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COMPUTER ANALYSIS PROGRAMS
COMPUTER GRAPHICS

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ABSTRACT

During the course of research in the Cavitation and Multiphase Flow Lab, it became necessary to write computer programs so that vast amounts of data could be simplified and correlated in a minimum amount of time. A total of five FORTRAN programs were written, one dealing with a cavitation project and the other four for wet steam tunnel research under the direction of a doctoral student, Mr. Wontaik Kim. In addition to these computer programs, machine plotting was done for the cavitation project using a canned plotting program known as the Adroit Display System (ADS). All of the computer work was done on the Michigan Terminal System (MTS). This report contains the purpose of each computer program, explains what it does, and lists the equations that are used in it. Also included are program listings, lists of variables, user's quides, and flow charts.

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FOREWARD AND ACKNOWLEDGEMENTS

Except for the linefit program for the cavitation project, the other four computer programs are very closely related. Each program deals with wet steam flow across a simulated turbine blade, and more importantly, water droplet behavior after these drops leave the edge of the blade. Approximately forty high-speed movie films were analyzed and recordings were made for several hundred droplets. All of the data from these observations are stored in the computer and every program dealing with this subject matter makes use of this data file. Thus every program involving the steam tunnel research is similar in what it starts out with as a base but is different in what it calculates.

The author would like to express his extreme appreciation of the help that was given to him by Mr. Michael Wegenka, a graduate student in Mechanical Engineering, who provided some much needed assistance, particularly with the plotting programs.

ACCELERATION RATIO PROGRAM

One of the major investigations undertaken in the wet-steam tunnel research during the past year was to determine the acceleration of water droplets after they left the blade to see just how much velocity they could obtain if they hit another row of turbine blades. This was measured from the data obtained from the films at various steam velocities and liquid flow rates. But even though the actual drop's acceleration could be found, it was of extreme additional interest to see if the test results could be verified by analytical calculations. This computer program first determined the measured drop acceleration and then found the analytical acceleration, using three different equation to give three different definitions of analytical acceleration. The ratio of measured acceleration to analytical acceleration was also found, and displayed in the output.

Program Calculations

The measured acceleration was calculated from the relations

Velocity = Distance/Time

and

Acceleration = Velocity/Time

This was done for every observation and an average droplet acceleration was calculated for use in the rest of the program.

There is one equation that is used to find the analytic acceleration. It is:

$$\text{Acceleration} = (\text{Drag Coefficient})\left(\frac{3}{4}\right)\left(\frac{\rho_s}{\rho_w}\right)\left(\frac{\text{Steam Vel}^2}{\text{Drop Diame}}\right.$$

The reason why we have three different analytic accelerations is because we are using three ways to calculate the droplet drag coefficient. Each of these equations is different in the relations that they use. The three expressions have been proposed by Serafini, Abraham, and Churchill.

The Serafini expression for the drag coefficient is:

$$C_{DS} = \frac{24}{Re} (1+ 0.17 \, Re^{2/3})$$

The Abraham expression for the drag coefficient is:

$$C_{DA} = 0.292 \left(1 + \sqrt{\frac{9.06}{Re}} \right)^2$$

The Churchill expression for the drag coefficient is:

$$C_{DC} = \frac{24}{Re} \left(1 + \left(\frac{Re}{60}\right)^{5/9} \right)^{9/5}$$

All of these equations involve the droplet Reynolds number, or Re, which is found by:

Re=(Drop Diameter)(Steam Velocity)/(Kinematic viscosity

After all these drag coefficients were found, different analytic accelerations could be calculated and the ratio of measured acceleration was taken to each analytic acceleration. This was done in order to find the expression of analytic acceleration that was best suited to our experiment and gave reasonable predictions for every steam velocity and flow rate.

After the computer calculated the various accelerations and ratios for a particular steam velocity and flow rate, it performed averaging routines to find the mean values of measured acceleration, drop diameter, Reynolds number, measured acceleration, analytic acceleration, and ratios. This allowed us to find the scatter around the mean value and how many of the points were far away from the norm. The standard method of taking averag was used:

$$\overline{Re} = \sum_{n=1}^{m} Re/M$$

Once the averages were obtained and written out, the control and the counter were reset and the program resumed its calculations. This process continued for five steam velocities and many different flow rates until all the data was used and converted into the desired units. A fter this was done the output was examined and the best relation for analytic acceleration was choose

BREAK UP TIME ANALYSIS PROGRAM

When one is studying water particle motion, a number of relationships become important and many different numbers can be calculated. Many of these numbers relate the droplet's speed and size in a dimensionless way. The purpose of this computer program was to find, for split particles only, the drop's initial and final dimensions, its velocity, the total time that observations were recorded, and the Weber number, Reynolds number, dimensionless break-up time, dynamic pressure ratio, and type of dimensionless time ratio. All of the calculations were carried out from the basic data file containing only the droplet's diameter, thickness, and position from the edge of the blade for each observation. It should be noted that there were very few particles that split up in our recordings at the lowest steam velocity, but as the steam velocity increases, the number of split particles increases until the higher steam velocities when almost every particle splits up.

Program Calculations

The real time is calculated by subtracting one from the total number of observations and multiplying this number by 0.001; the number of seconds between every observation. The 0.001 was found from a motion picture film speed of five thousand frames per second and the fact that observations were recorded every five frames. Therefore there is one millisecond for every interval over which data was recorded.

Distance was found by subtracting the final position of the droplet from the initial position and converting it into metric dimensions. Velocity of the droplet is simply distance divided by time and the initial and final drop thicknesses and diameters were easily found. Next, the proper Mach number of the steam was determined. In order to find the Weber number, the following equation was used:

$$We = \frac{(\rho_s)(V_s)^2(D_o)}{\sigma}$$

$$We = \frac{(\text{steam density})(\text{steam velocity})^2(\text{drop diameter})}{\text{surface tension}}$$

Reynolds number can be found from

$$Re = \frac{(V_s)(D_o)}{\mu}$$

$$Re = \frac{(\text{steam velocity})(\text{drop diameter})}{\text{kinematic viscosity of steam}}$$

Dimensionless break-up time is calculated according to the equation:

$$T_b = \frac{(t)(V_s)}{(D_o)}\sqrt{\frac{\rho_s}{\rho_w}}$$

$$T_b = \frac{(\text{real time})(\text{steam velocity})}{(\text{drop diameter})} \cdot \sqrt{\frac{\text{steam density}}{\text{water density}}}$$

The dynamic pressure ratio depends on the Mach number of the steam and follows from:

$$Q_m = 0.78 + \frac{1.47}{1 + (2.1)(M)^{3.4}} = \frac{P_d \text{ at Drop Surfa}}{P_d \text{ far ahead of D}}$$

Finally, the expression for dimensionless time times the square root of Q_m or the dynamic pressure ratio was calculated. This was done to give some correlation between the actual dimensionless time and a time that it takes as the force moves around the droplet.

The results were printed out for every split droplet in one line across the page. Headings were written and the program continued for five different steam velocities until the data was exhausted.

DEFORMATION OF DROPLET PROGRAM

In the study of fluid mechanics and water droplet behavior, many important relations involve non-dimensional numbers. These dimensionless quantities do not have the same value as their actual counterparts, but can merely give a representation of what was happening and allow for some extra relationships to be developed. For this particular computer program, the water droplet observations were reduced into subsets and for every droplet observation, the ratio of the present drop diameter to the initial drop diameter was found, along with the mass ratio between present and initial droplets, dimensionless time and distance, and the ratio of droplet diameter divided by thickness. When particles split, the program calculated the dimensionless break-up time, Weber number, dynamic pressure, and a type of nondimensional "acceleration". This computer program is different from the other three dealing with the same experiment because it writes out results for every observation instead of just one line for every droplet with the average diameter being used for all the calculations.

Program Calculations

The area of the droplet was calculated from the relation $A = \pi/4\ d^2$ and the volume of the droplet was found from the equation $V = 16/3\ At$, where t is the thickness of the drop. The mass of the droplet is simply the volume times the density of the water. The real time is again calculated from the motion picture film speed and the number of frames between each observation. Dimensionless time is calculated in the same way as it was in the Break-up Time Analysis Program except that it is calculated at every observation and not just for split particles. Dimensionless distance is found by subtracting the droplet's initial position from its present position and dividing it by the initial diameter. These simple relationships were calculated for every observation and written out.

If the particles split, some additional expressions were found. Initially, if the particle split up, dimensionless break-up time was defined as dimensionless time for the last observation. The Weber number was found as previously described and the dynamic pressure was found in two different units. Dynamic pressure is defined as

$$P_d = \frac{1}{2}\rho V^2$$

and this number was calculated in both psia and newtons per meter squared. Finally, a dimensionless number was calculated that takes dimensionless distance and divides it by the dimensionless time squared. This type of dimensionless "acceleration" gives some relation between these two quantities and proved to be quite interesting.

INDUCED VELOCITY PROGRAM

After obtaining the data from the Acceleration Ratio program it was observed that for the higher steam velocities, the measured acceleration was consistently less than the analytical accelerations. In order to try to explain this phenomena, this computer program was written to find the induced velocity by the vortex, which affects the motion of the droplet, and also the vortex strength. Also included in this program is the work of Mr. Richard Tseng, who calculated a frequency of the droplet movement for the two lower steam velocities also called the periodicity of deceleration. Knowing this periodicity, we were able to calculate Strouhal numbers for the steam, liquid film, and the blade. All of this data, along with the average drop diameter, Reynolds number, measured acceleration, and acceleration ratio, was written out in a variety of formats.

Program calculations

The measured and analytic accelerations were calculated in the same way as in the previous programs. The definition of analytical acceleration that we used was the one by Serafini. The periodicity of deceleration data was stored in a file and read in so that the Strouhal number could be calculated as follows:

$$S_v = \frac{(D_0)}{(V_s)(f)}$$

$$S_v = \frac{(\text{Drop diameter})}{(\text{Steam velocity})(\text{frequency})}$$

The Strouhal number for the film was calculated and film velocities were read into the program

$$S_{v\ film} = \frac{(D_0)}{(V_f)(f)}$$

$$S_{v\ film} = \frac{(\text{Drop diameter})}{(\text{film velocity})(\text{frequency})}$$

The Strouhal number for the simulated turbine blade was found using the equation

$$S_{v\ blade} = \frac{.4}{(V_s)(f)}$$

$$S_{v\ blade} = \frac{(\text{blade width})}{(\text{steam velocity})(\text{frequency})}$$

The induced velocity caused by the vortex involves first a calculation of the acceleration difference of analytical minus measured and then disregarding the calculational steps if the measured acceleration is greater than analytical acceleration. If this difference is positive, then the induced velocity is calculated by:

$$\text{Induced velocity} = \sqrt{(\Delta a)(\text{average diameter})\left(\frac{4}{3}\right)\left(\frac{\rho_{drop}}{\rho_s}\right)}$$

The vortex strength is found by the following equation:

$$\text{Vortex strength} = (\text{Induced velocity})\left(\frac{2\pi b}{\tan^{-1}\frac{b}{c}}\right)$$

After all these numbers are calculated, a series of IF statements determine which format code to write on.The results are written out and the program continues to calculate accelerations and ratios throughout but the Strouhal numbers are only calculated for the first two steam velocities.

Introduction and Purpose

During the course of cavitation damage research it became necessary to write a computer program to verify hand-drawn graphs and the observation that when a log plot of incubation period and MDPR was made, a straight line was obtained with a slope approximately equal to one. In order to confirm this observation, a linear regression analysis was carried out by the method of least squares. The logarithm base 10 was taken of each definition of incubation period(Tangent intercept and 0.1 Mil) and the logarithm base 10 was taken of the inverse of the maximum MDPR and these values were plotted on the x and y axes, respectively. Through regression analysis the slope of the best-fit line was found as well as the proportional constant for the best-fit line. Computer output verifies the fact that for each set of data, the slope of the line is approximately equal to one. It should also be noted that the original computer program was written by Michael Wegenka, who is now a graduate student in Mechanical Engineering at the University of Michigan, and who is responsible for a portion of the final computer program used in this report.

Program Calculations

The major relationship between the incubation period and MDPR can be found in the equation

$$(IP)^m \approx C/MDPR$$

Taking the logarithm base 10 of each side of the equation we obtain

$$m \log_{10} IP = \log_{10} C + \log_{10} 1/MDPR$$

Or, rearranging the equation

$$\log_{10} 1/MDPR = m \log_{10} IP - \log_{10} C$$

This equation now has the same form as the basic equation for a line: $y = mx + b$ where m is the slope of the line and b corresponds to the log of the proportional constant. In order to find m and C, the following equations were used

$$m = \frac{\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i \Big/ n}{\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2 \Big/ n}$$

$$C = 10^{\left[\left(\left|\sum_{i=1}^{n} y_i\right| + m\left(\sum_{i=1}^{n} x_i\right)\right)/n\right]}$$

These two numbers are the ones that are most important in the MDPR and incubation period analysis. In addition to a proportional constant for the best-fit line, a constant can be found for each pair of data points using the calculated slope according to the original equation

$$C = (x_i^m)(y_i) \quad \text{or} \quad C = (\text{Incubation Period})^m\ (\text{MDPR})$$

By finding the proportional constant for each pair of data points, an analysis can be made of all the proportional constants obtained for a set. The average proportional constant is calculated by

$$\overline{C} = \frac{1}{N} \sum_{i=1}^{n} C_i$$

The proportional constant mean deviation is found by

$$MD = \frac{1}{N} \sum_{i=1}^{n} \left| C_i - \overline{C} \right|$$

The proportional constant standard deviation is defined by

$$SD = \sqrt{\frac{(\overline{C} - C_i)^2}{(N - 1)}}$$

The proportional constant root mean square is calculated by

$$RMS = \sqrt{\left(\frac{1}{N}\right) \sum_{i=1}^{n} C_i^2}$$

Output Results

An inspection of the computer printout will show that underneath the title are two headings, one to describe the material tested and the other to detail which measure of incubation period was used. Then the raw data and their base 10 logarithms are listed as well as the proportional constant for each pair of data points. The slope of the line or exponent m in the original equation can then be found along with the proportional constant for the best fit line. Finally, there is a statistical analysis of the proportional constants from each pair of points and the average, mean and standard deviation, root mean square, and maximum and minimum proportional constants are listed for the set of data. All of these figures can be found for each material tested and the particular method of measuring incubation period that was used.

MACHINE PLOTTING OF CAVITATION DATA

Once all of the data was collected for the cavitation damage research program, [illegible] Company and after a computer program was written to calculate the slope of the best-fit line and the corresponding proportional constant, the next logical thing to do was to make computer plots showing all of the data and the best fit line through them. This was accomplished by using the Adroit Display Subsystem(ADS) written by Professor Richard Phillip of the University of Michigan Aerospace Engineering Department. This plotting program can only be used on special graphics terminals and require that all data to be plotted be in a file and that some file is empty to store the graphs. A full,detailed description of ADS is in the possession of Michael Wegenka, the author, and Peter Felbeck, and this text is very necessary before any plots can be made.

ADS is completely separate from the Plot Description System (PDS) that is on public file and is described in Volume 11 of the Mighigan Terminal System manuals. ADS can accomplish just about as much as the much more difficult MTS 11 plots. ADS has its own set of commands and produces CALCOMP plots. If the person plotting desires to do as little work as possible, he can specify the type of axes and specify the data file and use the AUTO command to produce everything but the text.

The basic procedure to making plots with ADS is relatively simple. First, specify the maximum and minimum x and y values. Next specify the axes(either rectangular, semi-log, or log-log) and then tell the computer where to put the tick marks. Once you have the tick marks you can label the tick marks and the axes. ADS has a separate TEXT subroutine mode, using it you can put any text in the graph as large or as small as you want it wherever you want it. HORZ or VERT specifies the orientation of the text in the graph and SCAT controls the size of the text. The GO command allcws you to enter text and position it wherever you want, using cross-hairs that appear on the screen of the graphics terminal. The ADD command allows you to enter data into the graph structure and the DATA command plots the data(using the default character +) on the screen. Of particular importance to Aerojet graphs was the CRVF command. CRVF (for curvefit) calculated the best fit straight line (in our case) and draws it on the screen. There is a variety of other very useful commands, all of which can be found in the ADS description.

There are a few more very important ADS commands that save a lot of time and make plotting easier. The SAVE command will place whatever is on the screen into a file, which can be called back by the REST (restore) command. This eliminates having to always having to specify general text and axes labels and tick marks. Finally the CALC command produces the necessary commands to produce a CALCOMP plot and stores this in a file. Actual plots cannot be made until the $RUN *CCQUEUE command is used.

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USER'S GUIDE

In order to run the computer programs that are described in this report, some basic knowledge of the Michigan Terminal System is required. The actual commands that are used will be provided for each program, and can also be found in the program listings themselves. All of the programs are on punched cards except for the linefit program, which is on file in the computing center. All of the data, however, is on file, and in order to run the programs smoothly and change things when needed, one really needs to know about how to operate terminals and how to edit files. All of the programs were written in FORTRAN , and one should know exactly what each program does before he attempts to change it. Keeping all of this in mind , it should be noted that the detailed explanation of the requirements for putting data into a file can be found in Michael Wegenka's December, 1977 report number UMICH 014571-11-I and will not be repeated here. The programmer should have no problem with his data files, however, as long as he keeps two things in mind: first, make the formats large enough to accomodate a large range of data with a lot of decimal places; and, second, when entering data into a file, be sure to always include a decimal point and a comma between each number.

The basic commands to run a MTS job from the card reader are as follows:

```
$SIGNON ODLU T=3 P=20
PASSWORD
$RUN *FTN
```

These three comands sign you on the computer and allow you to identify yourself as aparticular user with a signon ID. The password is your control to prevent other people from using your account. The first parameter after the signon ID is a time limit of the use of the main unit of the computer in seconds and the second parameter is the page limit. These two parameters should always be used so that if something is wrong with your program, it will not go on continously and use all of your money. Additionally, if you want to specify a higher-quality printer, the command PRINT=TN on the signon card will assure that this happens. The $RUN card tells the computer that it should use the Fortran compiler for your program. These three cards must always appear at the beginning of every program. After all of the program cards appear, some additional MTS commands are necessary:

```
$RUN -LOAD 1=T3DATA 2=FDATA 5=WDATA(1,1873)
$ENDFILE
$SIGNOFF
```

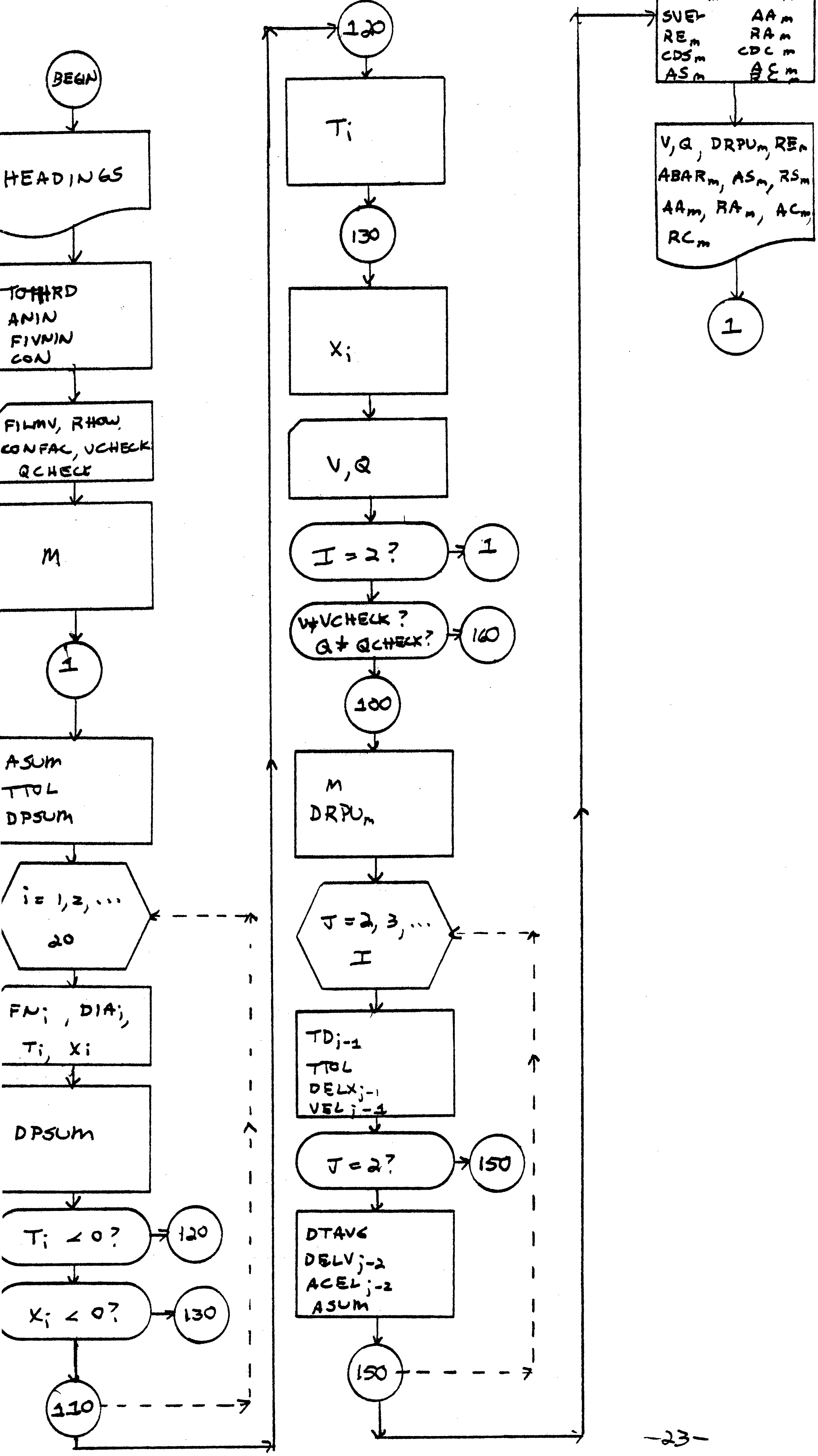
The $RUN -LOAD card is probably the most important because it specifies which files are to be used in the input/output statements. Whenever you use a read or write statement, a particular unit is specified. Usually, by default, Unit 5 is attache to a card reader and unit 6 is attached to a line printer. For our purposes, however, unit 5 must be attached to a data file and other units(for example, units one and two in the induced velocity program) can be attached to other files with other necessary data. Things can also be written into a file in additio to getting output on a printer. This can be done by using, for example, Unit 7 as a place to store data in a file (as it was in the linefit program). In order to run the linefit program off a terminal (using the compiled program LF) the following MTS command card is necessary:

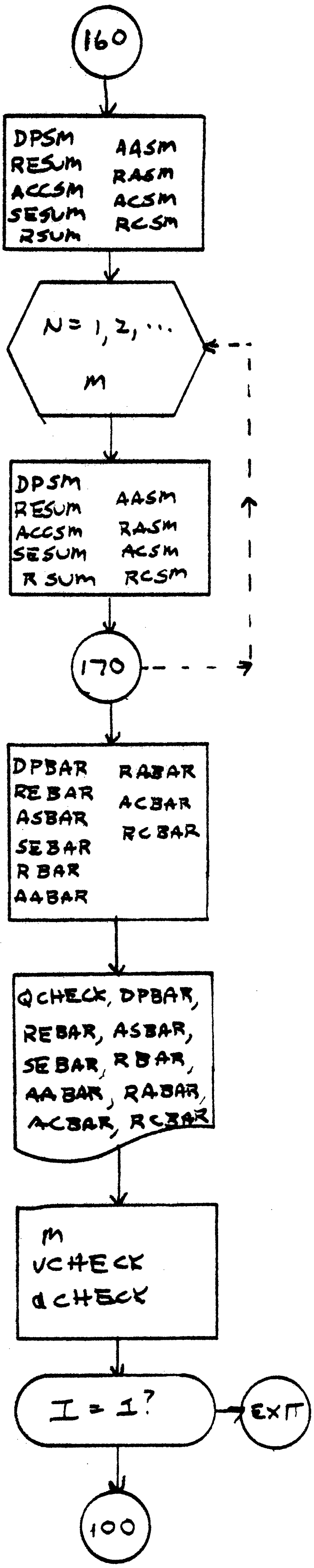
$RUN LF 5=MDPRDATA 6=*PRINT* 7=-A ROUTE=CNTR

This tells the computer to use the compiled program, read the data from the file MDPRDATA, print the results on a line printer, and store some of the calculations in the temporary file -A. The ROUTE=CNTR is not necessary because the Computing Center on North Campus is the default route but if you want to pick up your output at NUBS, you must specify ROUTE=NUBS on this line. If you use punched cards, the ROUTE= and 6= can be omitted because you are automatically defaulted to a line printer at wherever you are originating your job.

CURRENT LINE FILES

FDATA	Contains values of liquid film velocity
LF	Compiled linefit program
LINEFIT	Program listing of the best straight line-fit program
MDPRDATA	Data file with incubation periods and MDPR values
PFILE	Plot file with data in the proper form to be used the ADS plot routine
T3DATA	Contains periodicity of deceleration data based on .3 peak
T5DATA	Contains periodicity of deceleration data based on .5 peak
WATERDROP	Original acceleration program listing
WD	Compiled acceleration program
WGABAR	Listing of measured acceleration and ratio for every droplet
WGAVG	Listing of measured acceleration and ratio for a given steam velocity and flow rate
WDATA	Complete data file containing all of the data for all the observations and the distance away from the edge of the blade, drop diameter, and drop thickness


BEGIN
HEADINGS
TOTHRD
ANIN
FIVNIN
CON
FILMV, RHOW
CONFAC, VCHECK
QCHECK
M
1
ASUM
TTOL
DPSUM
i = 1, 2, ...
20
FN_i, DIA_i,
T_i, X_i
DPSUM
T_i < 0?
120
X_i < 0?
130
110
120
T_i
130
X_i
V, Q
I = 2?
1
V ≠ VCHECK?
Q ≠ QCHECK?
160
100
M
DRPU_m
J = 2, 3, ...
I
TD_{j-1}
TTOL
DELX_{j-1}
VEL_{j-1}
J = 2?
150
DTAVG
DELV_{j-2}
ACEL_{j-2}
ASUM
150
SVEL
RE_m
CDS_m
AS_m
AA_m
RA_m
CDC_m
AC_m
V, Q, DRPU_m, RE_m
ABAR_m, AS_m, RS_m
AA_m, RA_m, AC_m,
RC_m
1


160
DPSM AASM
RESUM RASM
ACCSM ACSM
SESUM RCSM
RSUM
N = 1, 2, ...
M
DPSM AASM
RESUM RASM
ACCSM ACSM
SESUM RCSM
R SUM
170
DPBAR RABAR
REBAR ACBAR
ASBAR RCBAR
SEBAR
R BAR
AABAR
QCHECK, DPBAR,
REBAR, ASBAR,
SEBAR, RBAR,
AA BAR, RABAR,
ACBAR, RCBAR
M
VCHECK
dCHECK
I = 1?
EXIT
100

```
$SIG ODLU T=3 P=20
$R *FTN 5=WDATA
C      ****************** ACCELERATION RATIO PROGRAM ******************
C      THIS PROGRAM CALCULATES THE MEASURED ACCELERATION AND THREE
C      ANALYTIC ACCELERATIONS:SERAFINI, CHURCHILL, AND ABRAHAM.
C      IT ALSO FINDS THE ACCELERATION RATIOS AND DETERMINES AVERAGE
C      VALUES FOR EACH STEAM VELOCITY AND FLOW RATE.
C      ***************************************************************
       DIMENSION ACEL(20),FN(20),DIA(20),T(20),X(20),TD(20),DELX(20),
      1 VEL(20),DELV(20),ABAR(25),DRPU(25),RE(25),CDS(25),AS(25),RS(25),
      2 CDA(25),AA(25),RA(25),CDC(25),AC(25),RC(25)
       WRITE(6,199)
       TOTHRD=2./3.
       ANIN=9./5.
       FIVNIN=5./9.
       CON=30.48
       READ(5,101) FILMV,RHCW,CONFAC,VCHECK,QCHECK
       M=0.0
     1 ASUM=0.0
       TTOL=0.0
       DPSUM=0.0
C      ***** READ THE DATA FOR EACH OBSERVATION *****
       DO 110 I=1,20
       READ(5,101) FN(I),DIA(I),T(I),X(I)
       DPSUM=DPSUM+DIA(I)
       IF(T(I) .LT. 0.0) GO TO 120
       IF(X(I) .LT. 0.0) GO TO 130
   110 CONTINUE
   120 T(I)=ABS(T(I))
   130 X(I)=ABS(X(I))
       READ(5,101) V,Q
       IF(I .EQ. 2) GO TO 1
C      ***** CHECK TO SEE IF THERE ARE NEW CONDITIONS *****
       IF(V.NE.VCHECK .OR.Q.NE.QCHECK) GO TO 160
   100 M=M+1
       DRPU(M)=DPSUM/I*.45
C      ***** CALCULATE THE MEASURED ACCELERATION *****
       DO 150 J=2,I
       TD(J-1)=0.001
       TTOL=TTOL+TD(J-1)
       DELX(J-1)=(X(J)-X(J-1))*0.45
       VEL(J-1)=DELX(J-1)/TD(J-1)
       IF(J .EQ.2) GO TO 150
       DTAVG=(TD(J-1)+TD(J-2))/2.0
       DELV(J-2)=VEL(J-1)-VEL(J-2)
       ACEL(J-2)=DELV(J-2)/2./DTAVG
       ASUM=ACEL(J-2)+ASUM
   150 CONTINUE
       IM2=I-2
       ABAR(M)=ASUM/IM2
       SVEL=V*CON
C      ***** CALCULATE THE ANALYTIC ACCELERATIONS *****
       RE(M)=V*DRPU(M)*32.61
       CDS(M)=24./RE(M)*(1.+0.17*RE(M)**TOTHRD)
       AS(M)=(CDS(M)*0.75)*.0001135/DRPU(M)*SVEL**2
       RS(M)=ABAR(M)/AS(M)
       CDA(M)=.292*((1.+(9.06/(2*RE(M))**.5))**2)
       AA(M)=(CDA(M)*0.75)*.0001135/DRPU(M)*SVEL**2
       RA(M)=ABAR(M)/AA(M)
       CDC(M)=24./RE(M)*((1.+(RE(M)/60)**FIVNIN)**ANIN)
```

```
      AC(M)=(CDC(M)*.75)*.C001135/DRPU(M)*SVEL**2
      RC(M)=ABAR(M)/AC(M)
      WRITE(6,200) V,Q,DRPU(M),RE(M),ABAR(M),AS(M),RS(M),AA(M),RA(M)
     1 AC(M),RC(M)
      GO TO 1
C     ***** DETERMINE AVERAGES *****
  160 DPSM=0.0
      RESUM=0.0
      ACCSM=0.0
      SESUM=0.0
      RSUM=0.0
      AASM=0.0
      RASM=0.0
      ACSM=0.0
      RCSM=0.0
      DO 170 N=1,M
      DPSM=DPSM+DRPU(N)
      RESUM=RESUM+RE(N)
      ACCSM=ACCSM+ABAR(N)
      SESUM=SESUM+AS(N)
      RSUM=RSUM+RS(N)
      AASM=AASM+AA(N)
      RASM=RASM+RA(N)
      ACSM=ACSM+AC(N)
      RCSM=RCSM+RC(N)
  170 CONTINUE
      DPBAR=DPSM/M
      REBAR=RESUM/M
      ASBAR=ACCSM/M
      SEBAR=SESUM/M
      RBAR=RSUM/M
      AABAR=AASM/M
      RABAR=RASM/M
      ACBAR=ACSM/M
      RCBAR=RCSM/M
      WRITE (6,201) QCHECK,DPBAR,REBAR,ASBAR,SEBAR,RBAR,AABAR,
     1 RABAR,ACBAR,RCBAR
      M=0.0
      VCHECK=V
      QCHECK=Q
      IF(I.EQ.1) CALL EXIT
      GO TO 100
  101 FORMAT(6(F10.5))
  199 FORMAT ('1','STEAM',4X,'FLOW',3X,'DROP',4X,'REYNOLDS',3X,
     1 'MEASURED',5X,'SERAFINI   SERAFINI    ABRAHAM   ABRAHAM',3X,
     2 'CHURCHILL',2X,'CHURCHILL'/'VELOCITY',2X,'RATE DIAMETER',
     3 3X,'NUMBER',2X,'ACCELERATION ACCELERATICN',2X,'RATIO',3X,
     4 'ACCELERATION  RATIO  ACCELERATICN',3X,'RATIO'/'(FEET/S)',
     5 1X,'(CC/M)   (CM)',13X,'(CM/SEC**2)   (CM/SEC**2)',
     6 11X,'(CM/SEC**2)',11X,'(CM/SEC**2)')
  200 FORMAT ('0',1X,F6.1,3X,F4.1,2X,F6.4,3X,F8.3,1X,F11.3,3X,
     1 F10.3,3X,F6.3,3X,F10.3,3X,F6.3,2X,F10.2,4X,F6.3)
  201 FORMAT ('0','**AVG FCR Q=',F3.0,1X,F6.4,3X,F8.3,1X,F11.3,3X,
     1 F10.3,3X,F6.3,3X,F10.3,3X,F6.3,2X,F10.2,4X,F6.3)
      END
$ENDFILE
$R -LOAD 5=WDATA
$ENDFILE
$SIG
```

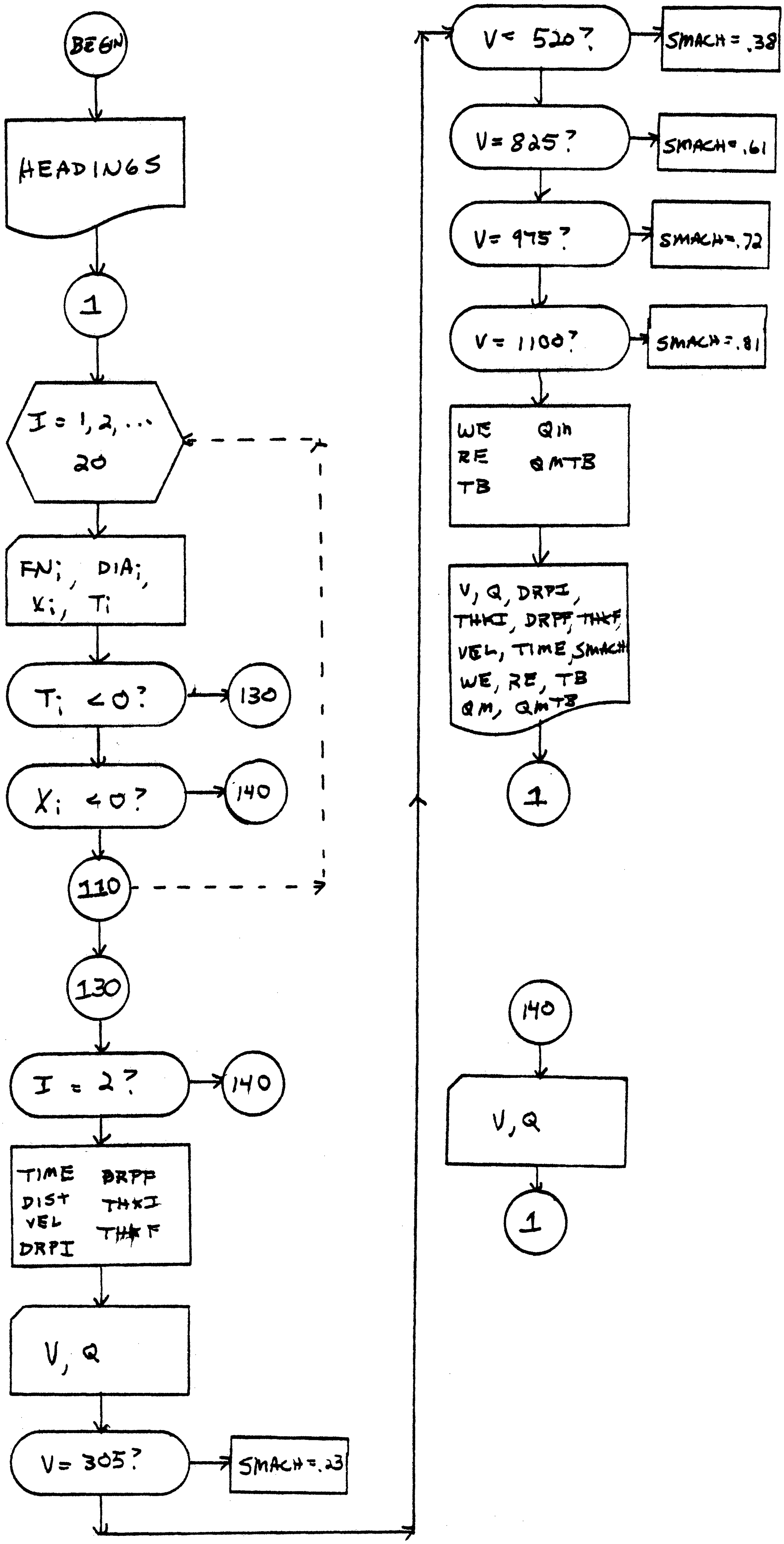
Acceleration Ratio Program

AA(M)	Analytical acceleration as calculated by Abraham
AABAR	Average of all Abraham accelerations for a particular steam velocity and flow fate
AASM	Sum of all Abraham accelerations for a particular steam velocity and flow rate
ABAR(M)	Average of the measured acceleration for one droplet
AC(M)	Analytical acceleration as calculated by Churchill
ACBAR	Average of all Churchill accelerations for a particular steam velocity and flow rate
ACCSM	Sum of all the measured accelerations for a particular steam velocity and flow rate
ACEL(J)	Measured acceleration of one droplet for three successive film readings
ACSM	Sum of all the Churchill accelerations for a particular steam velocity and flow rate
ANIN	A constant, five-ninths
AS(M)	Analytical acceleration as calculated by Serafini
ASBAR	Average of all measured accelerations for a particular steam velocity and flow rate
ASUM	Sum of all the measured accelerations for one droplet
CDA(M)	Abraham's experssion for the drag coefficient
CDC(M)	Churchill's expression for the drag coefficient
CDS(M)	Serafini's expression for the drag coefficient
CON	A constant conversion factor, 30.48, the number of cm/sec in one foot/sec
CONFAC	A constant conversion factor, .45, the number of centimeters in one measured screen unit
DELV(J)	The difference between two consecutively measured velocities
DELX(J)	The difference between two consecutively measured distances
DIA(J)	The diameter of the water droplet for a particular observation
DPBAR	The average of all the diameters for a particular steam velocity and flow rate

DPSM	The sum of all the diameters for a particular steam velocity and flow rate
DPSUM	The sum of all the diameters observed for a particular droplet
DRPU(M)	The average of all diameters observed for a particular droplet
DTAVG	The average time between each successive observation
FILMV	The film speed at which the pictures were taken
FIVNIN	A constant, five-ninths
FN(I)	Number of frames between each successive observation
IM2	The number of observations in a set minus two
M	A counter which teels how many different cases were obser for each steam velocity and flow rate
Q	Flow rate of water entering the test section
QCHECK	A control that is used to see if the flow rate has change
RA(M)	The ratio of measured acceleration to Abraham acceleratic for a particular water droplet
RABAR	The average of all measured/Abraham acceleration ratios for a particular steam velocity and flow rate
RASM	The sum of all measured/Abraham acceleration ratios for a particular steam velocity and flow rate
RBAR	The average of all measured/Serafini acceleration ratios for a particular steam velocity and flow rate
RC(M)	The ratio of measured acceleration to Churchill acceleration for a particular water droplet
RCBAR	The average of all measured/Churchill acceleration ratios for a particular steam velocity and flow rate
RCSM	The sum of all measured/Churchill acceleration ratios for a particular steam velocity and flow rate
RE(M)	Reynolds number for a particular water droplet
REBAR	The average of all Reynolds numbers for a particular steam velocity and flow rate
RESUM	The sum of all Reynolds numbers for a particular steam velocity and flow rate
RHOW	Density of water

RS(M)	The ratio of measured acceleration to Serafini acceleration for a particular water droplet
RSUM	The sum of all measured/Serafini acceleration ratios for a particular steam velocity and flow rate
SEBAR	Average of all Serafini accelerations for a particular steam velocity and flow rate
SESUM	Sum of all Serafini accelerations for a particular steam velocity and flow rate
SVEL	Steam velocity in cm/sec
T(I)	Thickness of the water droplet for a particular observation
TD(J)	Elapsed time between observations
TOTHRD	A constant, two-thirds
TTOL	Total time that observations on a particalar drop were made
V	Steam velocity
VCHECK	A control that is used to see if the steam velocity has changed
VEL(J)	Measured velocity of one droplet for two successive film readings
X(I)	Distance an individual particle was away from the edge of the blade

Break Up Time Analysis Program



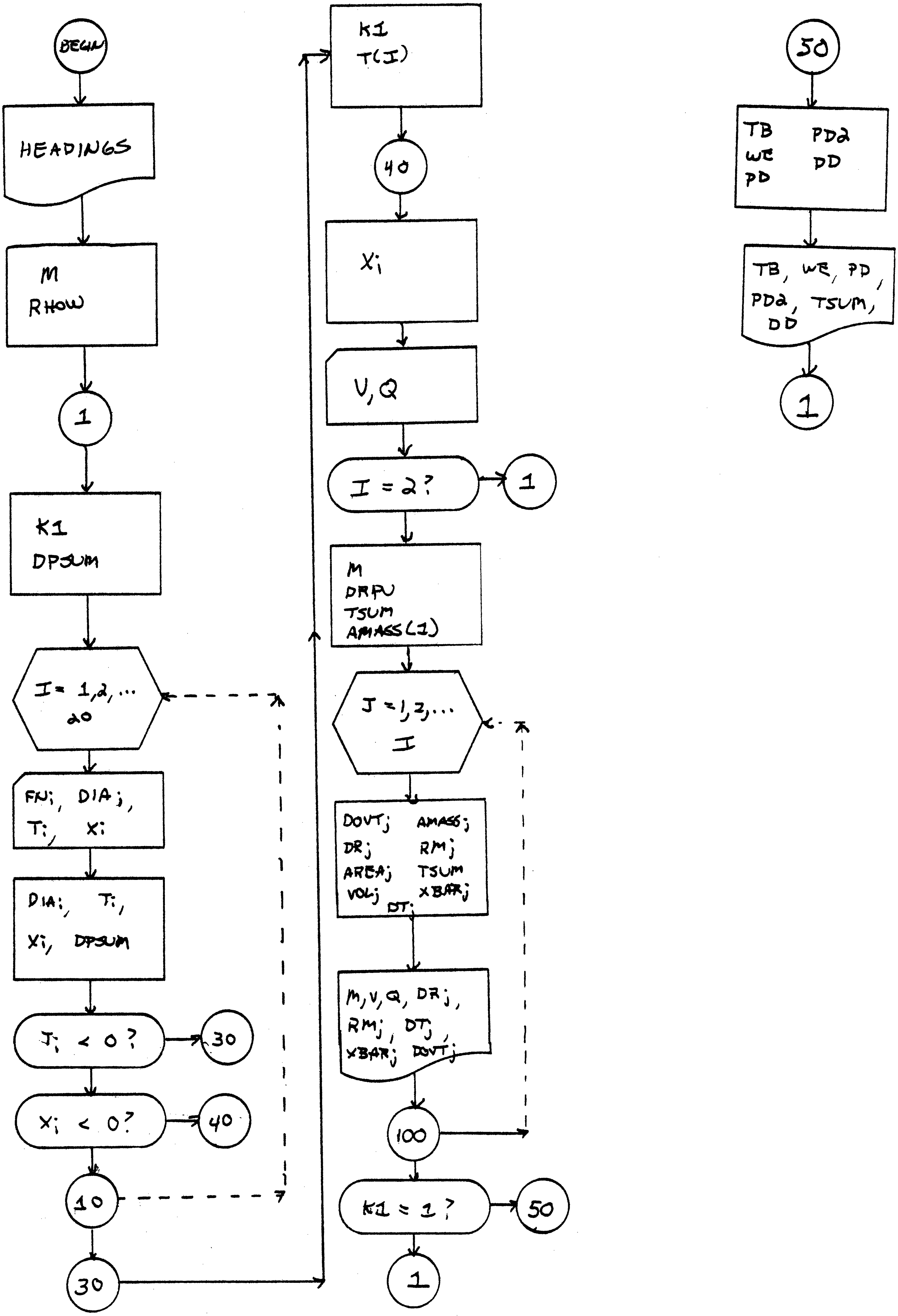
```
$SIG ODLU T=3 P=20
$R *FTN 5=WDATA(2,1873)
C       **************** BREAK-UP TIME ANALYSIS PROGRAM ***************
C       THIS PROGRAM CALCULATES THE INITIAL AND FINAL
C       DIMENSIONS OF A DROP AND ITS VELOCITY FOR SPLIT CASES ONLY.
C       IT ALSO FINDS WEBER NUMBER, REYNCLDS NUMBER, DIMENSIONLESS
C       BREAK-UP TIME, AND THE DYNAMIC PRESSURE RATIO.
C       ****************************************************************
        DIMENSION FN(20), DIA(20), T(20), X(20)
        WRITE(6,199)
C       ***** READ THE DATA FOR EACH CBSERVATICN *****
      1 DO 110 I=1,20
        READ (5,101) FN(I), DIA(I), T(I), X(I)
        IF (T(I) .LT.0.0) GO TO 130
        IF (X(I) .LT.0.0) GO TO 140
    110 CONTINUE
   130  IF (I .EQ. 2) GO TO 140
        TIME=(I-1.0)*0.001
        DIST=(X(I)-X(1))*0.45
        VEL=DIST/TIME
C       ***** FIND THE INITIAL AND FINAL DROP DIMENSIONS *****
        DRPI=DIA(1)*0.45
        DRPF=DIA(I)*0.45
        THKI=T(1)*0.45
        THKF=ABS(T(I))*0.45
        READ(5,101) V,Q
C       ***** DETERMINE THE STEAM MACH NUMBER *****
        IF (V.EQ.305.0) SMACH=0.23
        IF(V.EQ.520.0) SMACH=0.38
        IF (V.EQ.825.0) SMACH=0.61
        IF (V.EQ.975.0) SMACH=0.72
        IF(V.EQ.1100.0) SMACH=0.81
        WE=(V**2)*DRPI*1.435E-3
        RE=V*DRPI*32.61
        TB=(TIME*V)/DRPI*0.323
        QM=0.78+1.47/(1.+2.1*SMACH**3.4)
        QMTB=SQRT(CM)*TB
        WRITE(6,200) V,Q,DRPI,THKI,DRPF,THKF,VEL,TIME,SMACH,WE,RE,TB,
       1 QM,QMTB
        GO TO 1
    140 READ(5,101) V,Q
        GO TO 1
    101 FORMAT (6(F10.5))
    199 FORMAT ('1',2X,'STEAM',4X,'FLCW',2X,'INITIAL',3X,
       1 'INITIAL',4X,'FINAL',6X,'FINAL',6X,'DROP',5X,
       2 'TOTAL MACH',5X,'WE',6X,'RE',6X,'TB',5X,'CM',4X,'QM.5TB'/
       3 2X,'VELOCITY  RATE  DIAMETER THICKNESS  DIAMETER  THICKNESS',
       4 2X,'VELOCITY   TIME NUMBER (RS*V**2 (V*DO/',
       5 1X,'(T*V/DC  PRESS'/2X,'(FEET/S) (CC/M)    (CM)',6X,
       6 '(CM)',6X,'(CM)',6X,'(CM)',5X,'(CM/S)',4X,'(SEC)',8X,
       7 '*DO/SIG)  KVIS) *RS**.5)  RATIO')
    200 FORMAT ('0',F8.3,2X,F4.1,2X,F8.5,1X,F9.5,2X,
       1 F8.5,2X,F9.5,2X,F8.3,3X,F4.3,2X,F4.2,3X,F6.2,2X,F6.1,
       2 2X,F6.3,2X,F5.3,2X,F5.2)
        END
$ENDFILE
$R -LOAD 5=WDATA(2,1873)
$ENDFILE
$SIG
```


****

Break Up Time Analysis Program

DIA(I)	Diameter of an individual droplet at a particular observa
DIST	The distance that the particle travelled since the last observation
DRPF	Final observed diameter of a particular droplet
DRPI	Initial observed diameter of a particular droplet
FN(I)	Number of frames between each successive observation
Q	Flow rate of water in the test section
QM	Ratio of dynamic pressure
QMTB	Square root of the dynamic pressure ratio times dimensio less break-up time
RE	Reynolds number for a particular particle
SMACH	Mach number of the steam through the test section
T(I)	Thickness of an individual droplet at a particular observation
TB	Dimensionless break-up time
THKF	Final observed thickness of a particular droplet
THKI	Initial observed thickness of a particular droplet
TIME	Real time measured between observations
V	Steam velocity in the system
VEL	Droplet velocity across the test section
WE	Weber number for a particular particle
X(I)	Distance of an individual droplet from the edge of the blade at a particular observation

Deformation of Droplet Program



```
$SIG ODLU T=4 P=75
$R *FTN 5=WDATA(2,1873)
C     **************** DEFORMATION OF DROPLET PROGRAM ****************
C     THIS PROGRAM CALCULATES A MASS RATIO, DIMENSIONLESS DISTANCE
C     AND DIMENSIONLESS TIME. IT ALSO FINDS THE WEBER NUMBER AND
C     DYNAMIC PRESSURE FOR SPLIT PARTICLES.
C     ****************************************************************
      DIMENSION FN(20),DIA(20),T(20),X(20),DR(20),RM(20),DT(20),
     1 XBAR(20),AREA(20),VOL(20),AMASS(20),DOVT(20)
      WRITE (6,500)
      M=0
      RHOW=1.0
    1 K1=0
      DPSUM=0.0
C     ***** READ THE DATA FOR EACH OBSERVATION *****
      DO 10 I=1,20
      READ(5,101) FN(I),DIA(I),T(I),X(I)
      DIA(I)=DIA(I)*0.45
      T(I)=T(I)*0.45
      X(I)=X(I)*0.45
      DPSUM=DPSUM+DIA(I)
      IF (T(I).LT.0.0) GO TO 30
      IF (X(I).LT.0.0) GO TO 40
   10 CONTINUE
   30 K1=1
      T(I)=ABS(T(I))
   40 X(I)=ABS(X(I))
      READ(5,101) V,Q
      IF(I.EQ.2) GO TO 1
      M=M+1
      DRPU=DPSUM/I
      TSUM=0.0
      AMASS(1)=(3.141593/4*DIA(1)**2)*T(1)*16./3.
C     ***** ITERATIVE CALCULATING OPERATIONS *****
      DO 100 J=2,I
      DOVT(J)=DIA(J)/T(J)
      DR(J)=DIA(J)/DIA(1)
      AREA(J) =3.141593/4*DIA(J)**2
      VOL(J)=AREA(J)*T(J)*16./3.
      AMASS(J)=VOL(J)*RHOW
      RM(J)=AMASS(J)/AMASS(1)
      TSUM=TSUM+0.001
      DT(J)=(TSUM*V)/DIA(1)*0.323
      XBAR(J)=(X(J)-X(1))/DIA(1)
      WRITE(6,600) M,V,Q,DR(J),RM(J),DT(J),XBAR(J),DOVT(J)
  100 CONTINUE
C     ***** SEE IF THE PARTICLE SPLIT *****
      IF(K1.EQ.1) GO TO 50
      GO TO 1
   50 TB=DT(J)
      WE=(V**2)*DRPU*1.435E-3
      PD=7.7E-7*V**2
      PD2=PD*6.89E3
      DD=XBAR(J)/TB**2
      WRITE(6,610) TB,WE,PD,PD2,TSUM,DD
      GO TO 1
  101 FORMAT (6(F10.5))
  500 FORMAT ('1',2X,'SET',4X,'STEAM',4X,'FLOW  DIAMETER',3X,
     1 'MASS  DIMENSIONLESS DIMENSIONLESS  DIAMETER/',/'NUMBER',2X,
     2 'VELOCITY',2X,'RATE',4X,'RATIO',4X,'RATIO',5X,'TIME',9X,
```

```
      3 'DISTANCE',4X,'THICKNESS'/8X,'(FEET/S)  (CC/M)    (D/DO)',3X,
      4 '(M/MO)',7X,'T',11X,'(X/DO)')
  600 FORMAT ('0',1X,I4,4X,F5.0,4X,F4.1,3X,F6.2,3X,F6.2,
      1 2X,F9.4,6X,F9.4,5X,F6.3)
  610 FORMAT ('0','PARTICLE BROKE UP',2X,'TB=',F6.3,2X,'WE=',
      1 F6.2,2X,'PD=',F8.5,'PSIA',F9.2,'N/M**2',2X,'TIME=',F5.3,2X,
      2 'X/TB**2=',F10.6)
       END
$R -LOAD 5=WDATA(2,1873)
$ENDFILE
$SIG
```

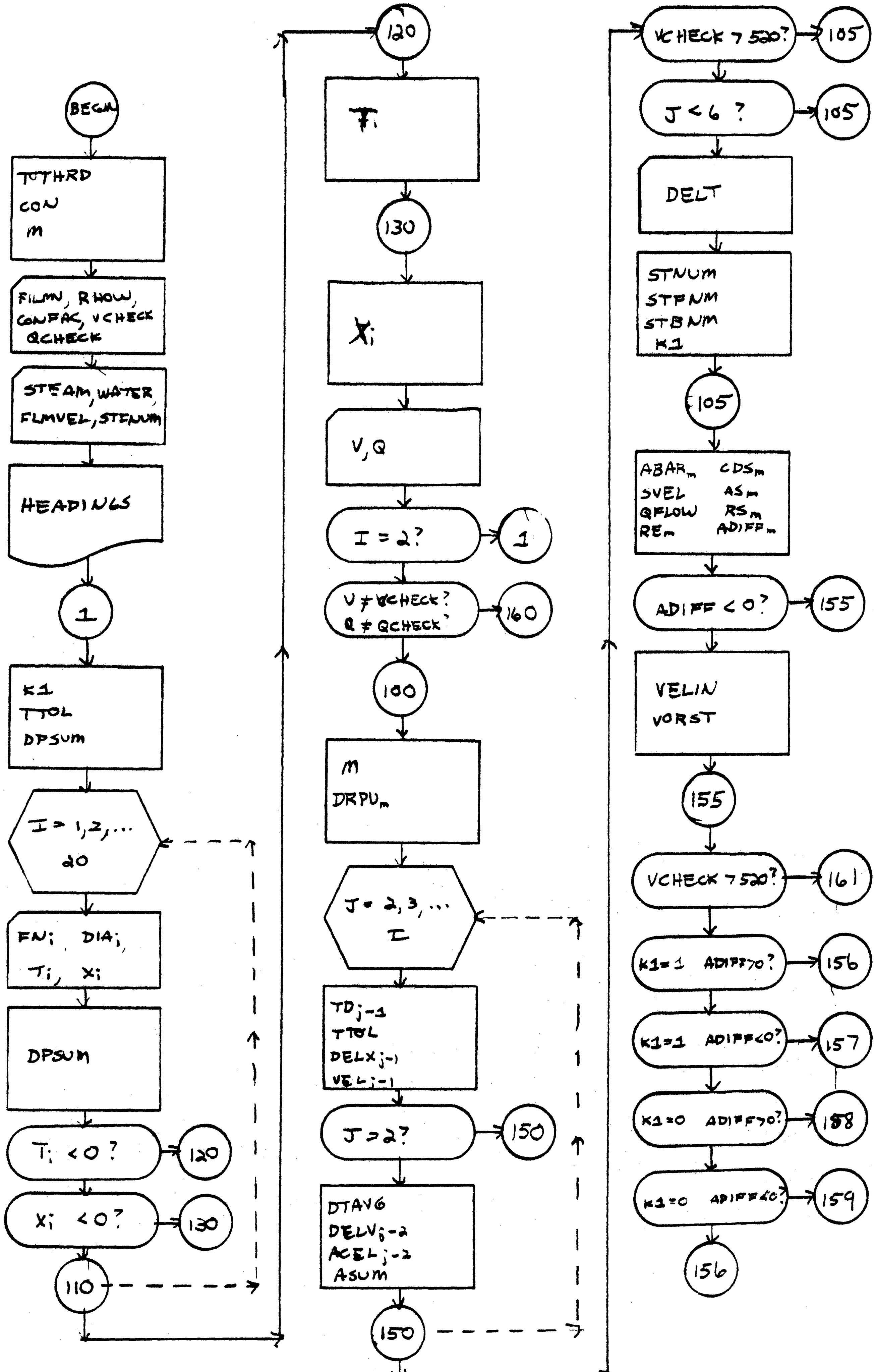

****

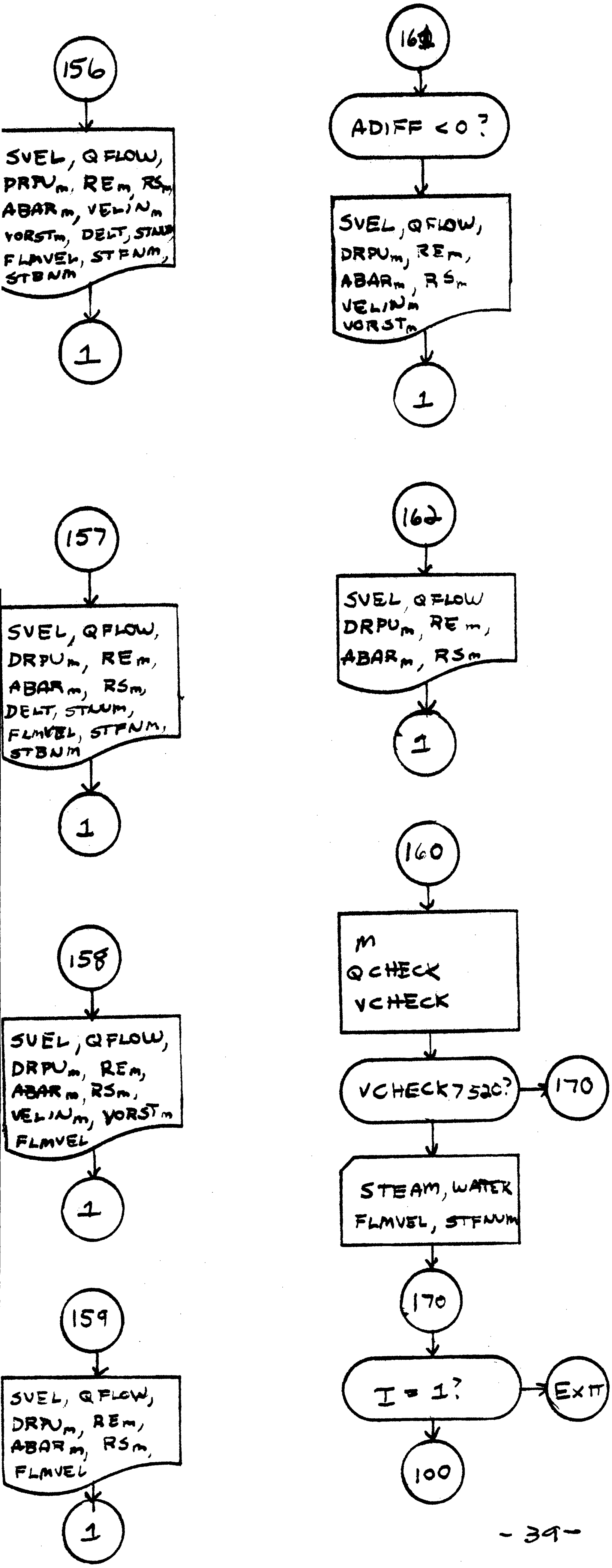
Deformation of Droplet Program

AMASS(J)	Mass of an individual droplet
AREA(J)	Surface area of an individual droplet
DD	Dimensionless distance divided by break-up time
DIA(I)	Diameter of an individual droplet at a particular observation
DOVT(J)	The ratio of diameter to thickness for a particular drop
DPSUM	The sum of all the diameters observed for a particular droplet
DR(J)	The ratio of each diameter to the initial diameter for a particular droplet
DRPU	The average diameter of a particular droplet
DT(J)	Dimensionless time
FN(I)	Number of frames between each successive observation
K1	A control to see if the particle split
M	A counter which tells the total number of droplets obser and assigns them a set number
PD	Dynamic pressure for a split droplet in psia
PD2	Dynamic pressure for a split droplet in Newtons/meter^2
Q	Flow rate of water in the test section
RHOW	Density of water
RM(J)	The ratio of each droplet mass to the initial mass for a particular droplet
T(I)	Thickness of an individual droplet at a particular observation
TB	Dimensionless break-up time in which the droplet splits
TSUM	The sum of the time over which observations of a particu droplet were measured
V	Steam velocity in the system
VOL(J)	Volume of an individual droplet
WE	Weber number for a split droplet
X(I)	Distance an individual particle was away from the edge o the blade

XBAR(J)	Dimensionless distance, distance away from the blade divided by drop diameter

INDUCED VELOCITY PROGRAM




156
SVEL, QFLOW, DRPUm, REm, RSm, ABARm, VELINm, VORSTm, DELT, STNUM, FLMVEL, STFNM, STBNM
1
161
ADIFF < 0 ?
SVEL, QFLOW, DRPUm, REm, ABARm, RSm, VELINm, VORSTm
1
157
SVEL, QFLOW, DRPUm, REm, ABARm, RSm, DELT, STNUM, FLMVEL, STFNM, STBNM
1
162
SVEL, QFLOW, DRPUm, REm, ABARm, RSm
1
158
SVEL, QFLOW, DRPUm, REm, ABARm, RSm, VELINm, VORSTm, FLMVEL
1
160
M
QCHECK
VCHECK
VCHECK > 520 ?
170
STEAM, WATER, FLMVEL, STFNUM
170
I = 1 ?
EXIT
100
159
SVEL, QFLOW, DRPUm, REm, ABARm, RSm, FLMVEL
1

```
$SIG ODLU T=3 P=20
$R *FTN 5=WDATA
C      ****************** INDUCED VELOCITY PROGRAM *****************
C      THIS PROGRAM CALCULATES THE MEASURED AND ANALYTIC
C      ACCELERATION AND THE INDUCED VORTEX VELOCITY AND VORTEX
C      STRENGTH. IT ALSO FINDS STEAM,FILM,AND BLADE STROUHAL NUMBERS
C      ***************************************************************
       DIMENSION ACEL(20),FN(20),DIA(20),T(20),X(20),TD(20),DELX(20),
      1 VEL(20),DELV(20),ABAR(25),DRPU(25),RE(25),CDS(25),AS(25),
      2 VELIN(25),VORST(25),ADIFF(25),RS(25)
       TOTHRD=2./3.
       CON=30.48
C      ***** READ SOME PRELIMINARY DATA *****
       READ(5,101) FILMV,RHOW,CONFAC,VCHECK,QCHECK
       READ(2,102)STEAM,WATER,FLMVEL,STFNUM
       WRITE(6,90)
       M=0.0
     1 ASUM=0.0
       K1=0
       TTOL=0.0
       DPSUM=0.0
C      ***** READ THE DATA FOR EACH OBSERVATION *****
       DO 110 I=1,20
       READ(5,101) FN(I),DIA(I),T(I),X(I)
       DPSUM=DPSUM+DIA(I)
       IF(T(I) .LT. 0.0) GO TO 120
       IF(X(I) .LT. 0.0) GO TO 130
   110 CONTINUE
   120 T(I)=ABS(T(I))
   130 X(I)=ABS(X(I))
       READ(5,101) V,Q
       IF(I .EQ. 2) GO TO 1
C      ***** CHECK TO SEE IF THERE ARE NEW CONDITIONS *****
       IF(V.NE.VCHECK .OR.Q.NE.QCHECK) GO TO 160
   100 M=M+1
       DRPU(M)=DPSUM/I*.45
C      ***** CALCULATE THE MEASURED ACCELERATION *****
       DO 150 J=2,I
       TD(J-1)=0.001
       TTOL=TTOL+TD(J-1)
       DELX(J-1)=(X(J)-X(J-1))*0.45
       VEL(J-1)=DELX(J-1)/TD(J-1)
       IF(J .EQ.2) GO TO 150
       DTAVG=(TD(J-1)+TD(J-2))/2.0
       DELV(J-2)=VEL(J-1)-VEL(J-2)
       ACEL(J-2)=DELV(J-2)/2./DTAVG
       ASUM=ACEL(J-2)+ASUM
   150 CONTINUE
       IF(VCHECK.GT.520) GO TO 105
       IF(J.LT.6) GO TO 105
C      ***** READ PERIODICITY OF DECELERATION DATA *****
       READ(1,99) DELT
       STNUM=DRPU(M)/V/CON/DELT*1000.
       STFNM=DRPU(M)/FLMVEL/DELT*1000.
       STBNM=400/DELT/V/CON
       K1=1
   105 IM2=I-2
       ABAR(M)=ASUM/IM2
       SVEL=V*CON/100.
       QFLOW=Q/480.
```

```
C     ***** CALCULATE THE SERAFINI ANALYTIC ACCELERATION *****
      RE(M)=V*DRPU(M)*32.61
      CDS(M)=24./RE(M)*(1.+0.17*RE(M)**TOTHRD)
      AS(M)=(CDS(M)*0.75)*.0001135/DRPU(M)*SVEL**2*10000.
      RS(M)=ABAR(M)/AS(M)
      ADIFF(M)=AS(M)-ABAR(M)
      IF(ADIFF(M).LT.0.0) GO TO 155
C     ***** FIND INDUCED VELOCITY AND VORTEX STRENGTH *****
      VELIN(M)=SQRT(ADIFF(M)*DRPU(M)*1.333)*100.
      VORST(M)=VELIN(M)*0.168*100.
  155 IF(VCHECK.GT.520.) GO TO 161
C     ***** DETERMINE WHICH WRITE STATEMENT TO USE *****
      IF(K1.EQ.1 .AND. ADIFF(M) .GT.0.0) GO TO 156
      IF(K1.EQ.1 .AND.ADIFF(M).LT.0.0) GO TO 157
      IF (K1.EQ.0 .AND.ADIFF(M).GT.0.0) GO TO 158
      IF(K1.EQ.0 .AND. ADIFF(M).LT.0.0) GO TO 159
  156 WRITE(6,600) SVEL,QFLOW,DRPU(M),RE(M),ABAR(M),RS(M),VELIN(M),
     1 VORST(M),DELT,STNUM,FLMVEL,STFNM,STBNM
      GO TO 1
  157 WRITE(6,610) SVEL,QFLOW,DRPU(M),RE(M),ABAR(M),RS(M),DELT,STNUM,
     1 FLMVEL,STFNM,STBNM
      GO TO 1
  158 WRITE(6,620) SVEL,QFLOW,DRPU(M),RE(M),ABAR(M),RS(M),VELIN(M),
     1 VORST(M),FLMVEL
      GO TO 1
  159 WRITE(6,630) SVEL,QFLOW,DRPU(M),RE(M),ABAR(M),RS(M),FLMVEL
      GO TO 1
  161 IF (ADIFF(M).LT.0.0) GO TO 162
      WRITE(6,640) SVEL,QFLOW,DRPU(M),RE(M),ABAR(M),RS(M),VELIN(M),
     1 VORST(M)
      GO TO 1
  162 WRITE (6,650) SVEL,QFLOW,DRPU(M),RE(M),ABAR(M),RS(M)
      GO TO 1
C     ***** RESET THE COUNTER *****
  160 M=0
      VCHECK=V
      QCHECK=Q
      IF(VCHECK.GT.520.) GO TO 170
      READ(2,102) STEAM,WATER,FLMVEL,STFNUM
  170 IF(I.EQ.1) CALL EXIT
      GO TO 100
   90 FORMAT('1',1X,'STEAM    FLOW',6X,'DROP    REYNOLDS   MEASURED',
     1 3X,'ACCELER- INDUCED   VORTEX  PERIODICITY OF  STROUHAL',2X,
     2 'FILM    STROUHAL  STROUHAL'/'VELOCITY  RATE    DIAMETER',3X,
     3 'NUMBER  ACCELERATION  ATION   VELOCITY STRENGTH  DECELERATION',
     4 4X,'NUMBER  VELOCITY  NUMBER    NUMBER'/'(M/SEC) (CM**2/S)',3X,
     5 '(CM)',14X,'(CM/SEC**2)  RATIO   (CM/SEC) (CM**2/S)',2X,
     6 '(10**3 SEC)',5X,'STEAM  (CM/SEC)   FILM',5X,'BLADE')
   99 FORMAT (F5.2)
  101 FORMAT(6F10.5)
  102 FORMAT(4F8.4)
  600 FORMAT ('0',1X,F5.1,3X,F6.4,4X,F6.4,3X,F7.2,3X,F10.2,2X,F6.3,3X,
     1 F8.2,1X,F9.2,4X,F5.2,7X,F8.6,2X, F6.3,3X,F6.4,4X,F7.5)
  610 FORMAT ('0',1X,F5.1,3X,F6.4,4X,F6.4,3X,F7.2,3X,F10.2,2X,F6.3,25X,
     1 F5.2,7X,F8.6,2X,F6.3,3X,F6.4,4X,F7.5)
  620 FORMAT ('0',1X,F5.1,3X,F6.4,4X,F6.4,3X,F7.2,3X,F10.2,2X,F6.3,3X,
     1 F8.2,1X,F9.2,26X,F6.3)
  630 FORMAT ('0',1X,F5.1,3X,F6.4,4X,F6.4,3X,F7.2,3X,F10.2,2X,F6.3,
     1 47X,F6.3)
  640 FORMAT ('0',1X,F5.1,3X,F6.4,4X,F6.4,3X,F7.2,3X,F10.2,2X,F6.3,3X,
```

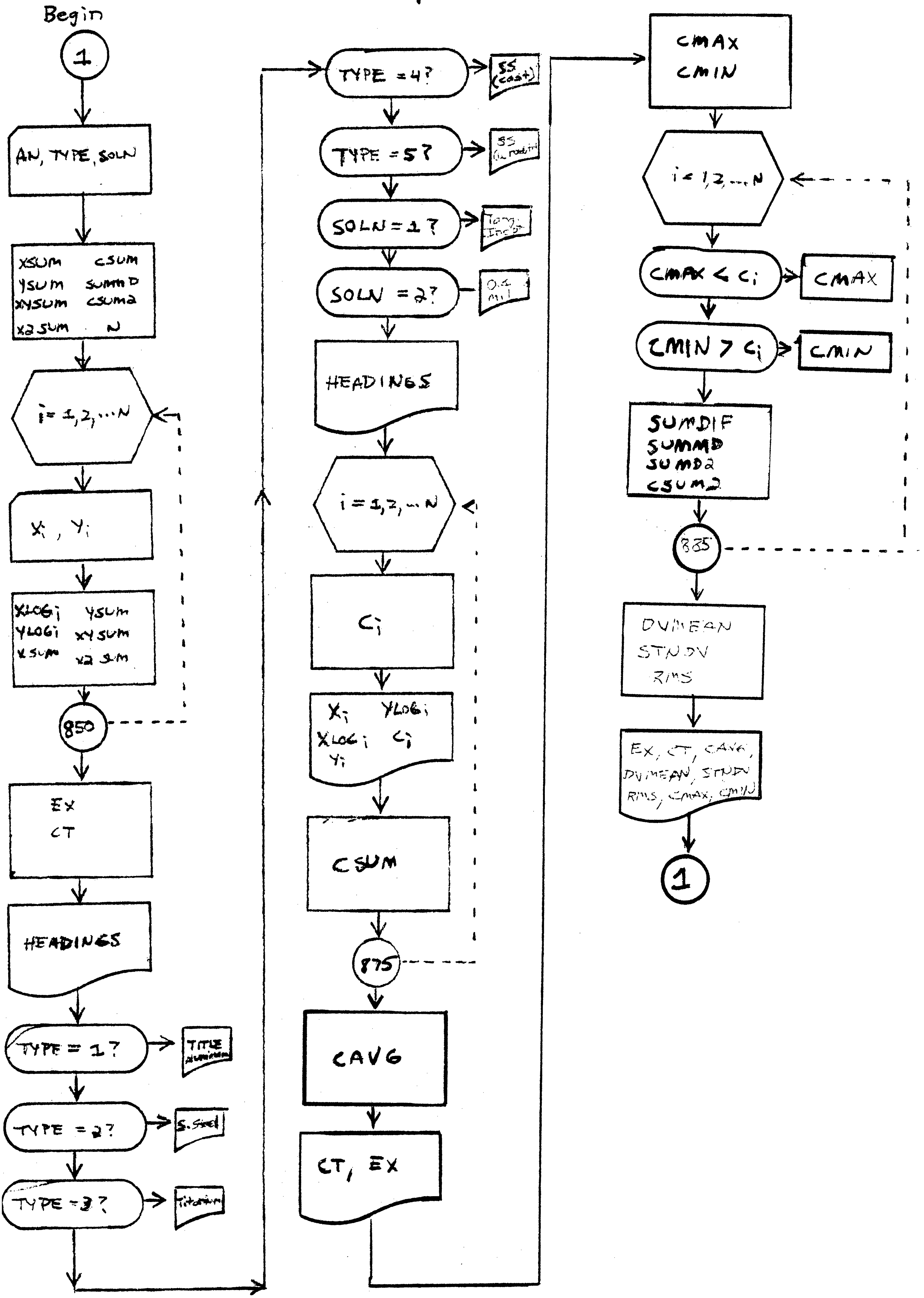
```
     1 F8.2,1X,F9.2)
  650 FORMAT ('0',1X,F5.1,3X,F6.4,4X,F6.4,3X,F7.2,3X,F10.2,2X,F6.3)
      END
$R -LOAD 1=T3DATA 2=FDATA 5=WDATA
$ENDFILE
$SIG
```

Induced Velocity Program

ABAR(M)	Average of the measured acceleration for one droplet
ACEL(J)	Measured acceleration of one droplet for three successive film readings
ADIFF(M)	The difference between Serafini and measured acceleration
AS(M)	Analytical acceleration as calculated by Serafini
ASUM	Sum of all the measured accelerations for one droplet
CDS(M)	Serafini's expression for the drag coefficient
CON	A constant conversion factor, 30.48, the number of centimeters in one foot
CONFAC	A constant conversion factor, .45, the number of centimeters in one measured screen unit
DELT	The periodicity of deceleration of one given droplet
DELV(J)	The difference between two consecutively measured velocities
DELX(J)	The difference between two consecutively measured distances
DIA(I)	Diameter of the water droplet for a particular observation
DPSUM	The sum of all diameters observed for a particular droplet
DRPU(M)	The average of all diameters observed for a particular droplet
DTAVG	The average time between each successive observation
FILMV	The film speed at which the pictures were taken
FLMVEL	Liquid film velocity on the blade
FN(I)	Number of frames between each successive observation
IM2	The number of observations in a set minus two
K1	A control which tells if the particle has a periodicity of deceleration associated with it
M	A counter which tells how many different cases were observed for each steam velocity and flow rate
Q	Flow rate of water entering the test section
QCHECK	A control that is used to see if the flow rate has changed
QFLOW	Specific water flow rate in centimeters squared per second

RE(M)	Reynolds number for a particular droplet
RHOW	Density of water
RS(M)	The ratio of measured acceleration to Serafini acceleratio for a particular droplet
STBNM	Strouhal number calculated from the blade width
STEAM	Steam velocity
STFNM	Strouhal number calculated from the film velocity
STFNUM	Average values of film Strouhal number for a particular steam velocity and flow rate
STNUM	Strouhal number calculated from the steam velocity
SVEL	Steam velocity in meters per second
T(I)	Thickness of the water droplet for a particular observati
TD(I)	Elapsed time between observations
TOTHRD	A constant, two-thirds
TTOL	Total time that observations on a particular drop are being made
V	Steam velocity
VCHECK	A control to see if the steam velocity has changed
VEL(J)	Measured velocity of one droplet for two successive film readings
VELIN(M)	Induced velocity caused by the vortex shedding
VORST(M)	Vortex strength
WATER	Flow rate of water entering the test section
X(I)	Distance an individual particle was away frcm the edge of the blade

Linefit Program



COMPUTER PROGRAM

```
$SIG ODLU T=1 P=10 PRINT=TN ROUTE=CNTR
BATCH,NORMAL,UNIV
**LAST SIGNON WAS: 15:34:39
 USER "ODLU" SIGNED ON AT  15:39:16 ON FRI MAR 31/78
$L LINEFIT
C   ********    STRAIGHT LINE FIT PROGRAM   ******
C       **  THIS PROGRAM CALCULATES THE BEST LINE FIT TO A
C       ** OF LOGARITHMIC DATA BY THE METHOD OF LEAST SQUA
      DIMENSION X(99), XLOG(99), Y(99), YLOG(99), C(99)
C  ***  READ NUMBER OF DATA POINTS FOR THE SET  ***
    1 READ(5,800)  AN,TYPE,SOLN
      XSUM   = 0.0
      YSUM   = 0.0
      XYSUM  = 0.0
      X2SUM  = 0.0
      CSUM   = 0.0
      SUMMD  = 0.0
      CSUM2  = 0.0
      N  =  AN
      DO 850 I=1,N
      READ(5,800) Y(I), X(I)
      XLOG(I)= ALOG10(X(I))
      YLOG(I)= ALOG10(1/Y(I))
      XSUM= XLOG(I)+XSUM
      YSUM=YLOG(I)+YSUM
      XYSUM= XLOG(I)*YLOG(I) +XYSUM
  850 X2SUM= XLOG(I)**2 +X2SUM
      EX     =  (XYSUM - XSUM*YSUM/AN) / (X2SUM - XSUM**2/
      CT    =  10.**((ABS(YSUM)+EX*XSUM ) / AN )
      WRITE(6,200)
      IF(TYPE.EQ.1.0) WRITE (6,201)
      IF (TYPE.EQ.2.0) WRITE(6,202)
      IF(TYPE.EQ.3.0) WRITE(6,203)
      IF (TYPE.EQ.4.0) WRITE  (6,204)
      IF (TYPE.EQ.5.0) WRITE  (6,205)
      IF(SOLN.EQ.1.0) WRITE(6,211)
      IF(SOLN.EQ.2.0) WRITE(6,212)
      WRITE(6,220)
      DO 875 I=1,N
      C(I)    =  Y(I)*X(I)**(ABS(EX))
      WRITE(6,820) X(I), XLOG(I), Y(I), YLOG(I), C(I)
  875 CSUM    =  C(I)   + CSUM
      CAVG    =  CSUM/AN
      WRITE(7,840) CT , EX
      CMAX    =  C(1)
      CMIN    =  C(1)
      DO 885 I=1,N
      IF( CMAX .LT. C(I) ) CMAX  = C(I)
      IF( CMIN .GT. C(I) ) CMIN  = C(I)
      SUMDIF =  ABS(C(I) - CAVG)
      SUMMD  =  SUMDIF  +  SUMMD
      SUMD2  =  SUMDIF**2  +  SUMD2
  885 CSUM2  =  C(I)**2  +  CSUM2
      DVMEAN =  SUMMD / AN
      STNDV  =  SQRT( SUMD2 / (AN-1) )
      RMS    =  SQRT( CSUM2 / AN )
C  *** PRINT STATISTICS OF PROPORTIONAL CONSTANTS  ***
      WRITE(6,830)  EX , CT, CAVG,DVMEAN,STNDV,RMS,
     1 CMAX, CMIN
      GO TO 1
```

```
      800 FORMAT(3F10.3)
      200 FORMAT ('1', 15X, 'MDER AND INCUBATION DATA ANALYSIS')
      201 FORMAT ('0', 24X,'ALUMINUM 1100-0')
      202 FORMAT('0', 20X, 'STAINLESS STEEL 17-4 PH')
      203 FORMAT ('0', 24X,'TITANIUM GAL-4V')
      204 FORMAT ('0',17X,'STAINLESS STEEL 17-4 PH (CAST)')
      205 FORMAT ('0',15X,'STAINLESS STEEL 17-4 PH (WROUGHT)')
      211 FORMAT (' ',23X, 'TANGENT INTERCEPT')
      212 FORMAT (' ',28X,'0.1 MIL')
      220 FORMAT ('0',4X,'INCUBATION DATA',8X,'MDPR DATA',7X,
         1 'PROPORTIONAL'/5X,'INCBT',2X,'LOG(INCBTN)',3X,'MDPR',2X
         2 'LOG(MDPR)',5X,'CONSTANT'/)
      820 FORMAT(2(F10.3,F10.6),F15.3)
      830 FORMAT(//T2,'SLOPE OF LINE(EXPCNENT,N)    =',T35,F11.7//
         3T2,    'BEST PROPORTIONALITY CONSTANT =',  T34,F11.3////
         4 '  STATISTICAL ANALYSIS CF PROPORTIONAL CONSTANT'///
         5T2,    'ARITHMATIC MEAN                =',T34,F12.3//
         6T2,    'MEAN DEVIATION                 = ',T34,F12.3//
         7T2,    'STANDARD DEVIATION             =  ',T34,F12.3//
         9T2,    'ROOT MEAN SQUARE               = ',T34,F12.3//
         1T2,    'MAXIMUM PROPORTIONAL CONSTANT =',T34,F12.3//
         2T2,    'MINIMUM PROPORTIONAL CONSTANT =',T34,F12.3//
         3 28('* '))
      840 FORMAT(F20.10,',',F20.10,',')
          END
END OF FILE


$SIG
```

LIST OF VARIABLES

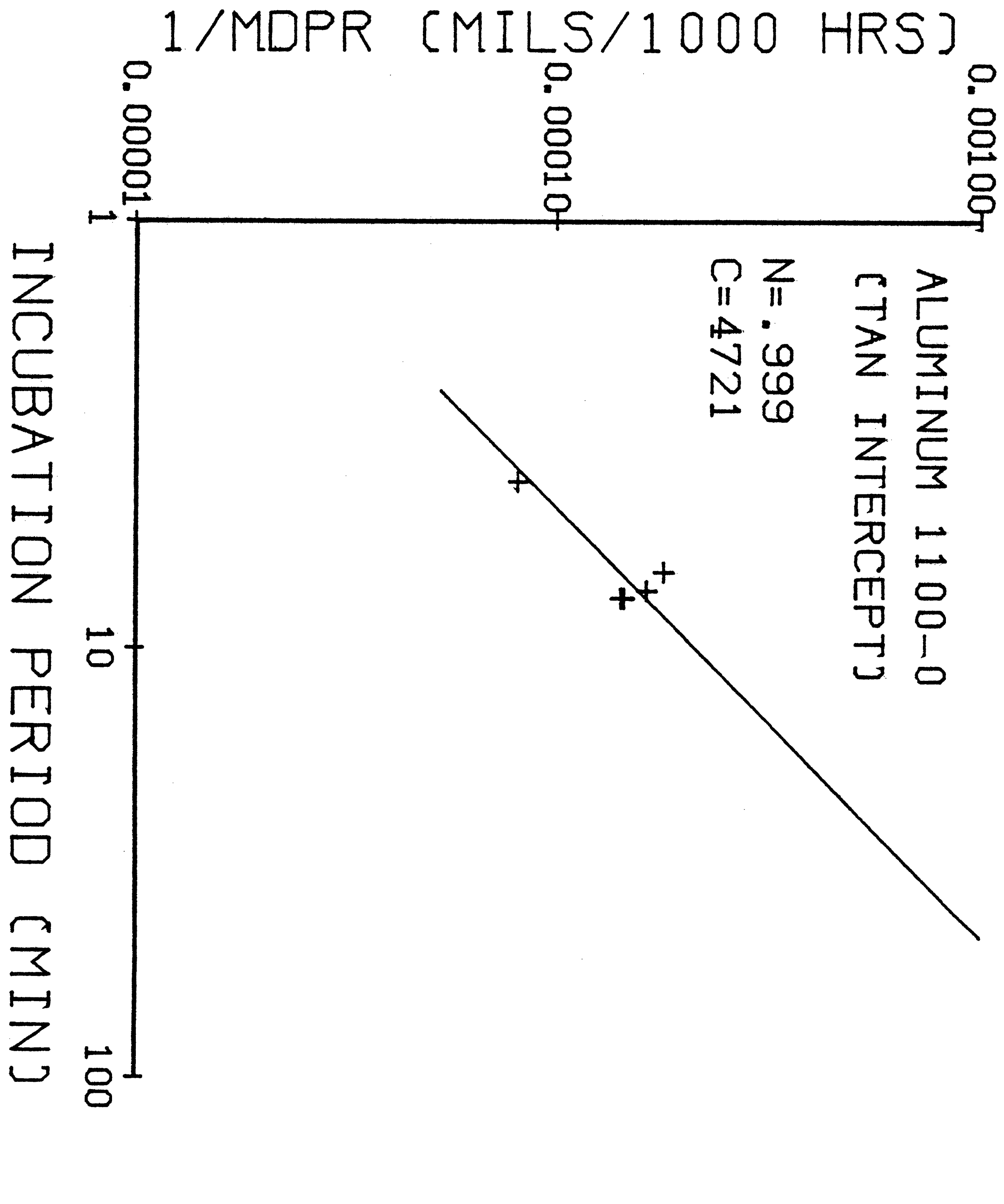
AN	Number of data points through which the line is to be drawn
C(I)	Proportionality constant for each pair of data points
CAVG	Average of all proportional constants for each set
CMAX	Maximum proportional constant in a set
CMIN	Minimum proportional constant in a set
CSUM	Sum of all proportional constants for each set
CSUM2	Sum of all the squares of the proportional constants for each set
CT	Best proportional constant as measured from the calculated slope of the line
DVMEAN	Mean deviation of all proportional constants in a set
EX	Exponent of the best fit line
N	Number of data points in a set
RMS	Root mean square of all proportional constants in a set
SOLN	Method by which incubation period is measured
SUMDIF	Absolute value of the difference between the average and individual proportional constants
SUMMD	Sum of all the SUMDIF values
SUMMD2	Sum of all the squares of the SUMDIF values
STNDV	Standard deviation of all proportional constants in a set
TYPE	The particular material that was tested
X(I)	Abscissa input data point
XLOG(I)	Log base 10 of the point X(I)
XSUM	Sum of all the XLOG(I) points for a set
X2SUM	Sum of all the squares of XLOG(I) points for a set
XYSUM	Sum of all the XLOG(I) and YLOG(I) points for a set
Y(I)	Ordinate input data point
YLOG(I)	Log base 10 of the inverse of the point Y(I)
YSUM	Sum of the YLOG(I) points for a set

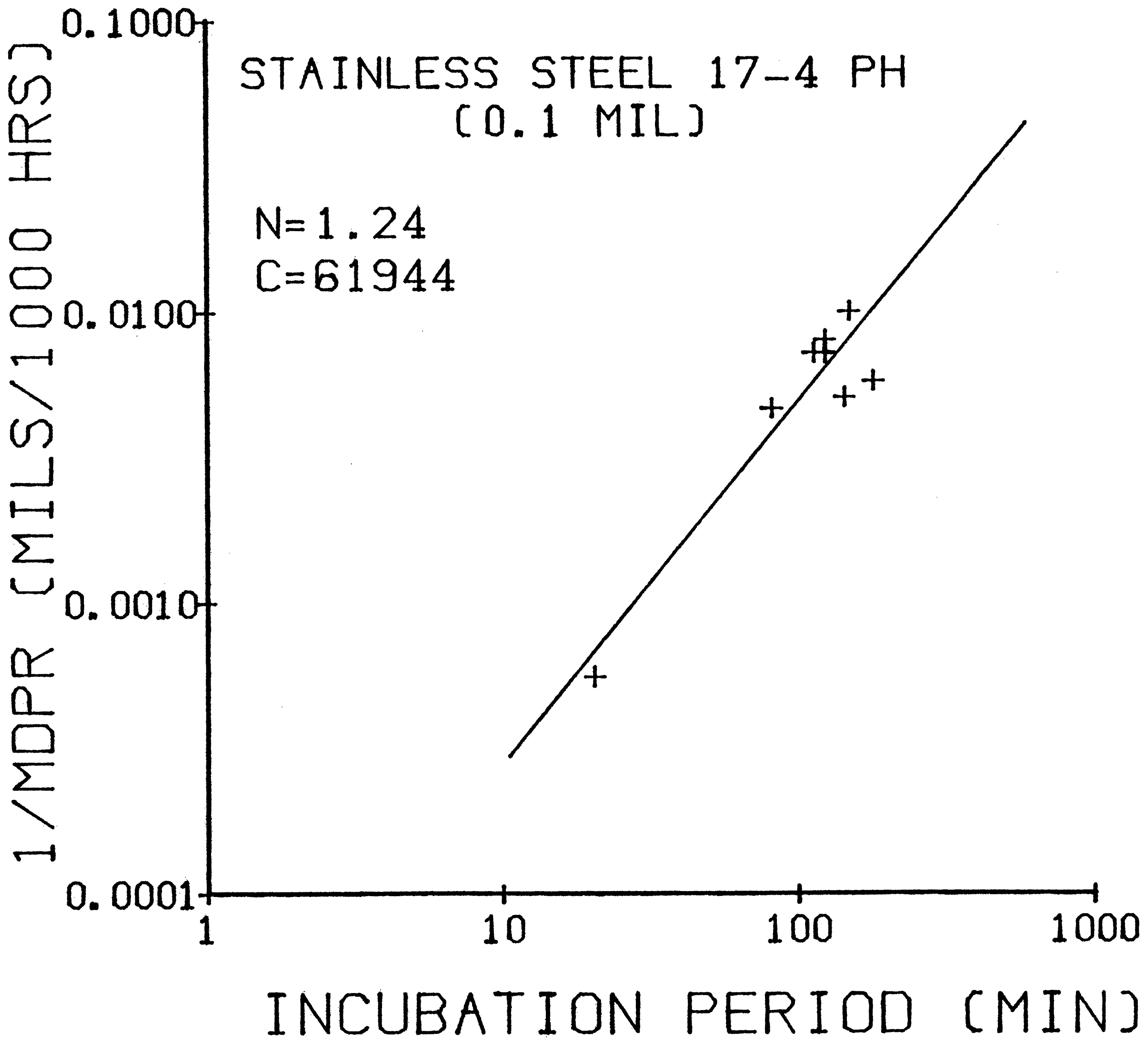
SAMPLE ADS COMMANDS

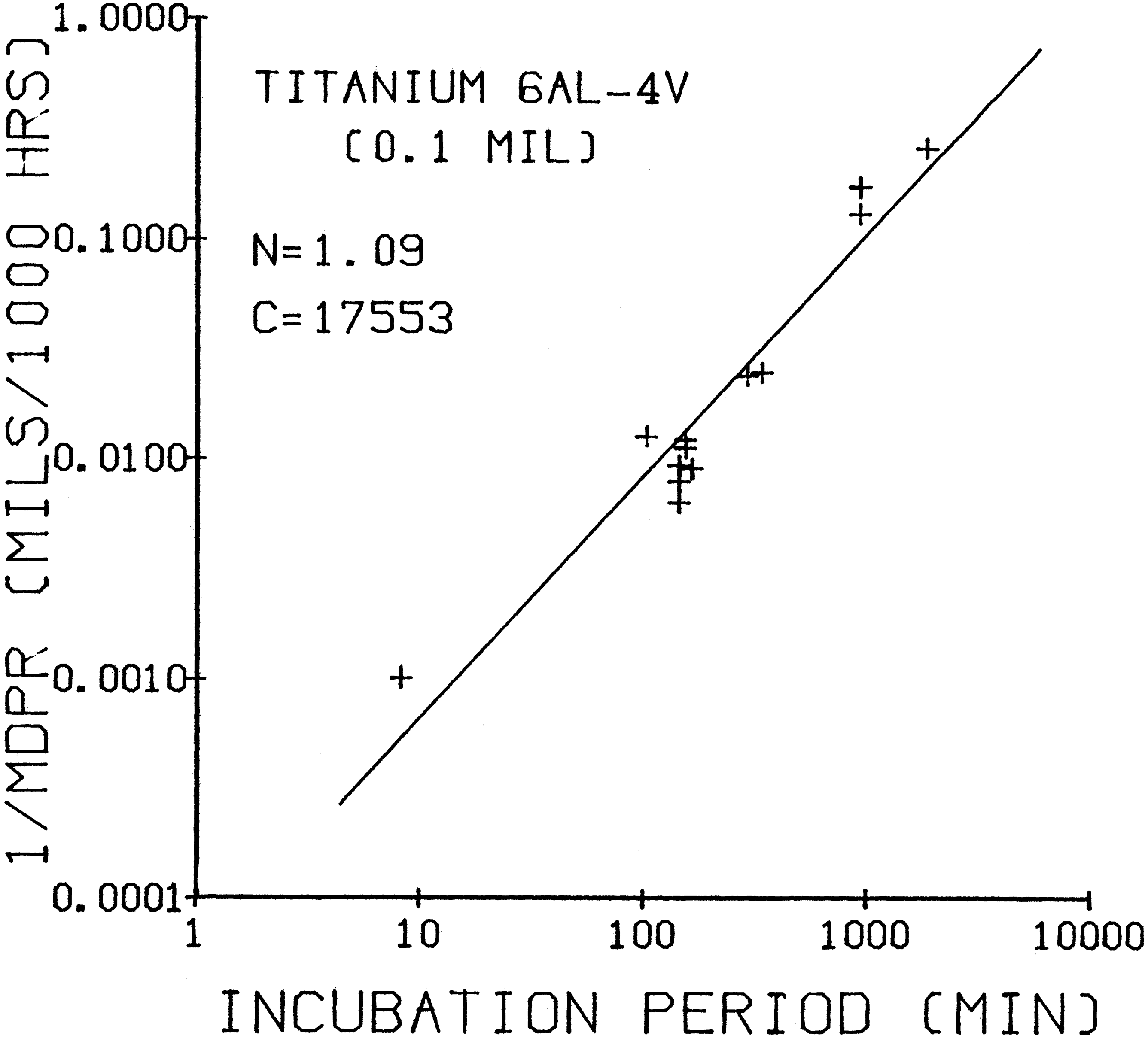
(TITANIUM)

```
$SIGNON ODLU
$RUN AERO:GRAF
C:  YMIN=.0001
C:  YMAX=1.
C:  XMIN=1.
C:  XMAX=10000.
C:  LLOG
C:  TICY=.0001,9
C:  TICX=1,9
C:  LBLY=F6.4,1,1
C:  LBLX=I6,1,1
C:  ADD FILE PFILE(1,16)
C:  DATA
C:  CRVF=1,14
C:  TEXT
    T:  HORZ
    T:  SCAT=1
    T:  GO
INCUBATION PERIOD (MIN)@
    T:  VERT
    T:  GO
1/MDPR (MILS/1000 HRS)@
    T:  HORZ
    T:  SCAT=.75
    T:  GO
```

```
TITANIUM 6AL-4V@

    T: GO

(TAN INTERCEPT)@

    T: GO

N=.918@

    T:  GO

C=4721@

    T: END

C:   AUTO

C:   CALC=1.25

C:   MTS

#RUN *CCQUEUE PAR=PLOT1

#SIGNOFF
```


1/MDPR (MILS/1000 HRS)
0.00001
0.00010
0.00100
ALUMINUM 1100-0
(TAN INTERCEPT)
N=.999
C=4721
1
10
100
INCUBATION PERIOD (MIN)


STAINLESS STEEL 17-4 PH
(0.1 MIL)
N=1.24
C=61944
1/MDPR (MILS/1000 HRS)
0.1000
0.0100
0.0010
0.0001
1
10
100
1000
INCUBATION PERIOD (MIN)


TITANIUM 6AL-4V
(0.1 MIL)
N=1.09
C=17553
1/MDPR (MILS/1000 HRS)
1.0000
0.1000
0.0100
0.0010
0.0001
1
10
100
1000
10000
INCUBATION PERIOD (MIN)