U2
      VA(I)=V2
      VELA(I)=VEL
      SA(I)=S
      U1A(I)=U1
      V1A(I)=V1
   13 IF(I-NP)  70,72,70
   70 I=I+1
      GO TO 50
   72 PRINT 5
      PRINT 6,NRN,DF,X,Y
C     END OF DATA CONVERSION FOR FIRST APPROXIMATION
C
C     CALL SOUBROUTINE CURFI WITH TEMP DATA
      ZRAT=Z1A(1)
      CALL CURFI (Z1A,TA,NP,CFT,BACKT,NST)
C     THROW OUT SMALL VELAS  .LE.  .005FPS
      I=1
   99 IF (VELA(I)-.005) 96,96,97
   96 IF (I-NU) 98,44,98
   98 I=I+1
      GO TO 99
C     CALL SUBROUTINE CURFI WITH TRUNCATED DATA
   97 NUP=NU-I+1
      ITE=0
   30 DO 35 I=1,NUP
      VELAA(I)=VELA(NU-NUP+I)
   35 ZUAA(I)=ZUA(NU-NUP+I)
      CALL CURFI (ZUAA,VELAA,NUP,CFV,BACKV,NSU)
      DO 36 I=1,NUP
   36 BACKV(NU+1-I)=BACKV(NUP+1-I)
      NUPR=NU-NUP
      NUPR1=NUPR+1
```

```
      ITE=ITE+1
      IF (ITE  .GE.  10) GO TO 16
C     PRINT APPROXIMATED VALUES BY CURFI
      GO TO (31,32,33,34,34,34,34,34,34),ITE
   31 PRINT 51,ITE
      GO TO 90
   32 PRINT 52,ITE
      GO TO 90
   33 PRINT 53,ITE
      GO TO 90
   34 PRINT 54,ITE
   90 PRINT 93,(Z1A(I),TA(I),BACKT(I),ZUA(I),VELA(I),I=1,NUPR)
      PRINT 91,(Z1A(I),TA(I),BACKT(I),ZUA(I),VELA(I),BACKV(I),I=NUPR1,NU
     1)
      NU1=NU+1
      PRINT 92, (Z1A(I),TA(I),BACKT(I),I=NU1,NP)
C
C     TEST BY BACKWD. IF ALL DATA PASS TEST GO TO OUTPUT. OTHERWISE MAKE
C     CORRECTION STARTING WITH STATEMENT 21
      ZRAV=ZUA(NU-NUP+1)
      K=NU-NUP+1
   22 CALL BACKWD (D(NB),L(NB),SS(NB),DW(NB),SW(NB),ZUA(K),CFV,NSU,CFT,
     1 NST,VELA(K),ZRE,SB)
      DUREF=SA(K)-SB
      DELVEL=.05*DUREF/L(NB)
      TEST=DUREF/SA(K)
      PRINT 61,TEST
      IF (ABS(TEST)-.05) 20,20,21
   20 IF (K-NU) 23,24,23
   23 K=K+1
      GO TO 22
C
C     MAKE CORRECTION
   21 DO 25 K=K,NU
      ITEI=0
   27 CALL BACKWD (D(NB),L(NB),SS(NB),DW(NB),SW(NB),ZUA(K),CFV,NSU,CFT,
     1 NST,VELA(K),ZRE,SB)
      DUREF=SA(K)-SB
      DELVEL=.05*DUREF/L(NB)
      TEST=DUREF/SA(K)
      RAVEL=DELVEL/VELA(K)
      PRINT 62,TEST ,RAVEL
      IF (ABS(TEST)-.05) 25,25,26
   26 VELA(K)=VELA(K)+DELVEL
      ZUA(K)=Z1A(K)-ZRE
      VELAA(NUP-NU+K)=VELA(K)
      ZUAA(NUP-NU+K)=ZUA(K)
      CALL CURFI(ZUAA,VELAA,NUP,CFV,BACKV,NSU)
      ZRAV=ZUA(NU-NUP+1)
      ITEI=ITEI+1
      IF (ITEI  .GE.  25) GO TO 16
      GO TO 27
   25 CONTINUE
      GO TO 30
C
C     IF ZUA(NU) IS NEGATIVE ADJUST TO 0.01
   24 IF(ZUA(NU)) 84,84,85
   84 DIFF=-ZUA(NU)+.01
      DELZU=DIFF
      DO 86 I=1,NU
```

```
   86 ZUA(I)=ZUA(I)+DELZU
C
C     CALCULATE X AND Y COMPONENTS AND PRINT FINAL RESULTS
   85 DO 42 K=1,NU
      UA(K)=VELA(K)*U1A(K)/SA(K)
   42 VA(K)=VELA(K)*V1A(K)/SA(K)
      PRINT 5
      PRINT 6,NRN,DF,X,Y
   44 PRINT 41, (Z1A(I),TA(I),ZUA(I),UA(I),VA(I),VELA(I),SA(I),I=1,NU)
      PRINT 43,(Z1A(I),TA(I),I=NU1,NP)
C
C     PRINT TEMPERATURE AND VELOCITY PROFILES USING SUBROUTINE SCLPLT
      CALL SCLPLT (TA,Z1A,NP,60HTEMPERATURE DISTRIBUTION
     1                     ,60HWATER TEMPERATURE IN DEGREES FAHRENHEIT
     2                   ,60HDEPTH FROM WATER SURFACE IN FEET
     3                 , SCRATCH)
      CALL SCLPLT (VELA,ZUA,NU,60H  VELOCITY DISTRIBUTION
     1                       ,60HTOTAL VELOCITY Q IN FEET PER SECOND
     2                     ,60HDEPTH FROM WATER SURFACE IN FEET
     3                   , SCRATCH)
      CALL SCLPLT (UA,ZUA,NU,60HU=VELOCITY DISTRIBUTION
     1                     ,60HU=VELOCITY COMPONENT OF VELOCITY IN FEET P
     2ER SECOND          ,60HDEPTH FROM WATER SURFACE IN FEET
     3                 , SCRATCH)
      GO TO 71
   16 PRINT 17
   11 STOP
      END
C
C
C     S U B R O U T I N E   V E L O
C
      SUBROUTINE VELO(U1,V1,D,SS,L,DW,SW,T,ZREF,S,VEL)
      TYPE REAL KS,KN, KN1, L, M
      DELTAS=L/20.
      RHO=1.94
      S=SQRT(U1**2+V1**2)
      SL=S/L
      ZS=L-S
      IF(ZS .LE. 0.) GO TO 101
      VELCO=.25
      VEL=VELCO*SL
  199 VISC=.000019142/(.471101+.0143454*T+.0000682074*T**2)
      RED=VEL*D/VISC
      BR=1.0+3.0*RED/16.0
      CS=24.0*SQRTF(BR)/RED
      DRAGS=CS*3.1415*D**2*VEL**2*RHO/8.
      BUOYS=3.1415*D**3*RHO*32.2*(1.0-SS)/6.0
      SQUA=DRAGS**2+BUOYS**2
      KS=SQRTF(SQUA)
      KN=KS
      M=DW**2*3.1415*DELTAS*RHO*(SW-1.)/4.
      SUM=0
      UREF=0.
      ZREF=0.
      TANAL1=BUOYS/DRAGS
      AL1=ATAN(TANAL1)
      ALN=AL1
      REW=VEL*DW/VISC
      CW=8*3.1415/(2*REW-REW*ALOG(REW))
```

```
  111 ALPHA=ALN
  110 DRAGW=CW*DW*DELTAS*(VEL*SIN(ALPHA))**2*RHO/2.
      FUNV=KN*SINF(ALN)-M*32.2-DRAGW*COSF(ALPHA)
      FUNH=KN*COSF(ALN)+DRAGW*SINF(ALPHA)
      FUN=FUNV/FUNH
      ALN1=ATAN(FUN)
      SQ=FUNV**2+FUNH**2
      KN1=SQRTF(SQ)
      ALV=(ALN+ALN1)/2.0
      RAT=(ALV-ALPHA)/ALV
      IF(.001-RAT)  105,105,106
  105 ALPHA=ALV
      GO TO 110
  106 UREF=UREF+DELTAS*COS(ALPHA)
      ZREF=ZREF+DELTAS*SIN(ALPHA)
      SUM= SUM + DELTAS
      IF (SUM-L)  112,113,113
  112 KN=KN1
      ALN=ALN1
      GO TO 111
  113 DUREF=S-UREF
      DELVEL=VELCO*DUREF/L
      RAVEL=DELVEL/VEL
      IF (ABS(RAVEL)-.01) 115,115,116
  116 VEL=VEL+DELVEL
      GO TO 199
  101 ZREF=0.
      UREF=0.
      VEL=0.
  115 RETURN
      END
C
C     S U B R O U T I N E   C U R F I
C
      SUBROUTINE CURFI(Z,Y,NP,CF,BACK,JRANK)
      DIMENSION PHI(80,40),Z(80),Y(80),W(80),SEC(40),CF(80),DELTAS(80),
     1 BACK(80)
      EXTERNAL FPOLF
C     DATA ARE SUPPOSED TO HAVE EQUAL WEIGHT
      DO 201 I=1,80
  201 W(I)=1.
C     STARTING POLYNOMIAL TO BE USED IS OF SECOND DEGREE
      NDEG=1
  203 NDEG=NDEG+1
      NSMALL=NDEG+1
      CALL ORTHON (FPOLF,PHI,80,Z,Y,W,NP,0,NSMALL,CF,SEC,BACK,DELTAS,
     1 1.E-8,JRANK)
      RMS=SQRT(DELTAS(NP+1)/FLOAT(NP))
C     PICK NONZERO MINIMUM OF DATA
      I=1
  213 IF (Y(I)  .NE.  0.) GO TO 212
      I=I+1
      GO TO 213
  212 PMIN =Y(I)
  214 I=I+1
      IF (Y(I)  .EQ.  0.) GO TO 215
      IF (PMIN  .GT.  Y(I)) PMIN=Y(I)
  215 IF (I  .NE.  NP) GO TO 214
C     DEFINE ERROR
      ERROR=RMS/PMIN
```

```
      IF (JRANK  .NE.  NSMALL) GO TO 202
      IF (ERROR  .GT.  .01) GO TO 203
  202 PRINT 204,JRANK,ERROR
  204 FORMAT (  15X,*JRANK=*,I5,8X,*RELATIVE ERROR=*,F12.6)
      RETURN
      END
      FUNCTION FPOLF(X,LL)
      IF (X) 501,500,501
  500 IF (LL-1) 503,504,503
  504 FPOLF=1.
      GO TO 502
  503 FPOLF=0.
      GO TO 502
  501 FPOLF=X**(LL-1)
  502 RETURN
      END
C
C     S U B R O U T I N E   B A C K W D
C
      SUBROUTINE BACKWD (D,L,SS,DW,SW,Z,CFV,NSU,CFT,NST,VEA,ZRE,SB)
C     THIS SUBROUTINE COMPUTES TOTAL DEFLECTION AND ZREF OF A SPHERE WITH AN
C     GIVEN VELOCITY AT THE SPHERE AND GIVEN VELOCITY PROFILE TO CALCULATE D
C     ON WIRE
C     D,L,SS,DW,SW, ARE PROBE DATA,  Z GIVEN DEPTH OF A SPHERE
C     CFV  COEF,S OF POLYN. APPROX. OF VELOCITY PROFILE,  NSU  NUMBER OF CFV
C     CFT  COEF,S OF POLYN. APPROX. OF TEMP PROFILE,  NST  NUMBER OF CFT,
C     VEA  ANY GIVEN VELOCITY AT Z,  ZRE  OUTPUT ZREF,  SB  OUTPUT  S
      DIMENSION CFV(80),CFT(80)
      COMMON ZRAV,ZRAT
      TYPE REAL L,KS,KN,KN1
      RHO=1.94
      DELTAS=L/20.
      VEL=VEA
      T=APPROX(Z,CFT,NST,ZRAT)
      VISC=.000019142/(.471101+.0143454*T+.0000682074*T**2)
      RED=VEL*D/VISC
      RED=ABS(RED)
      CS =24./RED*SQRT(1.+3./16.*RED)
      DRAGS=CS*3.1415*D**2*VEL**2*RHO/8.*SIGN(1.,VEL)
      BUOYS=3.1415*D**3*RHO*32.2*(1.-SS)/6.
      SQUA=DRAGS**2+BUOYS**2
      KS=SQRT(SQUA)
      KN=KS
      M=DW**2*3.1415*DELTAS*RHO*(SW-1.)/4.
      TANAL1=BUOYS/DRAGS
      AL1=ATAN(TANAL1)
      ALN=AL1
      ZRE=0.
      SB  =0.
      SUM=0.
      Z1=Z
  311 ALPHA=ALN
  310 Z1=Z1+.5*DELTAS*SIN(ALPHA)
      VEL=APPROX(Z1,CFV,NSU,ZRAV)
      T=APPROX(Z1,CFT,NST,ZRAT)
      VISC=.000019142/(.471101+.0143454*T+.0000682074*T**2)
      REW=VEL*DW/VISC
      REW=ABS(REW)
      CW=8.*3.1415/(2.*REW-REW*ALOG(REW))
      DRAGW=CW*DW*DELTAS*(VEL*SIN(ALPHA))**2*RHO/2.*SIGN(1.,VEL)
```

```
      FUNV=KN*SINF(ALN)-M*32.2-DRAGW*COSF(ALPHA)
      FUNH=KN*COSF(ALN)+DRAGW*SINF(ALPHA)
      FUN=FUNV/FUNH
      ALN1=ATAN(FUN)
      SQ=FUNV**2+FUNH**2
      KN1=SQRTF(SQ)
      ALV=(ALN+ALN1)/2.0
      RAT=(ALV-ALPHA)/ALV
      IF (.001-RAT) 305,305,306
  305 ALPHA=ALV
      GO TO 310
  306 SB   =SB   +DELTAS*COS(ALPHA)
      ZRE =ZRE +DELTAS*SIN(ALPHA)
      SUM=SUM+DELTAS
      IF(SUM-L)  312,313,313
  312 KN=KN1
      ALN=ALN1
      Z1   =Z1   +.5*DELTAS*SIN(ALPHA)
      GO TO 311
  313 RETURN
      END
C
C     F U N C T I O N   A P P R O X
C
      FUNCTION APPROX(Z ,CF, NSM, ZRA)
      DIMENSION CF(80)
      IF (Z-ZRA)  402,402,403
  403 Z=ZRA
  402 APPROX=0.
      DO 401 I=1,NSM
      A=CF(I)*Z**(I-1)
  401 APPROX=APPROX+A
      RETURN
      END

      .00920.0097
      .9150 .9200
      .2354 .2420
      .00001.00001
      1.200 1.200
207 1.40 34.6 64.5 46.1 03 27 15 0.50 0.50 17.0 64.5 46.6 62.1 28.1
207 1.40 34.6 64.5 46.1 03 27 15 0.50 0.50 19.0 64.7 45.8 62.1 28.1
207 1.40 34.6 64.5 46.1 03 27 15 0.50 0.50 20.0 65.2 45.8 62.1 28.1
207 1.40 34.6 64.5 46.1 03 27 15 0.50 0.50 21.0 65.7 45.5 62.1 28.1
207 1.40 34.6 64.5 46.1 03 27 15 0.50 0.50 22.0 66.0 45.6 62.1 28.2
207 1.40 34.6 64.5 46.1 03 27 15 0.50 0.50 23.0 66.6 45.5 62.1 28.1
207 1.40 34.6 64.5 46.1 03 27 15 0.50 0.50 24.0 66.5 44.5 62.1 28.2
207 1.40 34.6 64.5 46.1 03 27 15 0.50 0.50 25.0 67.2 43.9 62.1 28.4
207 1.40 34.6 64.5 46.1 03 27 15 0.50 0.50 26.0 67.1 43.3 62.1 28.4
207 1.40 34.6 64.5 46.1 03 27 15 0.50 0.50 27.0 66.8 42.8 62.1 28.6
207 1.40 34.6 64.5 46.1 03 27 15 0.50 0.50 27.5 65.4 41.6 62.1 28.8
207 1.40 34.6 64.5 46.1 03 27 15 0.50 0.50 28.0 64.4 40.6 62.1 28.8
207 1.40 34.6 64.5 46.1 03 27 15 0.50 0.50 28.5 60.1 45.0 62.1 28.8
207 1.40 34.6 64.5 46.1 03 27 15 0.50 0.50 29.0 57.2 52.0 62.1 28.8
207 1.40 34.6 64.5 46.1 03 27 15 0.50 0.50 29.5 56.7 59.5 62.1 29.2
207 1.40 34.6 64.5 46.1 03 27 15 0.50 0.50 30.0           62.1 29.5
207 1.40 34.6 64.5 46.1 03 27 15 0.50 0.50 30.5           62.1 30.5
207 1.40 34.6 64.5 46.1 03 27 15 0.50 0.50 31.0           62.1 31.4
207 1.40 34.6 64.5 46.1 03 27 15 0.50 0.50 31.5           62.1 37.7
207 1.40 34.6 64.5 46.1 03 27 15 0.50 0.50 31.8           62.1 41.1
```

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207 1.40 34.6 64.5 46.1 03 27 15 0.50 0.50 32.2           62.1 50.6
207 1.40 34.6 64.5 46.1 03 27 15 0.50 0.50 32.6           62.1 57.6
207 1.40 34.6 64.5 46.1 03 27 15 0.50 0.50 33.0           62.1 64.3
207 1.40 34.6 64.5 46.1 03 27 15 0.50 0.50 33.4           46.9 27.7
207 1.40 34.6 64.5 46.1 03 27 15 0.50 0.50 33.8           46.9 34.0
207 1.40 34.6 64.5 46.1 03 27 15 0.50 0.50 34.2           46.9 35.1
207 1.40 34.6 64.5 46.1 03 27 15 0.50 0.50 34.6           46.9 44.1
207 1.40 34.6 64.5 46.1 03 22 13 0.50-0.50 21.0 65.3 45.4 62.1 28.2
207 1.40 34.6 64.5 46.1 03 22 13 0.50-0.50 22.0 66.1 47.2 62.1 28.3
207 1.40 34.6 64.5 46.1 03 22 13 0.50-0.50 23.0 66.2 47.6 62.1 28.3
207 1.40 34.6 64.5 46.1 03 22 13 0.50-0.50 24.0 66.5 48.0 62.1 28.4
207 1.40 34.6 64.5 46.1 03 22 13 0.50-0.50 25.0 66.7 48.9 62.1 28.4
207 1.40 34.6 64.5 46.1 03 22 13 0.50-0.50 26.0 67.0 48.8 62.1 28.5
207 1.40 34.6 64.5 46.1 03 22 13 0.50-0.50 27.0 67.1 50.1 62.1 28.5
207 1.40 34.6 64.5 46.1 03 22 13 0.50-0.50 28.0 62.5 48.6 62.1 28.6
207 1.40 34.6 64.5 46.1 03 22 13 0.50-0.50 29.0 54.2 36.7 62.1 28.7
207 1.40 34.6 64.5 46.1 03 22 13 0.50-0.50 29.5 53.4 31.6 62.1 28.8
207 1.40 34.6 64.5 46.1 03 22 13 0.50-0.50 30.0 53.4 27.4 62.1 29.2
207 1.40 34.6 64.5 46.1 03 22 13 0.50-0.50 30.5 45.8 19.5 62.1 30.3
207 1.40 34.6 64.5 46.1 03 22 13 0.50-0.50 31.0 47.9 14.7 62.1 30.9
207 1.40 34.6 64.5 46.1 03 22 13 0.50-0.50 31.5           62.1 32.7
207 1.40 34.6 64.5 46.1 03 22 13 0.50-0.50 32.0           62.1 37.2
207 1.40 34.6 64.5 46.1 03 22 13 0.50-0.50 32.5           62.1 44.9
207 1.40 34.6 64.5 46.1 03 22 13 0.50-0.50 33.0           62.1 50.1
207 1.40 34.6 64.5 46.1 03 22 13 0.50-0.50 33.2           62.1 64.3
207 1.40 34.6 64.5 46.1 03 22 13 0.50-0.50 33.5           62.1 62.7
207 1.40 34.6 64.5 46.1 03 22 13 0.50-0.50 33.8           46.9 26.8
207 1.40 34.6 64.5 46.1 03 22 13 0.50-0.50 34.3           46.9 33.6
207 1.40 34.6 64.5 46.1 03 22 13 0.50-0.50 34.6           46.9 41.8
207 1.40 34.6 64.5 46.1 03 26 12 0.50-1.00 18.0 65.6 45.8 62.1 28.4
207 1.40 34.6 64.5 46.1 03 26 12 0.50-1.00 20.0 65.7 45.8 62.1 28.5
207 1.40 34.6 64.5 46.1 03 26 12 0.50-1.00 22.0 66.4 46.3 62.1 28.5
207 1.40 34.6 64.5 46.1 03 26 12 0.50-1.00 24.0 67.0 46.3 62.1 28.5
207 1.40 34.6 64.5 46.1 03 26 12 0.50-1.00 25.0 66.9 46.3 62.1 28.5
207 1.40 34.6 64.5 46.1 03 26 12 0.50-1.00 26.0 67.2 47.1 62.1 28.6
207 1.40 34.6 64.5 46.1 03 26 12 0.50-1.00 27.0 67.2 48.4 62.1 28.7
207 1.40 34.6 64.5 46.1 03 26 12 0.50-1.00 27.5 67.2 48.8 62.1 28.8
207 1.40 34.6 64.5 46.1 03 26 12 0.50-1.00 29.0 68.0 47.3 62.1 29.0
207 1.40 34.6 64.5 46.1 03 26 12 0.50-1.00 28.0 67.1 49.4 62.1 28.8
207 1.40 34.6 64.5 46.1 03 26 12 0.50-1.00 28.5 67.7 48.9 62.1 29.0
207 1.40 34.6 64.5 46.1 03 26 12 0.50-1.00 29.2 68.0 47.5 62.1 29.3
207 1.40 34.6 64.5 46.1 03 26 12 0.50-1.00 29.5           62.1 29.4
207 1.40 34.6 64.5 46.1 03 26 12 0.50-1.00 30.0           62.1 30.1
207 1.40 34.6 64.5 46.1 03 26 12 0.50-1.00 30.5           62.1 31.5
207 1.40 34.6 64.5 46.1 03 26 12 0.50-1.00 31.0           62.1 33.5
207 1.40 34.6 64.5 46.1 03 26 12 0.50-1.00 31.5           62.1 33.0
207 1.40 34.6 64.5 46.1 03 26 12 0.50-1.00 31.8           62.1 39.5
207 1.40 34.6 64.5 46.1 03 26 12 0.50-1.00 32.1           62.1 43.5
207 1.40 34.6 64.5 46.1 03 26 12 0.50-1.00 32.4           62.1 47.3
207 1.40 34.6 64.5 46.1 03 26 12 0.50-1.00 32.8           62.1 53.3
207 1.40 34.6 64.5 46.1 03 26 12 0.50-1.00 33.2           62.1 59.2
207 1.40 34.6 64.5 46.1 03 26 12 0.50-1.00 33.5           62.1 63.3
207 1.40 34.6 64.5 46.1 03 26 12 0.50-1.00 33.9           46.9 23.2
207 1.40 34.6 64.5 46.1 03 26 12 0.50-1.00 34.5           46.9 27.3
207 1.40 34.6 64.5 46.1 03 26 12 0.50-1.00 34.6           46.9 32.8
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List of Parameters Used in Main Program DACON 103

D	Input, Array size 10 Diameters of spheres in feet. Decimal point be placed any column in a field.	Field	10F6.0
SS	Input, Array size 10 Specific gravities of spheres of probes. Decimal point be placed any column in a field.	Field	10F6.0
L	Real Input, Array size 10 Lengths of wire plus radius of spheres of probes in feet. Decimal point be placed any column in a field.	Field	10F6.0
DW	Input, Array size 10 Diameters of wires of probes in feet. Decimal point be placed any column in a field.	Field	10F6.0
SW	Input, Array size 10 Specific gravities of wires of probes. Decimal point be placed any column in a field.	Field	10F6.0
NRN	Input Run no.	Field	I3
DF	Input Densimetric Froude number. Decimal point be placed any column in a field.	Field	F5.0
ZO	Input Zero reading of probe tip. Decimal point be placed any column in a field.	Field	F5.0
UO	Input Zero reading of sphere deflection x-component. Decimal point be placed any column in a field.	Field	F5.0
VO	Input Zero reading of sphere deflection y-component. Decimal point be placed any column in a field.	Field	F5.0
NB	Input Probe number.	Field	I3
NP	Input Number of points where temperature measurement is taken at this vertical line.	Field	I3
NU	Input Number of points where both temperature and velocity measurements are taken.	Field	I3

X	Input X-position of probe tip in feet. Decimal point be placed any column in a field. Ex.	Field -2.50	F5.0 12.25
Y	Input Y-position of probe tip in feet. Decimal point be placed any column in a field.	Field	F5.0
Z	Input Reading of probe tip depth where this measurement is taken. Decimal point be placed any column in a field.	Field	F5.0
U	Input Reading of sphere deflection in x-direction. Decimal point be placed any column in a field.	Field	F5.0
V	Input Reading of sphere deflection in y-direction. Decimal point be placed any column in a field.	Field	F5.0
TR	Input Reading of temperature range. Decimal point be placed any column in a field.	Field	F5.0
T	Input Reading of temperature. Decimal point be placed any column in a field.	Field	F5.0
Z1	Probe tip depth in feet.		
T	After conversion, measured temperature in Fahrenheit.		
Z1A	Array size NP Probe tip depth in feet.		
TA	Array size NP Real temperature in Fahrenheit at Z1A.		
U1	X-component sphere deflection in feet.		
V1	Y-component sphere deflection in feet.		
ZRAT	The deepest (largest) depth of Z1A below which temperature is assumed unchanged in using polynomial approximation.		
CFT	Output of subroutine CURFI, Array size NST Coefficients of least square polynomial approximation of temperature measurements.		
BACKT	Output of subroutine CURFI, Array size NP Approximated temperatures by subroutine CURFI at NP points where measurements are taken in Fahrenheit.		

NST	Output of subroutine CURFI. Degree of polynomial to be used for least square approximation plus one.
NUP	Number of velocity measurements where velocity exceeds 0.005 fps.
ITE	Number of approximation. If this number exceeds nine, control is transferred to EMERGENCY OUT.
VELAA	Array size NUP. Total velocity data greater than 0.005 fps. In fps.
ZUAA	Array size NUP. Depth of a sphere where velocity which is greater than 0.005 fps is measured.
CFV	Output of subroutine CURFI. Array size NSU. Coefficients of least square polynomial approximation of velocity measurements.
ZREF	Vertical deflection of sphere in feet as an output of subroutine VELO. In other words, z-component of distance in feet between a sphere and a probe tip.
S	Total sphere deflection in feet, output of VELO.
VEL	Output of subroutine VELO. First approximation of velocity conversion. Total velocity at the sphere where measurement is taken in feet per second.
ZU	Depth of a sphere below water surface in feet. First approximation.
U2	First approximation of x-component of velocity in feet per second.
V2	First approximation of y-component of velocity in feet per second.
ZUA	Array size NU. Depth of a sphere below water surface in feet where measurements are taken.
UA	Array size NU. X-component of velocity in feet per second.
VA	Array size NU. Y-component of velocity in feet per second.
VELA	Array size NU. Total velocity in feet per second.
SA	Array size NU. Total sphere deflection in feet.
U1A	Array size NU. X-component of sphere deflection in feet.
V1A	Array size NU. Y-component of sphere deflection in feet.
BACKV	Output of subroutine CURFI. Array size NUP. Approximated velocities by subroutine CURFI at NUP points where velocities which are greater than 0.005 fps are measured.

NSU	Output of subroutine CURFI Degree of polynomial to be used for least square approximation of velocity data plus one.
NUPR	NU-NUP. Number of velocity measurements where velocities are less than and equal to 0.005 fps.
NUPR1	= NUPR + 1
NU1	= NU + 1
ZRAV	The deepest (largest) depth of ZUAA below which velocity is assumed unchanged in using polynomial approximation.
ZRE	Output of subroutine BACKWD. Vertical deflection of sphere in feet.
SB	Output of subroutine BACKWD. Total deflection of sphere in feet.
DUREF	Difference between true (observed) total deflection and calculated deflection by subroutine BACKWD of a sphere in feet.
DELVEL	Correction of total velocity, feet per second.
TEST	Ratio of DUREF to observed total sphere deflection.
DIFF	Absolute value of the depth of a sphere at which the last velocity measurement at one point is taken in feet plus 0.01.
DELZU	= DIFF

List of Parameters Used in Subroutine CURFI

W	Array size NP, weighting function.
NDEG	Degree of polynomial to be used for approximation.
NSMALL	= NDEG + 1, also a number of coefficients of polynomial.
FPOLF	Polynomial defined in subprogram.
PHI	The matrix array used to store all calculation in calling ORTHON.
Z	Array size NP, points at which observations are made.
Y	Array size NP. Observations.
NP	Number of observations.
CF	Array size JRANK. Coefficients of polynomial approximation.
SEC	Array size NSMALL + 1. Standard errors of coefficients. SEC(NSMALL + 1) is a standard error of Y estimates.
BACK	Array size NP, approximation at Z.
DELTAS	Array size NP + 1, differences between Y and BACK. DELTAS (NP + 1) is an error sum of squares.
JRANK	Number of independent functions.
RMS	Standard error of Y estimates.
PMIN	Non zero minimum value of Y.
ERROR	= RMS/PMIN

Parameters Used in Subroutine BACKWD

D	Diameter of a sphere of a probe in feet.
L	Type real, wire length plus a radius of a sphere of a probe in feet.
SS	Specific gravity of a sphere of a probe.
DW	Diameter of wire of a probe in feet.
SW	Specific gravity of a wire.
Z	Input, given depth of a sphere.
CFV	Input array size NSU, coefficients of polynomial approximation of velocity profile.
NSU	Input, number of CFV
CFT	Input array size NST. Coefficients of polynomial approximation of temperature profile.
NST	Input, number of CFT.
VEA	Input, given velocity acting on a sphere.
ZRE	Output, vertical distance between a sphere and a probe tip in feet.
SB	Output, total deflection of a sphere in feet.
ZRAV	The depth below which the velocity is assumed unchanged in using polynomial approximation.
ZRAT	The depth below which the temperature is assumed unchanged in using polynomial approximation.
RHO	Density of water.
DELTAS	A small element of a wire defined as one twentieth of L.
VEL	Velocity to calculate drag, set as VEA to calculate a drag on a sphere and called with APPROX when calculating a drag on a wire.
T	Temperature in Fahrenheit.
VISC	Kinematic viscosity of water in square feet per second.
RED	Reynolds number of a sphere.
CS	Drag coefficient of a sphere given by Olson's formula.
DRAGS	Drag force on a sphere.

BUOYS	Buoyancy on a sphere.
SQUA	= DRAGS * DRAGS + BUOYS * BUOYS
KS	Total force acting on a sphere.
KN	Total force acting on an n-th element from above.
M	Buoyancy on a wire.
TANAL1	= BUOYS/DRAGS
AL1	A tethering angle right on the sphere.
ALN	A tethering angle of the n-1-th element, in other words the angle KN is acting toward.
SUM	Sum of elements which the calculation has been done with.
Z1	Depth at the upper end of an element before calculation with respect to that element starts. Depth at the center of an element once the calculation with respect to that element starts.
ALPHA	A tethering angle of n-th element.
REW	Reynolds number of wire element.
CW	Drag coefficient of wire element given by Lamb's formula.
DRAGW	Drag on a wire element.
FUNV	Vertical component of forces acting on n-th wire element from below.
FUNH	Horizontal component of forces acting on n-th wire element from below.
FUN	= FUNV/FUNH
ALN1	A tethering angle of n+1-element.
ALV	= (ALN + ALN1)/2.
RAT	= (ALV-ALPHA)/ALV.