PART II

B. PROGRAMMING OF THE DATA PROCESSING SYSTEM

Contents

APPENDIX B1

DIGITIZATION AND CALIBRATION Program

The purpose of such a program is to enable the ICL Computer to read the output data from the ADC of the Hewlett Packard Fourier Analyzer and to reproduce the digitized data, after scaling, into a suitable format for further use in the data analyses programs. The new storing medium is abitrarily chosen to be punched cards for convenient replacement of damaged cards during data processing. The option of calibrating the recorded signals to their actual values at the output of instruments are also provided at this stage.

Figure (B1) shows an example of the data format on tapes produced by the PUNCH command (via high speed punch) on the ADC.

SF	-4	0	9	8192	CR	LF
(	20)	32767	16384	....		
(	28)	24523	....			

Fig. (B1) Example of data on output tapes of the Hewlett Packard ADC

where CR = Carriage return

LF = Line feed

SF = Stands for 'Scale Factor'

-4 = Is (K) in the expression 10^K.

All data words are multiplied by 10^K. Thus in the above example all data words are multiplied by $10^{-4} = 0.0001$

0 = Is a coordinate code (e.g. rectangular, polar etc...) (for further details see Table B 1).

9 = Frequency Code, which expresses data sampling parameters in terms of SAMPLE MODE and MULTIPLIER switch setting on ADC. (for further details see Table B2).

8192 = Block Calibrator.

20,28 = Are the locations of the first data word in each data record (of 8 words) in the data block of the ADC.

32767,) = Are data words. Data word system is as follows:
16384,) 0 stands for 0 and 32767 for -1.
24523) Therefore to convert data words into physical values, use the following formula

$$\text{Physical Value} = \frac{\text{Data word}}{32767} \times \frac{\text{Block Calibrator}}{32767} \times 10^{K} \qquad \text{(B1)}$$

Examination of the above mentioned example for paper tape output indicates that appropriate format are required to pick up the values of (K) and the Block Calibrator for scaling the data and to ignore other characters which could not be recognised by the ICL tape reader.

The first part of the program performs the reading and scaling processes, while the second part converts the data into their physical values as given by equation (B1).

Calibration of the recorded signals to their actual values could be carried out at this step using equation (B2).

$$E_{actual} = C.\ E_{recorded} + D \qquad \text{(B2)}$$

where C is the attenuation factor on the recorded signal

and D is the biased DC level from the recorded signals.

In fact two versions of this program are available. The first one, calculates the values of C and D from input data giving the values of the calibration voltages and their corresponding digitized values. The latter set of data should be punched on the same tapes of the digitized signals, while the second version of this program could be used for signals with known calibration constants.

Finally, the program calculates the correct engine speed and the sample size of the digitized data as given by the following equations

$$rpm = \frac{1.2 \times 10^8}{NP \times SR} \qquad (B3)$$

and

$$SS = 720/NP \qquad (B4)$$

where NP is the number of samples per cycle as obtained from the recorded timing mark

SR is the sampling intervals on the ADC (micro-sec/sample) - (see Table (B 1).

and SS is the sample size in crank angle degrees.

TABLE (B1) Frequency Codes of the ADC

Freq. Code	F_{max} MAX.FREQ.	ΔT Δ TIME	Freq. Code	Δf Δ FREQ.	T TOTAL TIME
47	50 KHz	10 μsec	63	100 Hz	10 msec
46	25 KHz	20 μsec	62	50 Hz	20 msec
45	10 KHz	50 μsec	61	20 Hz	50 msec
44	5 KHz	100 μsec	60	10 Hz	100 msec
43	2.5 KHz	200 μsec	59	5 Hz	200 msec
42	1 KHz	500 μsec	58	2 Hz	500 msec
41	0.5 KHz	1000 μsec	57	1 Hz	1000 msec
40	0.25 KHz	2000 μsec	56	0.5 Hz	2000 msec
39	0.10 KHz	5000 μsec	55	0.2 Hz	5000 msec
15	50 Hz	10 msec	31	100 mHz	10 sec
14	25 Hz	20 msec	30	50 mHz	20 sec
13	10 Hz	50 msec	29	20 mHz	50 sec
12	5 Hz	100 msec	28	10 mHz	100 sec
11	2.5 Hz	200 msec	27	5 mHz	200 sec
10	1 Hz	500 msec	26	2 mHz	500 sec
9	0.5 Hz	1000 msec	25	1 mHz	1000 sec
8	0.25 Hz	2000 msec	24	0.5 mHz	2000 sec
7	0.1 Hz	5000 msec	23	0.2 mHz	5000 sec

TABLE (B2) Coordinate S Codes of the ADC

Coordinate Code	Time	Frequency	Rectangular	Polar	log	Linear	Single Precision	Double Precision
0	X		X			X	X	
2	X		X		X		X	
4		X	X			X	X	
5		X		X		X	X	
7		X		X			X	
12		X	X			X		X
14		X	X					X

Version No. 1

DIGITIZATION AND CALIBRATION
Program

INPUT DATA:

NS	Number of individual signals punched on tape.
NT	Number of individual tapes for each signal.
NC	Control variable calling the calibration subroutine if an input value of 9 is introduced.
N1	Number of samples digitized on each tape.
N2	Number of calibration voltages.
N3	Number of samples digitized from each calibration voltage recorded signal.
NI	First sample number on trace (accounts for any shift of the digitized signal.
N GRAPH	Control variable calling graph plotter subroutine if an input value of 9 is introduced.
NGP	Number of graph plots required.
NX	Control variable for selecting x axis variable according to the type of digitized signal.

NX = 1	For crank angles	(degrees)
NX = 2	For time	(sec)
NX = 3	For frequencies	(Hz)

VCV(I)	Actual values of calibration voltages.
SR	Sampling interval on the ADC (micro-sec/sample).
C	Attenuation factor on recorded signals.
D	Biased DC voltages from recorded signals, for known calibration of signals.
VARIABLE(I)	A string of alphanumeric characters describing the digitized signals.
CR	Compression ratio of engine.

Version No. 1 (continued)

INPUT DATA:

YP	Probe vertical location in combustion chamber.
THETA	Hot wire orientation inside the combustion chamber.
X MIN, X MAX	Maximum and minimum values on x axis.
Y MIN, Y MAX	Maximum and minimum values on y axis.
X INS, Y INS	Length of x and x axis (in inches) - respectively.

OUTPUT DATA:

C	Attenuation factor on recorded signals.
D	Biased DC voltage from recorded signals.
VARIABLE (I)	(As introduced in input data).
RPM	Engine speed.
SS	Sample size (degrees)
A(I)	Actual values of recorded signals.

```
JOB N200,N,NS1505
LUFORTRAN
IN TRO(NON-STANDARD),ONLINE
RUN
JOBCORE 30000
DOCUMENT SOURCE
      LIBRARY (ED,SUBGROUPNAGF)
      LIBRARY (ED,SUBGROUPUSUB)
      LIBRARY (ED,SUBGROUPGRAF)
      PROGRAM(N200)
      COMPACT
      INPUT 1 = CRO
      INPUT 3=TRO
      OUTPUT 2 = LPO
      OUTPUT 4 =CPO
      TRACE 2
      END


      MASTER   DIGITIZATION AND CALIBRATION
C     ******************************************************************
C     NS = NUMBER OF INDIVIDUAL SIGNALS PUNCHED ON TAPE.
C     NT = NUMBER OF INDIVIDUAL TAPES FOR EACH SIGNAL.
C     NC = CONTROL VARIABLE CALLING CALIBRATION SUBROUTINE  IF EQUALS(9)
C     N1 = NUMBER OF POINTS DIGITIZED ON EACH TAPE.
C     N2 = NUMBER OF CALIBRATION VOLTAGES .
C     N3 = NUMBER OF POINTS DIGITIZED FROM EACH CALIBRATION VOLTAGE .
C     NI = FIRST SAMPLE NUMBER ON TRACE (COULD BE NEGATIVE).
C     NAME(X) = NAME OF X- AXIS VARIABLE .
C     NAME(Y) = NAME OF Y AXIS VARIABLE .
C     NX = CONTROL VARIABLE FOR SELECTING THE X-AXIS VARIABLE ACCORDING
C          TO THE TYPE OF DIGITIZED SIGNAL .
C     NX = 1 FOR CRANK ANGLES  (DEGREES) .
C     NX = 2 FOR TIME   (SEC) .
C     NX = 3 FOR FREQUENCIES   ( HZ) .
C     NGP = NUMBER OF GRAPH PLOTS REQUIRED FROM EACH SIGNAL .
C     NGRAPH = CONTROL VARIABLE FOR CALLING GRAPH PLOTTER SUBROUTINES
C              IF ITS INPUT VALUE EQUALS 9 .
C     VCV(I) = ACTUAL VALUES OF CALIBRATION VOLTAGES.
C     SR = SAMPLING INTERVAL ON THE ADC  (MICRO-SEC).
C     C = ATTENUATION FACTOR FOR RECORDED SIGNAL.
C     D = BIASED DC VOLTAGE FOR RECORDED SIGNALS.
C     VARIABLE(I) = A STRING OF ALPHANUMERIC  CHARACTERS DESCRIBING THE
C                   RECORDED SIGNAL.
      INTEGER SR
      COMMON /B1/ N1,IT
      COMMON /B2/ C,D,CT,NR,NRP
      COMMON /B3/ N2,N3,VCV(5)
      COMMON/B4/NAMEX(3),NAMEY(3),XMIN,YMIN,XMAX,YMAX,XINS,YINS,NX
      COMMON/B5/NP,SR,NI,IG
      DIMENSION VARIABLE(4)
      NR,NRP=0
      CT = 1073676289.
      READ(1,111) NS
      DO 500  IS =  ,NS
      READ(1,111) NT,NC
      IF(NC.EQ.9) GO TO 100
```

```
      READ(1,333) C,D
      READ(1,333) CR
      GO TO 200
 100  READ(1,11 ) N2,N3
      READ(1,333) (VCV(I),I=1,N2)
      CALL CALIBRATION
      WRITE(2,999) C,D
 200  CONTINUE
      IF(NT.EQ.0) NRP=NR
      IF(NT.EQ.0) GO TO 500
      DO 400 IT=1,NT
      READ(1,111) N1,NP,SR,NGRAPH,NGP,NX,NI
      READ(1,444) (VARIABLE(I),I=1,4)
      IF(NX.GT.1) READ(1,333) THETA ,YP
      SS=720./FLOAT(NP)
      RPM=120.*(10.**6)/FLOAT(NP*SR)
      MAX FREQ = 10./(FLOAT(SR)*2.)
      IF(NX.EQ.1) WRITE(2,777) (VARIABLE(I),I=1,2 ),RPM,(VARIABLE(I),I=3
     *,4),CR,NP,SS
      IF(NX.EQ.2) WRITE(2,888)RPM,( VARIABLE (I),I=1,2),CR,YP,THETA,SR,
     *MAX FREQ
      IF(NX.EQ.3) WRITE(2,666)RPM,( VARIABLE (I),I=1,2),CR,YP,THETA,SR,
     *MAX FREQ
      IF(NX.EQ.4) WRITE(2,555)RPM,( VARIABLE (I),I=1,2),CR,YP,THETA,SR,
     *MAX FREQ
      CALL TAPE READER
      IF (NGRAPH.NE.9) GO TO 300
      READ(1,333) XMIN,XMAX,YMIN,YMAX,XINS,YINS
      READ(1,444) (NAMEX(I),I=1,3),(NAMEY(I),I=1,3)
      IF(NS.EQ.1) CALL UTPOP
      DO 300 IG=1,NGP
      CALL GRAPH PLOTTER
 300  CONTINUE
 400  CONTINUE
 500  CONTINUE
      IF (NGRAPH.EQ.9) CALL UTPCL
 111  FORMAT(8I4)
 333  FORMAT(6F0.0)
 444  FORMAT(4A8)
 555  FORMAT(1H1,'          SECOND DERIVATIVE OF AUTO-CORRELATION FUNCTION
     *'/'  ENGINE SPEED  ',F8.3,'(RPM)',2A8,'  COMPRESSION RATIO = ',F2.
     *0,':1'/'   PROBE VERTICAL POSITION =',F6.3,'(MM)  CRANK ANGLE =',
     *F7.3,'(DEGREES)  SAMPLING RATE =',I3,'(MICRO-SEC)/SAMPLE)  MAXIMUM
     * FREQUENCY =',F5.2,'(KHZ)'//)
 666  FORMAT(1H1,'           POWER SPECTRAL DENSITY FUNCTION'/
     *'    ENGINE SPEED =',F8.3,'(RPM)',2A8,'  COMPRESSION RATIO = ',F2.
     *0,':1'/'   PROBE VERTICAL POSITION =',F6.3,'(MM)  CRANK ANGLE =',
     *F7.3,'(DEGREES)  SAMPLING RATE =',I3,'(MICRO-SEC)/SAMPLE)  MAXIMUM
     * FREQUENCY =',F5.2,'(KHZ)'//)
 777  FORMAT(1H1,'             DIGITIZED DATA FOR',2A8/
     *'    ENGINE SPEED =',F8.3,'(RPM)',2A8,'  COMPRESSION RATIO = ',F2.
     *0,':1 NUMBER OF SAMPLES =',I3,'SAMPLE SIZE =',F7.3,'(DEGREES) ')
 888  FORMAT(1H1,'                AUTO-CORRELATION FUNCTION'//
     *'    ENGINE SPEED =',F8.3,'(RPM)',2A8,'  COMPRESSION RATIO = ',F2.
     *0,':1'/'   PROBE VERTICAL POSITION =',F6.3,'(MM)  CRANK ANGLE =',
     *F7.3,'(DEGREES)  SAMPLING RATE =',I3,'(MICRO-SEC)/SAMPLE)  MAXIMUM
     * FREQUENCY =',F5.2,'(KHZ)'//)
 999  FORMAT (1H1,'                 ATTENUATION FACTOR = ',F8.4,
     *'  BIASED DC VOLTAGE = ',F8.4)

      STOP
```

```
      SUBROUTINE  TAPE READER
C     ******************************************************************
      INTEGER SR
      DIMENSION  IA(8)
      COMMON /B1/ N1,IT
      COMMON /B2/ C,D,CT,NR,NRP
      COMMON /B6/ X(3000),A(3000)
C     N1 = NUMBER OF POINTS PUNCHED ON THE TAPE ..
C     N2 , N3 ARE NUMBERS USED FOR CALCULATING THE SCALE FACTOR OF DATA
C             PUNCHED ON TAPE
      NPP =N1/8
      NPC =NPP *8
      IF((NR.EQ.0).AND.((IT.EQ.1).OR.(NRP.EQ.0))) READ(3,111) N2,N3
      IF((NR.GT.0).OR.((IT.GT.1).AND.(NRP.GT.0))) READ(3,222) N2,N3
      IF (N2.GT.0) SF = FLOAT(10**N2)*N3/CT
      IF(N2.LT.0) SF = FLOAT(N3)/(FLOAT(10**ABS(N2))*CT)
      DO 100 L =1,NPP
      READ(3,333) (IA(I),I=1,8)
       K = (L-1) *8
      DO 100 J =1,8
       M=J+K
      A(M) = C*FLOAT(IA(J))*SF +D
  100 CONTINUE
      NRP = N1-NPC
      IF(NRP.EQ.0) GO TO 200
      READ(3,333) (IA(I),I=1,NRP)
      DO 200 J=1,NRP
      M= NPC +J
      A(M) = C*FLOAT(IA(J))*SF +D
  200 CONTINUE
      NCR=NINT(FLOAT(N1)/10.)
      IF((NCR*10).LT.N1)NCR=NCR+1
      DO 300 J =1,NCR
      M1 = (J-1) *10
      WRITE(2,444) (A(M1+I),I=1,10),J
      WRITE(4,444) (A(M1+I),I=1,10),J
  300 CONTINUE
  111 FORMAT(2X,I7,14X,I7,/)
  222 FORMAT(1X,/,2X,I7,14X,I7,/)
  333 FORMAT (10X,8I7,/)
  444 FORMAT(2X,10F7.3,I8)
      RETURN
      END
      SUBROUTINE CALIBRATION
C     ******************************************************************
      INTEGER VRV
      DIMENSION VRV(100,5),VRVM(5),N5(5),N6(5),C1(5),D1(5),SF(5)
      COMMON /B2/ C,D,CT,NR,NRP
      COMMON /B3/ N2,N3,VCV(5)
      SC,SD =0.0
      N3C = N3/8
      DO 200 J =1,N2
      IF((NRP.EQ.0).AND.((J.EQ.1).OR.(NR.EQ.0)))READ(3,111) N5(J),N6(J)
      IF((NRP.GT.0).OR .((J.GT.1).AND.(NR.GT.0)))READ(3,222)N5(J),N6(J)
      WRITE(2,111) N5(J),N6(J)
      SF(J) = FLOAT(10**N5(J))*N6(J)/CT
      WRITE(2,444) SF(J)
```

```
444 FORMAT (10X,E20.6)
    DO 100 IN3 =1,N3C
    L = (IN3-1)*8
    READ(3,333) (VRV((L+I),J),I=1,8)
     WRITE(2,333) (VRV((L+I),J),I=1,8)
100 CONTINUE
    NR =N3- (N3C*8)
    M1 = N3-NR
    IF(NR.EQ.0) GO TO 200
    READ(3,333) (VRV((M1+I),J),I=1,NR)
    WRITE(2,333)(VRV((M1+I),J),I=1,NR)
200 CONTINUE
    WRITE(2,333) N2,N3,NR
    WRITE(2,444) (VCV(I),I=1,N2)
    DO 400 J=1,N2
    X=0.0
    DO 300 I=1,N3
300 X= X+FLOAT(VRV(I,J))
400 VRVM(J) =X*SF(J)/N3
    DO 500 I=1,(N2-1)
    C1(I) = (VCV(I+1)-VCV(I))/(VRVM(I+1) VRVM(I))
500 SC = SC + C1(I)
    C = SC/(N2-1)
    DO 600 I =1,N2
    D1(I) = VCV(I) -C*VRVM(I)
600 SD = SD +D1(I)
    D = SD/N2
111 FORMAT(2X,I7,14X,I7,/)
222 FORMAT(1X,/,2X,I7,14X,I7,/)
333 FORMAT(10X,8I7,/)
    RETURN
    END


    SUBROUTINE  GRAPH PLOTTER
C   *********************************************************************
    COMMON/B4/NAMEX(3),NAMEY(3),XMIN,YMIN,XMAX,YMAX,XINS,YINS,NX
    COMMON/B5/NP,SR,NI,IG
    COMMON /B6/ X(3000),Y(3000)
    IF(NX.EQ.1) CALL ANGLES
    IF((NX.EQ.2).OR.(NX.EQ.4)) CALL TIME INTERVALS
    IF(NX.EQ.3) CALL FREQUENCIES
    CALL UTP4A(XMIN,XMAX,YMIN,YMAX,XINS,YINS,NAMEX,3,NAMEY,3)
    CALL GRID(XMIN,XMAX,YMIN,YMAX,XINS,YINS)
    CALL UTP4B(X,Y,NP,2)
    RETURN
    END


    SUBROUTINE  ANGLES
C   *********************************************************************
C   Y(I) = MEASURED ENGINE PERFORMENCE PARAMETER.(E.G.VELO,PRES.,TEMP)
    COMMON/B5/NP,SR,NI,IG
    COMMON /B6/ X(3000),Y(3000)
    SS = 720. /NP
    DO 10 I=1,NP
    X(I) = SS*I
    Y(I) = Y((IG-1)*NP +I)
 10 CONTINUE
    RETURN
```

```
      SUBROUTINE FREQUENCIES
C     ******************************************************************
C     Y(I) = POWER SPECTRUM VALUES AT DIFFERENT FREQUENCIES .
      COMMON/B5/NP,SR,NI,IG
      COMMON /B6/ X(3000),Y(3000)
      DF = (10.**6)/(2.*SR*2048.)
      X(1) =NI*DF
      Y(1) = Y(1 +(IG-1)*NP)
      DO 10 I =2,NP
      X(I) = DF*I +X(1)
      Y(I) =Y((2*I-1) +(IG-1)*NP)
   10 CONTINUE
      RETURN
      END


      SUBROUTINE TIME INTERVALS
C     ******************************************************************
C     Y(I) = AUTO-CORRELATION FUNCTION OR ITS SECOND DERIVATIVE .
      COMMON/B5/NP,SR,NI,IG
      COMMON /B6/ X(3000),Y(3000)
      X(1) = NI*SR/(10.**6)
      Y(1) = Y(1 +(IG-1)*NP)
      DO 10 I =2,NP
      X(I) = I*SR/(10.**6)+X(1)
      Y(I) = Y((IG-1)*NP +I)
   10 CONTINUE
      RETURN
      END


      SUBROUTINE GRID (XMIN,XMAX,YMIN,YMAX,XINS,YINS)
C     ******************************************************************
      DIMENSION X(2),Y(2)
      NX=IFIX(XINS)
      NY = IFIX(YINS)
      X(1) = XMIN
      Y(1) = YMIN
      Y(2) = YMAX
      DX = ( XMAX-XMIN) /XINS
      DO 1 I=1,NX
      X(1) = X(1)+DX
      X(2) = X(1)
    1 CALL UTP4B(X,Y,2,3)
      X(1) = XMIN
      DY = (YMAX -YMIN) /YINS
      DO 2 I =1,NY
      Y(1) = Y(1) + DY
      Y(2) = Y(1)
    2 CALL UTP4B(X,Y,2,3)
      RETURN
      END
      FINISH
```

Version No. 2

DIGITIZATION OF CALIBRATED SIGNALS
Program

INPUT DATA:

N CAL	A control variable which states the requirement of calibrating the digitized signals using equation (1-2) if an input value of 9 is introduced.
NT	Number of individual signals punched on a single tape.
VARIABLE (I)*	A descriptive statement about the digitized signal and the test conditions.
NP	The number of samples per cycle.
N	The total number of samples for each individual signal digitized.
SR	The sampling interval on the ADC (micro-sec) (see Table (B1)).
C	Attenuation factor in equation (B2).
D	Biased DC voltage in equation (B1).

OUTPUT DATA:

VARIABLE (I)*	(As introduced in the input data).
RPM	Engine speed.
SS	Sample size (degrees).
A(I)	Actual values of recorded signals.

```
JOB N210,N,NS1505
LUFORTRAN
IN TRO(NON-STANDARD),ONLINE
RUN
VOLUME 7500
CARDLIST
DOCUMENT SOURCE
      PROGRAM(N210)
      INPUT 1  = CRO
      INPUT 3=TRO
      OUTPUT 2 = LPO
      OUTPUT 4 = CPO
      TRACE 0
      END


      MASTER     DIGITIZATION OF CALIBRATED SIGNALS
C                ***********************************
      INTEGER SR
      DIMENSION A(5000),IA(8),VARIABLE(10)
      DATA CT,C,D/1073676289.,1.0,0.0/
      READ(1,111) NT,NCAL
      IF(NCAL.EQ.1) READ(1,222) C,D
      DO 4 IT =1,NT
      READ(1,333) (VARIABLE(I),I=1,10)
      READ(1,444) N1,NP,SR
      SS=720./FLOAT(NP)
      RPM=120.*( 0.**6)/FLOAT(NP*SR)
      WRITE(4,555) (VARIABLE(I),I=1,10),RPM,NP,SS
      NPP = N1/8
      NPC = NPP*8
      IF(NPP.EQ.0) GO TO 1
      IF((IT.EQ.1).OR.(NRP.EQ.0)) READ(3,666) N2,N3
      IF((IT.GT.1).AND.(NRP.GT.0)) READ(3,777) N2,N3
      IF(N2.EQ.0) SF = FLOAT(N3)/CT
      IF(N2.GT.0) SF = FLOAT(10**N2)*N3/CT
      IF(N2.LT.0) SF = FLOAT(N3)/((10.**IABS(N2))*CT)
      WRITE(2,1000) N2,N3,SF
      WRITE(2,555) (VARIABLE(I),I=1,10),RPM,NP,SS
      DO 1 L =1,NPP
      READ(3,888) (IA(I),I=1,8)
      K = (L-1)*8
      DO 1 J =1,8
      M = J+K
      A(M) = C*FLOAT(IA(J))*SF + D
    1 CONTINUE
      NRP = N1-NPC
      IF(NRP.EQ.0) GO TO 2
      READ(3,888) (IA(II),II=1,NRP)
      DO 2 II=1,NRP
      K = NPC +II
      A(K) = C*FLOAT(IA(II))*SF +D
    2 CONTINUE
      NCR = NINT(FLOAT(N1)/10.)
      IF((NCR*10).LT.N1) NCR = NCR +1
      DO 3 J =1,NCR
```

```
      M1  = (J-1) *10
      WRITE(2,999) (A(M1+I),I-1,10),J
      WRITE(4,999) (A(M1+I),I=1,10),J
    3 CONTINUE
    4 CONTINUE
  111 FORMAT(2I3)
  222 FORMAT(2F0.0)
  333 FORMAT(10A8)
  444 FORMAT(3I4)
  555 FORMAT(1H1,10X,21HDIGITIZED DATA FOR    ,10A8//
     *8X,14HENGINE SPEED =,F7.2,19H   NO. OF SAMPLES  ,I3,16H   SAMPLE S
     *IZE =,F5.2,9H(DEGREES)//)
  666 FORMAT(2X,I7,14X,I7,/)
  777 FORMAT(1X,/,2X,I7,14X,I7,/)
  888 FORMAT(10X,8I7,/)
  999 FORMAT(2X,10F7.3,I8)
 1000 FORMAT(2X,'SCALE FACTORS ARE :'/ 20X,2(I8,2X),E20.5)
      STOP
      END
      FINISH
```

APPENDIX B2

SPECTRAL ANALYSIS
Program

This program is mainly concerned with the spectral analysis of the turbulence signals as discussed in Chapter 4. The different steps in the program structure could be summarised as follows:-

1. Digitization of turbulence signals at the appropriate sampling rates, usually 50 μ sec/sample is sufficient which corresponds to a maximum cut off frequency of 10 KHz.

2. Preparation of turbulence signals at a particular crank angle. This step includes the following programming operations:

   a) Isolation of a signal of width $\Delta\theta$, centred at the crank angle θ_i, i.e. from $\left[\theta - (\frac{\Delta\theta}{2})\right]$ to $\left[\theta + (\Delta\theta/2)\right]$.

   b) Addition of previously isolated samples to the present one (note for the first cycle the previous signal represents a clear data block).

   c) Storing of the obtained signal in step (b) into a storing location.

   d) Repetition of steps from (a) to (c) for a (N) number of cycles are given by

   Maximum number of analysed cycles (N)

   = (Block size)/(Width of individual sample) (B5)

3. Transformation of the synthesized signal to zero mean value signal. The obtained signal u(t) in step (2) is transferred into a new time history with zero mean value x(t) as follows:

$$x_n(t) = u_n(t) - \bar{x} \qquad \text{(B6)}$$

where

$$\bar{x} = \frac{1}{N} \sum_{n=1}^{N} x_n(t) \qquad \text{(B7)}$$

and N is the number of samples in the data record.

Such a process could be carried out in two ways.

a) Data record in time domain

Integrate the signal, then divide the result by the number of samples and subtract the latter value from the original signal.

b) Data record in frequency domain

Since the Fourier transform of the signal is an intermediate step in the calculations of the power spectrum function, as will be discussed later, a process of eliminating the DC component of the signal in the frequency domain gets rid of such a mean value.

4. Auto-correlation function.

As discussed in Chapter 4 the auto-correlation function is obtained by the following procedure:

a) Compute the Fourier transform of the time series signal as given by the following equation:

$$X(n) = \int_{-\infty}^{\infty} x_t\ (t)\ e^{-j2\pi nt} \qquad (B8)$$

b) Compute the spectrum of original data as given by:

$$S(n) = \underset{T \to \infty}{\text{limit}} \frac{1}{T}\ X(n)\ \ X^*\ (n) \qquad (B9)$$

where

$X^*(n)$ is the complex conjugate of $X(n)$ as given by

$$X^*(n) = \int_{-\infty}^{\infty} x(t)\ e^{j2\pi nt}\ dt \qquad (B10)$$

c) Compute the inverse Fourier transform to obtain the auto-correlation function as given by:

$$R_t(t) = F^{-1} \left[S(n) \right] \qquad (B11)$$

$$R_t(t) = \int_{-\infty}^{\infty} S(n)\ e^{j2\pi nt}\ dn$$

$$= \int_{-\infty}^{\infty} \underset{T \to \infty}{\text{limit}} \frac{1}{T}\ X(n)\ X^*(n)\ e^{j2\pi nt}\ dn \qquad (B12)$$

5. Obtain the auto-correlation coefficient as defined by:

$$R_t'\ (t) = \frac{R_t(t)}{\dot{x}^2} = \frac{R_t(t)}{R_t(0)} \qquad (B13)$$

where $R_t(0)$ is the value of auto-correlation function at zero time delay.

$$R_t(o) = \lim_{T \to \infty} \frac{1}{T} \int_{-\infty}^{\infty} x(t)\ x(t)\ dt = \overline{x^2(t)} \qquad \text{(B14)}$$

6. Store the auto-correlation coefficient in another data block for further analysis.

7. Obtain the time micro-scale of turbulence by double differentiation of auto-correlation coefficient as given by:

$$\frac{1}{\lambda_t^2} = -\frac{1}{2} \left[\frac{\partial^2 R_t'(t)}{\partial t^2} \right]_{t=0} \qquad \text{(B15)}$$

8. Obtain the integral scale of turbulence by integrating the auto-correlation coefficient as given by:

$$L_t = \int_0^{\infty} R_t'(t)\ dt \qquad \text{(B16)}$$

where the integration process is carried out only for positive values of $R_t'(t)$.

9. Obtain the normalised power spectrum function. This is carried out by taking the Fourier transform of the auto-correlation coefficient after applying a rectangular window of the same width as the original 'cycle sample B' as discussed in Chapter 4.

$$F(n) = 2 \int_{-\infty}^{\infty} R_t'(\tau)\ \mathrm{Cos}\ 2\pi n\ t\ dt \qquad \text{(B17)}$$

10. Individual cycles analysis. To obtain the analysis of individual cycles the synthesised data record for N cycles (step 2) is disintegrated to its constituents and the analysis from (3) to (9) are carried out for each individual cycle.

2.1 Details of the Spectral Analysis Program

(Listing of Instructions on the Hewlett Packard Fourier Analyzer)*

The meanings of each command are given in Table (B3)

a) Preparation of Turbulence Signal

```
L    1                      EN
BS   4096                   EN
CL   1                      EN
L    2                      EN
RA                          EN
←    0      (Nθ)            EN
CL   0    (NW)     4096     EN
A+   1                      EN
←    0    (NW)              EN
x>   1                      EN
#    2    (NC)              EN
```

where Nθ defines the location of the particular crank angle of interest

NW the number of samples for the width θ of the cycle

NC is the number of cycles analysed = $\frac{4096}{NW}$

Example: For 1000 r.p.m. engine speed, 10° sample width

NW = 33 samples at 50 μ sec sampling rate.

N = 125 cycles.

*See Table (B3) for definitions.

b(i) Transformation of Data to Zero Mean Value by Subtraction of Mean Value

```
L    3           EN
x<   1           EN
$    1           EN
←    1   4095    EN
:    1   4096    EN
CL   1  1  4096  EN
$    1           EN
*    1   -1      EN
A +  1           EN
#    3   (N1)    EN
```

where (N1) is the number of successive processes of subtractions.

b(ii) Transformation of Data to Zero Mean Value by Eliminating the DC Component in the Frequency Domain

```
x <  1           EN
F                EN
CL   0     1     EN
```

c) Spectrum Analysis

If the method described in (b(i)) is used, the analysis starts with a Fourier transform of the time signal, while for the method described in (b(ii)) the following sequence of commands are used directly:

*	-			EN	
F				EN	
x >	1			EN	
CL	1	1	4096	EN	
$	1			EN	
:	1			EN	
W	1	0	1	EN	* R(o) is obtained at this step
x >	1			EN	
←	0	2048		EN	
%				EN	
%				EN	
W	0	2045	2050	EN	* $\left(\frac{\partial^2 R(t)}{\partial t^2} \right)_{t=0}$ is obtained at this step
x <	1			EN	
D				EN	* Recognise visually the positive portion of the curve and clear the remaining part
CL	0	N2	4096		
$	0			EN	* Integral time scale is obtained at this step (L_t)
x<	1			EN	
CL	0	NW	(4096-NW)	EN	
F				EN	* Normalised power spectrum function is obtained at this step
END				EN	
TERM				EN	

Table (B3) Meanings of Symbols Used in the SPECTRUM ANALYSIS Program

(Hewlett Packard Fourier Analyser Code (142))

L N1	LABEL, this defines a starting statement of a loop in the program.
# N1 N2	COUNT, this determines the number of loops (N2) in the program segment starting at the statement labelled by N1.
BS	BLOCK SIZE.
RA	ANALOG IN, this instruction introduces an analog signal to the ADC as soon as a triggering pulse is sensed.
CL N1 N2 N3	CLEAR, this clears the data from the sample (N2) to the sample (N3) in the data block (N1).
← N1 N2	SHIFT, this instruction shifts the data in the block (N1) number of samples N2 to the lift.
A + N1	ADDITION, this instruction adds the data in block N1 to that in block (O)*.
A - N1	SUBTRACTION, this instruction subtracts point by point the data in block N1 from that in block (O).
(*N1 N2	MULTIPLICATION, this multiplies the data in block N1 by an integer number (N2) (between -32767 to +32767) with the exclusion of O value.
(*N1	BLOCK MULTIPLICATION, this multiplies the data block N1 by block (O).
*- N1 N2 N3	COMPLEX MULTIPLY (N2 + J N3) for data in block N1
(: N1 N2	DIVISION, this divides the data block N1 by the integer number N2.
(: N1	BLOCK DIVISION, this divides block (O) by block N1.

Table (B3) continued.

(*) Block (O) is the first data block in the memory of the Fourier analyser and is usually used as the working data block in any dual operations between two data blocks.

%N1 (d/dx)	DIFFERENTIATION, this differentiates the data in block N1 (First data point remains constant).
$ N1 (∫)	INTEGRATION, this integrates the data in block N1.
W N1 N2 N3	PRINT, this gives a print out (on the teleprinter) of the data words from (N2) to (N3) in the data block(N1).
P N1 N2 N3	PUNCH, this produces a punched paper tape for the data words from N2 to N3 in the block N1.
F N1 N2	FOURIER TRANSFORM

N1 and N2 are two data blocks

Forward

$$F(m \Delta n) = \frac{1}{N} \sum_{n=0}^{n=N-1} f(n \Delta t) e^{\frac{-j2\pi nm}{N}} \qquad (B18)$$

Inverse

$$F^{-1}(n \Delta t) = \sum_{m=0}^{m=N-1} F(m \Delta n) \, e^{\frac{+j2\pi nm}{N}} \qquad (B19)$$

where

Δt = time increment, n = frequency resolution

N = the total number of points in the time domain.

CR N1	CORRELATE, this performs a cross correlation between the data block N1 and block (O), if N1 is defaulted an auto-correlation of block (O) is obtained.

Table (B3) continued.

X<	N1	LOAD, this loads the data in block N1 into block (O).
X>	N1	STORE, this stores the data in block (O) into block N1.
.		END.

SPECTRAL ANALYSIS

Program.

Version No. 1

An example of the spectral analysis of turbulence signal at (TDC) compression, using a 'cycle sample' width of 10 crank angle degrees, a sampling rate of 50μ sec/sample, and a data block of 4096 data words.

(Test at 1000 RPM).

```
  1 L      1
  4 BS  4096
  7 CL     1
 10 L      2
 13 RA
 15 ←      0   1183
 19 CL     0     33   4096
 24 A+     1
 27 ←      0     33
 31 X>     1
 34 ≠      2    124      0
 39 X<     1
 42 F      0
 50 CL     0      0      2
 55 *-
 57 F
 59 X>     1
 62 CL     1      1   4096
 67 $      1
 70 :      1
 73 W      1      0      1
 78 X>     1
 81 ←      0   2048
 85 D
 87 %
 89 %
 91 W      0   2044   2052
 96 X<     1
 99 $      0
102 W      0     30     37
107 X<     1
110 CL     0     33   4063
115 F
117 .
```

Version No. 2

An example of carrying out the spectral analysis of turbulence signals at two crank angles, simultaneously. This version of the program is suitable for high engine speeds, e.g. 2000 RPM. In this case a data block of 2048 words can be used.

```
  1 L     1
  4 BS 2048
  7 CL    2
 10 CL    3
 13 L     2
 16 RA
 18 X>    1
 21 ←     0   540
 25 CL    0    17   2048
 30 A+    2
 33 ←     0    17
 37 X>    2
 40 X<    1
 43 ←     0   573
 47 CL    0    17   2048
 52 A+    3
 55 ←     0    17
 59 X>    3
 62 #     2  120       0
 67 X<    2
 70 L     3
 73 X>    1
 76 L     4
 79 P     1     0     16
 84 ←     1    17
 88 #     4   120      0
 93 F
 95 CL    0     0      2
100 *-
102 F
104 X>    1
107 CL    1     1   2048
112 $     1
115 :     1
```

Version No. 2 continued.

118	W	1	0	1
123	X>	1		
126	←	0	1024	
130	%			
132	%			
134	W	0	1022	1027
139	W	1	0	15
144	X<	1		
147	A+	1		
150	CL	0	33	2015
155	F			
160	D			
162	$			
164	D			
167	X<	3		
169	≠	3	2	0
172	.			

Version No. 3

An example of a 'data preparation ' program for the spectral analysis of turbulence signals at six crank angles simultaneously. This version of the program is suitable for very high engine speeds e.g. 3500 RPM. In this case a data block of 1024 data words can be used.

1	L	1		
4	BS	4096		
7	CL	0		
10	CL	1		
13	BS	1024		
16	L	2		
19	RA			
21	X >	1		
24	←	0	351	
28	CL	0	9	1024
33	A+	2		
36	←	0	9	
40	X >	2		
43	X <	1		
46	←	0	324	
50	CL	0	9	1024
55	A+	3		
58	←	0	9	
62	X >	3		
65	X <	1		
68	←	0	306	
72	CL	0	9	1024
77	A+	4		
80	←	0	9	
84	X >	4		
87	X <	1		
90	←	0	270	
94	CL	0	9	1024
99	A+	5		
102	←	0	9	
106	X >	5		
109	X <	1		
112	←	0	198	
116	CL	0	9	1024
121	A+	6		
124	←	0	9	

Version No. 3 continued.

128	X >	6		
131	X <	1		
134	←	0	162	
138	CL	0	9	1024
143	A+	7		
146	←	0	9	
150	X>	7		
153	≠	2	114	
158	.			

Version No. 4

SPECTRAL ANALYSIS FOR INDIVIDUAL DATA RECORDS.

This program is concerned with investigating the extent of cyclic variations in the turbulence characteristic parameters. Its input data consists of individual cycle samples of turbulence signals isolated at the particular crank angle of interest. The output results of the program can be summarised as follows:

1- Mean square value of the signal for each cycle sample.

2- The Time Micro and Macro scales of turbulence for each cycle sample.

```
 1 L     1
 4 BS    64
 7 CL
 9 CL    1
12 CL    2
15 L     2
18 CL
20 R
22 F
24 CL    0     0
28 *-
30 F
32 *     0     188
36 :     0     100
40 X>    1
43 CL    1     1     64
48 S     1
51 W     1     0
55 :     1
58 X>    1
61 ←     0     32
65 %
67 %
69 W     0     33
73 S     1
76 W     1     0     32
81 =     2     100   0
86 .
```

APPENDIX B3

VELOCITY PREDICTION Program

The main objective of this program is to calculate the gas velocities at different crank angles during the engine cycle. The analysis is usually carried out for a number of consecutive cycles to yield the statistical characteristics of the velocity signal.

The program is fed with a continuous data record of the hot wire anemometer signal digitized as discussed in Appendix B1. This requires a way of recognising the start and end of each individual cycle on the trace. Moreover, because of the limitations on the storage capacity of the ICL computer, a certain intermediate storing facility for the calculated gas velocities is required for further analysis. Magnetic tapes, paper tapes or cards could be used for such purpose. The latter facility was preferred in view of the reliability of cards and possible replacement of damaged ones. The use of magnetic tapes was also used in an earlier stage of this investigation.

The facilities for analysing any number of tests are provided, (e.g. probe rotations, different traverses, variable engine speeds or throttle settings). Also, the facilities of using any combinations of output peripherals (line printer, card punch and graph plotter) are also provided, together with a further option of the number of individual cycles produced on each of the above mentioned peripherals.

The required input data for this program could bo summarised in the following groups of variables:

1. A completo statement describing the test conditions for any particular experiment considered. This will appear on the heading of output results and do not enter in the program calculations. This group of variables includes: engine speed, throttle setting, engine compression ratio, probe vertical location in the combustion chamber and wires direction relative to probe axes of reference.

2: Another statement about the collected and digitized signal of the hot wire anemometer is also required. This provides the program with the required information about the sampling rate for the digitized data, the number of samples per cycle, the number of complete cycles consisting of the data record, the firing order of the particular cylinder considered (relative to the reference cylinder used for setting the timing mark) and the code number for the anemometer bridge used in collecting the signal.

3. The third group consists of a number of control variables used to select the particular output peripheral on the ICL computer or the combination of more than one peripheral together with a specification of the required number of cycles appearing on each peripheral.

4. The characteristics of the hot wire anemometer used. This includes the values of wire operating resistance and operating temperature, wire cold resistance, lead resistance, the wire length, the wire diameter, the temperature coefficient of resistance for the wire material and the electric resistivity of wire material.

5. A statement about the signal conditioning for both the hot wire anemometer and the pressure transducer. This gives the values for the biased DC level and the attenuation factors on the recorded signals, as discussed in Chapter 4 and in Appendix B1.

6. The sixth group of variables consists of the digitized data for the pressure trace for one engine cycle. A temperature trace is optional and is replaced by introducing the values for the gas temperature during the induction period and making use of polytropic relations.

7. The last group of variables represent the continuous trace of hot wire anemometer signals.

INPUT DATA

NS	Number of individual tests considered.
VC(I)	Coefficients of the dynamic viscosity function.
CPAC(I)	Coefficients of the specific heat at constant pressure function.
N PUNCH	A control variable for producing output results on punched cards.
N GRAPH	A control variable for producing output results on graph plots.
NC	Number of cycles analysed.
NP	Number of samples per cycle.
NEQ	A control variable for selecting the appropriate current equation according to the anemometer system used in collecting the signal.
	NEQ = 1 For DISA Aol system (100 Ω top resistanc
	NEQ = 2 For DISA M system (50 Ω " "
	NEQ = 3 For DISA M system (5 Ω " "
THROTTLING*(I)	Description of throttle setting.
DIRECTION*(I)	Description of wires direction.
YP*	Vertical location of probe inside the combustion chamber.
CR*	Compression ratio of the engine.
RPM*	Engine speed.
AMIN	Minimum crank angle on the x-axis of a graph plot of velocity.
AMAX	Maximum crank angle on the x-axis of a graph plot of velocity.
VMIN	Minimum value of gas velocity on the y axis.
VMAX	Maximum value of gas velocity on the y axis.

AINS	Length of x-axis of tho plot (inches).
VINS	Length of y-axis of tho plot (inches).

(*) The variables marked with (*) are used to give full description of test conditions which will appear with output results but do not enter in the calculations.

A	Biased DC level from the recorded velocity signal (volts).
B	Attenuation factor on the recorded signal of gas velocity (-).
SFP	Scale factor for the pressure trace (psi/volt).
E	Polytropic exponent.
RW	Wire operating resistance (ohms).
RC	Wire cold resistance (ohms).
RL	Probe lead resistance (ohms).
TW	Wire operating temperature (^oC).
To	Reference temperature (^oC).
Po	Reference pressure (N/m^2).
D	Wire diameter (m).
Z	Wire length (m).
ALPHA	Temperature coefficient for wire material ($/^oC$).
BETO	Coefficient of electric resistivity for wire material at the reference temperature T_o (Ω- mt).

OUTPUT DATA

CA(I)	Crank angles (degrees).
T(I)	Gas temperature (°C)
P(I)	Gas pressure (N/m^2).
CUR(I)	Hot wire current at the crank angle of index I (amps).
BV(I)	Bridge voltage.
H(I)	Heat transfer coefficient (W/m^2 °C).
VE(I)	Gas velocity (m/sec)
VM(I)	Gas mean velocity averaged over NC number of cycles (m/sec).

```
JOB N220,N,NS1505
LUFORTRAN
RUN ,,1500
DOCUMENT SOURCE
      LIBRARY (ED,SUBGROUPUSUB)
      LIBRARY (ED,SUBGROUPGRAF)
      LIBRARY (ED,SUBGROUPNAGF)
      PROGRAM(N220)
      COMPACT
      INPUT 1 = CRO
      OUTPUT 2 = LPO
      OUTPUT 4 = CPO
      TRACE 0
      END


      MASTER     VELOCITY  PREDICTION
C                ********************
C     THE USE OF DIFFERENT OUTPUT PREPHIRALS ARE PERMISSIBLE BY ASSIGNI-
C     G A VALUE OF 9 TO THE CORRESPONDING CONTROL VARIABLE AS FOLLOWING:
C     NG       FOR GRAPH PLOTTER.
C     NPUNCH FOR CARD PUNCH.
C     NWR      FOR LINE PRINTER.
C     NCPL     NUBER OF CONSECUTIVE CYCLES PLOTTED.
C     NCWR     NUBER OF CYCLES PRINTED OUT.
C     NCYL     CONTROL VARIABLE ALLOWING FOR ENGINE FIRING ORDER FOR A
C              FIXED TRIGGER LOCATION.
C     NEQ      SELECTOR FOR USE OF APROPIATE BRIDGE EQUATION.
C     NP       NUMBER OF SAMPLES PER CYCLE.
C     NC       NUMBER OF CYCLES ANALYZED.
C     NAI      NUMBER OF FIRST DATA POINT ON THE CYCLE.
      DIMENSION CA(400),T(400),P(400),BV(400),VE(400),BETA(400),RG(400),
     *TITLE(6),VM(400)
      COMMON/PROP/VC(9),CPAC(9)
      READ(1,1010)NS
      READ(1,1020)(VC(I),I=1,9)
      READ(1,1020)(CPAC(I),I=1,9)
      READ(1,1030)AMIN,AMAX,VMIN,VMAX,AINS,VINS
      DO 5000 IS =1,NS
      READ(1,1010)NG,NPUNCH,NCPL,NCWR,NCYL,NEQ,NP,NC,NAI
      READ(1,1015) NMAX
      READ(1,1030)RW,RC,RL,TW,TO,PO,D,Z,ALPHA,BETO
      READ(1,1030)A,B,SFP,E
      READ(1,1030)RPM,CR,YP
      READ(1,1040)(TITLE(I),I=1,2)
      READ(1,1040)(TITLE(I),I=3,6)
      IF(NPUNCH.NE.9) GO TO 5
      IF(IS.EQ.1) WRITE(4,1010) NS
      IF(IS.EQ.1) WRITE(4,1050)AMIN,AMAX,VMIN,VMAX,AINS,VINS
      WRITE(4,1060)RPM,(TITLE(L),L=1,2),CR,YP,(TITLE(L),L=3,6),NC,NP
      WRITE(4,1010)NP,NC
    5 CONTINUE
      SS=720./FLOAT(NP)
      NCR=NP/10
      IF((NCR*10).LT.NP)NCR=NCR+1
      IF((NG.EQ.9).AND.(IS.EQ.1)) CALL UTPOP
```

```
      READ(1,1050)(P(I),I=1,NP)
      NPM=NP/8+1
      NPME=7*NP/8
      DO10I=1,NPM
   10 SP=SP+P(I)
      P(1)=SP/NPM
      DO20I=1,NPM
      P(I)=P(1)
   20 P(I+NPME)=P(1)
      PMN=P(1)
      DO30I=1,NP
      IF(P(I).LT.PMN) P(I) = PMN
      P(I)=(((P(I)-PMN)*SFP)+14.7)*6895.
      T(I)=(TO+273.)*((P(I)/PO)**E)-273.
      COEF=(1+ALPHA*(T(I)-TO))
      RG(I)=RC*COEF
   30 BETA(I)=BETO*COEF
      MRI=0
      DO200JC=1,NC
      IF((NCYL.EQ.0).OR.(JC.NE.1)) GO TO 50
      NI=NINT(FLOAT(NP)*FLOAT(NCYL)/8.)
      NX=NI+NP
      NPP=NX/10
      IF((NPP*10).LT.NX)NPP=NPP+1
      NPC=NPP*10
      MRE=NPC-NI-NP+1
      READ(1,1050)(BV(I),I=1,NPC)
      DO  40 I=NI,NPC
      M=I-NI+1
   40 BV(M)=A*BV(I)+B
      GOTO70
   50 NX=NP-MRI
      NPP=NX/10
      IF((NPP*10).LT.NX)NPP=NPP+1
      NPC=NPP*10
      MRE=NPC-NX
      READ(1,1050) (BV(MRI+I),I=1,NPC)
      MI=MRI+1
      ME=MRI+NPC
      DO60I=MI,ME
   60 BV(I)=A*BV(I)+B
   70 CONTINUE
       WRITE(2,1010) NCYL,NP,NC,NEQ
      WRITE(2,1020) RW,RL,TW,TO,PO,D,Z,ALPHA,BETO
      NLAST = NLAST +NPC
      J2=0
      DO80I=1,NP
      IF(NEQ.EQ.1) CUR = BV(I)/(100.+RL+RW)
      IF(NEQ.EQ.2) CUR   BV(I)/( 50.+RL+RW)
      IF(NEQ.EQ.3) CUR = BV(I)/( 5.  +RL+RW)
      CA(I)=SS*(I+NAI)
      CALLDF(T(I),TW,CUR,RW,RG(I),BETA(I),Z,D,ALPHA,P(I),VE(I),H,M)
      IF(J2.EQ.51)J2=0
      IF((J2.EQ.0).AND.(JC.LE.NCWR))WRITE(2,1070)RPM,(TITLE(L),L=1,2),CR
     *,YP,(TITLE(L),L=3,6),JC
      J2=J2+1
      IF(JC.GT.NCWR)GOTO80
      WRITE(2,1080)CA(I),T(I),P(I),BV(I),VE(I),H,M
```

```
 20 CONTINUE
    DO 85 IM =1,NP
     IF(JC.EQ.1)VM(IM)=0.0
    VM(IM)=VM(IM)+VE(IM)
    IF(JC.NE.NC) GO TO 85
    VM(IM) =VM(IM)/NC
 85 CONTINUE
    IF(NG.NE.9)GOTO90
    IF(JC.GT.NCPL)GOTO90
    CALLUTP4A(AMIN,AMAX,VMIN,VMAX,AINS,VINS,23H CRANK ANGLE  (DEGREES)
   *,3,16HVELOCITY (M/SEC),2)
    CALLGRID(AMIN,AMAX,VMIN,VMAX,AINS,VINS)
    CALLUTP4B(CA,VE,NP,2)
 90 CONTINUE
    IF(NPUNCH.NE.9)GOTO110
    DO100IX=1,NCR
    MX=(IX-1)*10
100 WRITE(4,1090)(VE(MX+I),I=1,10),JC,IX
110 IF(JC.EQ.NC) GO TO 200
    DO120IR=1,MRE
    L=NP+IR
120 BV(IR)=BV(L)
    MRI=MRE
200 CONTINUE
    WRITE(2,990) (VM(IM),IM=1,NP)
    IF(NG.NE.9) GO TO 300
    CALLUTP4A(AMIN,AMAX,VMIN,VMAX,AINS,VINS,23H CRANK ANGLE  (DEGREES)
   *,3,21HMEAN VELOCITY (M/SEC),3)
    CALLGRID(AMIN,AMAX,VMIN,VMAX,AINS,VINS)
    CALLUTP4B(CA,VM,NP,2)
300 CONTINUE
990 FORMAT(10(2X,F8.3))
    NXY = (NMAX-NLAST)/10
    IF (NXY.EQ.0) GO TO 5000
    DO 4000 IXY =1,NXY
    READ(1,1050 ) (BV(I),I=1,10)
4000 CONTINUE
    NLAST =0
5000 CONTINUE
1010 FORMAT(2X,10I3)
1015 FORMAT(2I4)
1020 FORMAT(3E20.12)
1030 FORMAT(10F0.0)
1040 FORMAT(10A8)
1050 FORMAT(2X,10F7.3)
1060 FORMAT(2X,' ENGINE SPEED = ',F7.2,'(RPM)',2A8,'  COMPRESSION RATIO
   1 =',F2.0,': 1'/'  PROBE VERTICAL LOCATION =',F5.2,'(MM)',4A8/'  NU
   2MBER OF CYCLES ANALYZED =',I3,' NUMBER OF SAMPLES PER CYCLE =',I3)
1070 FORMAT(1H1,'             MEASUREMENT OF GAS VELOCITIES INSIDE A COMB
   1USTION CHAMBER OF A S.I. ENGINE'//'
   2ENGINE SPEED =',F7.2,'(RPM)',2A8,'  COMPRESSION RATIO =',F2.0,': 1
   3'//'                           PROBE VERTICAL LOCATION =',F5.2,'(MM
   4)',4A8,'  CYCLE NUMBER =',I2//'             CRANK ANGLE    TEMPERATUR
   5E    PRESSURE    BRIDGE VOLTS    VELOCITY          H          NO.OF I
   6TERATIONS '//)
1080 FORMAT(12X,F8.4,5X,5E14.6,5X,I4)
1090 FORMAT(2X,10F7.3,I3,2X,I3)
    CALLUTPCL
    STOP
    END
```

```
      SUBROUTINE DF(TO,TW,CUR,RW,RC,BETO,Z,D,ALPHA,P,V,H,M)
C     CALCULATES GAS VELOCITY FOR A HOT WIRE ANEMOMETER IN AIR USING
C     DAVIES AND FISCHER EQUATION FOR V- F(H)
C     PARAMETERS
C     TO-    AMBIENT TEMPERATURE
C     TW-    WIRE OPERATING TEMPERATURE.
C     CUR-   WIRE CURRENT.
C     RW-    WIRE OPERATING RESISTANCE.
C     RC-    WIRE COLD RESISTANCE AT TEMPERATURE TO.
C     BETO-WIRE RESISTIVITY AT TEMPERATURE TO
C     Z-   WIRE TOTAL LENGTH.
C     D-     WIRE DIAMETER.
C     ALPHA-WIRE MATERIAL 1ST TEMPERATURE COEF. OF RESISTANCE.
C     P-     AMBIENT PRESSURE.
C     V-   CALCULATED VELOCITY.
C     H--  HEAT TRANSFER COEFICIENT.
C     M-     NUMBER OF ITERATION LOOPS COMPLETED IN SUBROUTINE CJMIT.
      REAL K1
      COMMON/PROP/VC(9),CPAC(9)
      PI= 3.141592654
      VTO= VT(VC,0.00001717,0.0,TO,-139.5)
      CNTO= CNT(0.02435,0.0,0.82,TO)
      CPTO= CPT(CPAC,TO,9)
      CVTO= CPTO/1.403
      RHO= P*28.93/(8314.3*(TO+273.))
      CNTI= CNT(0.02435,0.0,0.82,TW)
      CALL HTRANS(H,K1,CUR,RW,RC,TW,TO,BETO,Z,D,ALPHA,M)
      IF(H.GT.99999999.0) GOTO 1
      G1= H*PI*CNTO/(2.6*CVTO*CNTI)
      G2= D/VTO
      FC= ((TW+273.)/(TO+273.))**0.3
      V= (G1**3.)*(G2**2.)*FC/RHO
      RETURN
    1 WRITE(2,2) K1
    2 FORMAT(29H ITERATION FAILURE IN DF IER=,E12.4)
      RETURN
      END


         SUBROUTINE CJMIT(X,V1,V2,V3,V4,F,FN,XLI,XRI,EPS,IEND,IER,M)
C     SOLVES GENERAL NON-LINEAR EQUATIONS OF THE FORM FN(X,A,B,C,D)=0
C     BY MUELLERS ITERATION METHOD
C     PARAMETER FN CALLS AN EXTERNAL FUNCTION SUPPLIED BY THE USER
C     DESCRIPTION OF PARAMETERS
C          X-   RESULTANT ROOT OF EQUATION FN(X,A,B,C,D)=0
C          V1-V4 VALUES OF CONSTANTS A,B,C,D
C          FN- NAME OF EXTERNAL FUNCTION USED
C          XLI-INITIAL LEFT BOUND OF THE ROOT X.
C          XRI-INITIAL RIGHT BOUND OF THE ROOT X
C          EPS-UPPER BOUND OF THE ERROR OF RESULT X
C          IEND-MAX NUMBER OF ITERATION STEPS SPECIFIED
C          IER-RESULTANT ERROR PARAMETER
C               IER=1 NO CONVERGENCE AFTER IEND ITERATIONS FOLLOWED
C                     BY IEND SUCCESSIVE STEPS OF BISECTION.
C               IER=2 BASIC ASSUMPTION FN(XLI)*FN(XRI)LESS THAN ZERO
C                     IS NOT SATISFIED.
C               IER=0 NO ERROR
C     SOLUTION OF EQUATION FN(X,A,B,C,D)=0 IS ACHIEVED BY MEANS OF
C     MUELLERS ITERATION METHOD OF SUCCESSIVE BISECTION AND INVERSE
C     PARABOLIC INTERPOLATION,WHICH STARTS AT THE INITIAL BOUNDS XLI
C     AND XRI.CONVERGENCE IS QUADRATIC IF THE DERIVATIVE OF FN AT THE
C     ROOT X IS NOT EQUAL TO ZERO.ONE ITERATION REQUIRES TWO
```

```
C       EVALUATIONS OF FN(X,A,B,C,D).
C       FOR REFERENCE SEE G.K.KRISTIANSEN,ZERO OF ARBITARY FUNCTIONS,BIT,
C       VOL3(1963),PP205-206.
C
C       PREPARE ITERATION
        IER=0
        XL=XLI
        XR=XRI
        X=XL
        TOL = X
        F= FN(TOL,V1,V2,V3,V4)
        IF(F) 1,16,1
      1 FL=F
        X=XR
        TOL= X
        F= FN(TOL,V1,V2,V3,V4)
        IF(F) 2,16,2
      2 FR=F
        IF(SIGN(1.00,FL)+SIGN(1.00,FR)) 25,3,25
C       BASIC ASSUMPTION FL*FR LESS THAN 0 SATISFIED.
C       GENERATE TOLERANCE FOR FUNCTION VALUES.
      3 I=0
        TOLF= 100.0*EPS
C       START ITERATION LOOP
      4 I=I+1
        M= I
C       START BISECTION LOOP
        DO 13 K=1,IEND
        X= 0.5*(XL+XR)
        TOL=X
        F= FN(TOL,V1,V2,V3,V4)
        IF(F) 5,16,5
      5 IF(SIGN(1.00,F)+SIGN(1.00,FR)) 7,6,7
C       INTERCHANGE XL AND XR IN ORDER TO GET SAME SIGN IN FL AND FR
      6 TOL= XL
        XL=XR
        XR= TOL
        TOL= FL
        FL=FR
        FR= TOL
      7 TOL= F-FL
        A= F*TOL
        A=A+A
        IF(A-FR*(FR-FL)) 8,9,9
      8 IF(I-IEND)  7,17,9
      9 XR=X
        FR=F
C       TEST ON SATISFACTORY ACCURACY IN BISECTION LOOP
        TOL= EPS
        A= ABS(XR)
        IF(A-1.00) 11,11,10
     10 TOL= TOL*A
     11 IF(ABS(XR-XL)-TOL) 12,12,13
     12 IF(ABS(FR-FL)-TOLF) 14,14,13
     13 CONTINUE
C       END BISECTION LOOP
```

```
C
C     NO CONVERGENCE AFTER IEND ITERATIONS AND BISECTIONS
C     SET IER=1 .ERROR RETURN.
      IER= 1
   14 IF(ABS(FR)-ABS(FL)) 16,16,15
   15 X=XL
      F=FL
   16 RETURN
C     COMPUTATION OF ITERATED X-VALUE BY INVERSE PARABOLIC INTERPOLATION
   17 A=FR-F
      DX=(X-XL)*FL*(1.00+F*(A-TOL)/(A*(FR-FL)))/TOL
      XM=X
      FM=F
      X=XL-DX
      TOL=X
      F= FN(TOL,V1,V2,V3,V4)
      IF(F) 18,16,18
C     TEST ON SATISFACTORY ACCURACY IN ITERATION LOOP
   18 TOL= EPS
      A=ABS(X)
      IF(A-1.00) 20,20,19
   19 TOL= TOL*A
   20 IF(ABS(DX)-TOL) 21,21,22
   21 IF(ABS(F)-TOLF) 16,16,22
C     PREPARATION OF NEXT BISECTION LOOP
   22 IF(SIGN(1.00,F)+SIGN(1.00,FL)) 24,23,24
   23 XR=X
      FR=F
      GOTO 4
   24 XL=X
      FL=F
      XR=XM
      FR=FM
C     END ITERATION
      GOTO 4
C     ERROR REURN IN CASE OF WRONG INPUT DATA.
   25 IER = 2
      RETURN
      END
```

```
      SUBROUTINE HTRANS(H,K1,CUR,RW,RO,TW,TO,BETO,Z,D,ELP,M)
C     CALCULATES THE HEAT TRANSFER COEFICIENT FOR A FINE WIRE IN A
C     CROSS FLOW OF GAS.
C     H-  HEAT TRANSFER COEFICIENT.
C     K1- FUNCTION VARIABLE.
C     CUR-WIRE CURRENT.
C     RW-  WIRE OPERATING RESISTANCE.
C     RO-  WIPE RESISTANCE AT TEMPERATURE TO
C     TW-  WIRE OPERATING TEMPERATURE.
C     TO-  REFERENCE AMBIENT TEMPERATURE.
C     BETO-RESISTIVITY OF WIRE MATERIAL AT TO.
C     Z-   TOTAL WIRE LENGTH.
C     D-  WIRE DIAMETER.
C     ELP- FIRST TEMPERATURE COEFICIENT OF RESISTANCE FOR WIRE MATERIAL.
C     M-  NO OF ITERATIONS EXECUTED IN CJMIT.
```

```
C     ADDITIONAL SUBROUTINES REQUIRED-- CJMIT,FK1.
C     FOR REFERENCE SEE INTERNAL REPORT.
      REAL K1
      DIMENSION FN(20)
      EXTERNAL FK1
      PI= 3.141592654
      A= PI*D*D/4
      CNWS= 2.23*(TO+273)/((10.**8)*BETO)
      CNWT= 2.23*(TW+273)/((10.**8)*BETO*(1+ELP*(TW-TO)))
      G1 = CUR*CUR*RW/(A*CNWT*Z*(TW-TO))
      G2= 2*CNWS*TO/(Z*CNWT*RW)
      G3= (RW-RO)/RW
      G4= Z/2
      XL= 0.01
      XR= 10.**(12.)
      EPS= 10.**(-7)
      IEND= 100
      CALL CJMIT(K1,G1,G2,G3,G4,F,FK1,XL,XR,EPS,IEND,IER,M)
      IF(IER.LT.1) GOTO 1
      H= 100000000.0
      CUR= F
      K1= IER
      RETURN
    1 CONTINUE
      K1= ABS(K1)
      H= (K1*CNWT*A+CUR*CUR*ELP*RO/Z)/(PI*D)
      RETURN
      END
```

```
      FUNCTION VT(CF,VO,TO,TT,TC)
C     CALCULATES THE DYNAMIC VISCOSITY OF A GAS AT TEMPERATURE TT.
C     INPUT PARAMETERS.
C     CF-  POLYNOMIAL COEFICIENTS FOR VISCOSITY  FUNCTION VALUES.
C     VO-  VISCOSITY AT REFERENCE TEMPERATURE TO.
C     TO-  REFERENCE TEMPERATURE .
C     TT-  GAS TEMPERATURE.
C     TC-  TEMPERATURE OF GAS AT ITS CRITICAL POINT.
C     FOR REF. SEE REID AND SHERWOOD,PROPERTIES OF GASES AND LIQUIDS,
C     CHAPTER 6,PUBLISHERS MC.GRAW-HILL.
      DIMENSION CF(9),X(2),F(2)
      TR1= (TO+273)/(TC+273)
      TR2= (TT+273)/(TC+273)
      X(1)= 1.33*TR1
      X(2)= 1.33*TR2
      DO 2 I=1,2
      F(I)= 0.0
      DO 1 J=1,9
    1 F(I)= F(I)+CF(J)*(X(I)**(J-1))
    2 CONTINUE
      VT= VO*F(2)/F(1)
      RETURN
      END
```

```
      FUNCTION FK1(K1,G1,G2,G3,G4)
C     EXTERNAL FUNCTION TO CJMIT.
C     DESCRIBES THE HEAT TRANSFER FROM A HEATED WIRE IN A CROSS FLOW OF
C     GAS.
C     INPUT PARAMETERS.
C     K1-   ITERATION VARIABLE.
C          (ABS(H*PI*D/CNWT-CUR*CUR*ALPHA*RO/(CNWT*Z)))
C     G1-   EQUATION CONSTANT. (CUR*CUR*RW/(A*CNWT*Z*(TW-TO))
C     G2-   EQUATION CONSTANT. (2*CNWS*RO/(Z*CNWT*RW))
C     G3-   EQUATION CONSTANT((RW-RO)/RW)
C     G4-EQUATION CONSTANT.    (Z/2)
      REAL K1,KA,KSA
      KA= ABS(K1)
      KSA= SQRT(KA)

      FK1= G1*(1-G2*TANH(KSA*G4)/KSA-G3)-KA
      RETURN
      END


      FUNCTION CNT(CNO,TO,P,TT)
C     INPUT PARAMETERS.
C     CNO-  THERMAL CONDUCTIVITY AT REFERENCE TEMPERATURE.
C     TO-REFERENCE TEMPERATURE.
C     PPOWER FOR PARTICULAR GAS UNDER CONSIDERATION.
C     FINDS THE THERMAL COND OF A SINGLE GAS AT TEMPERATURE TT
C     FOR REFERENCE SEE TSEDERBERG,THERMAL CONDUCTIVITY OF GASES AND
C     LIQUIDS,CHAPTER 3,PUBLISHERS ARNOLD.
      CNT= CNO*(((TT+273)/(TO+273))**P)
      RETURN
      END


      FUNCTION CPT(AC,T,N)
C     FINDS THE SPECIFIC HEAT OF A SINGLE GAS AT TEMP T
C     BY POLYNOMIAL FIT TO PUBLISHED DATA..
C     INPUT PARAMETERS.
C     AC- 1-D ARRAY OF LENGTH N CONTAINING THE COEFICIENTS.
C     T-- GAS TEMPERATURE.
C     N-  ORDER OF POLYNOMIAL +1
      DIMENSION AC(9)
      CPT= 0.0
      DO 1 I=1,N
      CPT= CPT+AC(I)*(T**(I-1))
    1 CONTINUE
      RETURN
      END
```

APPENDIX B4

STATISTICAL ANALYSIS
Program

This program is responsible for investigating the extent of cyclic variations in mean gas velocity. This causes cyclic variations in the turbulence parameters from one cycle to another which, consequently, affects the propagation of the combustion process and the development of the cylinder pressure.

It consists, therefore, of a complementary part of the statistical analysis of turbulence analysis which will be discussed in Appendix B5. The input data to this program are obviously the output results of the program 'VELOCITY PREDICTION' discussed in Appendix B3.

The calculations are carried out to give the statistical characteristics of the data in terms of: mean values, variance, standard deviations, coefficient of variations and range of variations. (The definitions of different terms are given in Appendix A2). It calculates also the Skewness and Kurtosis factors at each crank angle. These later variables are measures of the degree of symmetry and peakiness in the probability distribution of the data, which will show any deviations from the normal distribution usually assumed.

INPUT DATA

NS	Number of individual tests considered.
TITLE(I)	Description of each individual test condition.
NP	Number of samples per cycle.
NC	Number of cycles analysed.
V(I,J)	Instantaneous mean gas velocity at the crank angle of index I and the cycle number of index J.

OUTPUT DATA

CA(MP)	Crank angle of index (MP).
VM(MP)	Mean velocity over a number of cycles (NC).
V MX(MP), V MN(MP)	Maximum and minimum values of gas velocity for the crank angle of index (MP) over a number of cycles (NC).
MX	The cycle number (index) where the maximum value of velocity occurred.
MN	The cycle number (index) where the minimum value of velocity occurred.
SD(MP)	Standard deviation of the gas velocity at the crank angle of index (MP).
SDM(MP)	Coefficient of variation of gas velocity at the crank angle of index (MP).
SKEW	Skewness factor at the particular crank angle considered.

OUTPUT DATA (continued)

KURT	Kurtosis factor at the particular crank angle considered.
CVR	Range of variation of gas velocity at any particular crank angle considered.

```
JOB N230,N,NS1505
LUFORTRAN
RUN ,,1500
VOLUME 7500
JOBCORE 30000
CARDLIST
DOCUMENT SOURCE
      LIBRARY (ED,SUBGROUPUSUB)
      LIBRARY (ED,SUBGROUPGRAF)
      LIBRARY (ED,SUBGROUPNAGF)
      PROGRAM(N230)
      COMPACT
      INPUT 1  = CRO
      OUTPUT 2 = LPO
      TRACE 0
      END


      MASTER STATISTICAL ANALYSIS
C            ********************
      REAL KURT
      DIMENSION V(400,12),VM(400),VMN(400),VMX(400),SD(400),SDM(400),
     *TITLE(400),CA(400)
      DIMENSION X(1800)
      CALL UTPOP
      READ(1,111) NS
      READ(1,444) AMIN,AMAX,VMIN,VMAX,AINS,VINS
      DO 10 IS =1,NS
      READ(1,333) (TITLE(I),I=1,30)
      READ(1,111) NP,NC
      DO 1 J = 1,NC
      READ(1,444) (V(I,J),I=1,NP)
    1 CONTINUE
      SS = 720./NP
      JW = 0
      DO 6 MP =1,NP
      SV =0.0
      DO 2 J=1,NC
    2 SV = SV+V(MP,J)
      VM(MP) = SV/NC
      SVS,DV3,DV4=0.0
      DO 3 J = 1,NC
      SVS = SVS+ V(MP,J)*V(MP,J)
      DV = V(MP,J)-VM(MP)
      DV3 = DV*DV*DV+DV3
    3 DV4 = DV4+DV3*DV
      Y1 = VM(MP)*VM(MP)*NC
      VAR = (SVS-Y1)/(NC-1)
      SD(MP) = SQRT(VAR)
      SDM(MP) = SD(MP)/VM(MP)*100.
      SD3 = SD(MP)*VAR
      SD4 = VAR*VAR
      SKEW = DV3/(SD3*(NC-1))
      KURT   DV4/(SD4*(NC-3))
      VMN(MP),VMX(MP)= V(MP,1)
      DO 4 J =1,NC
      IF(VMN(MP).LT.V(MP,J)) GO TO 4
      VMN(
```

```
      VMN(MP) = V(MP,J)
      MN = J
    4 CONTINUE
      DO 5 J=1,NC
      IF(VMX(MP).GT.V(MP,J)) GO TO 5
      VMX(MP) = V(MP,J)
      MX = J
    5 CONTINUE
      CA(MP) = SS*MP
      CVR = (VMX(MP)-VMN(MP))/VM(MP)*100.
      IF(JV.EQ.50) JW=0
      IF(JW.EQ.0) WRITE(2,555) (TITLE(I),I=1,30)
      JW = JW+1
      WRITE(2,666) CA(MP),VM(MP),VMX(MP),MX,VMN(MP),MN,SD(MP),SDM(MP),
     *SKEW,KURT,CVR
    6 CONTINUE
      CALL MAXIMUM (SDM,NP,SMMX)
      CALL MAXIMUM (SD,NP,SDMX)
      CALL UTP4A(AMIN,AMAX,VMIN,VMAX,AINS,VINS,23H CRANK ANGLE  (DEGREES
     *),3,16HMEAN VEL (M/SEC),2)
      CALL GRID (AMIN,AMAX,VMIN,VMAX,AINS,VINS)
      CALL UTP4B(CA,VM,NP,2)
      CALL UTP4A(AMIN,AMAX,VMIN,VMAX,AINS,VINS,23H CRANK ANGLE  (DEGREES
     *),3,15HMAX AND MIN VEL,2)
      CALL GRID (AMIN,AMAX,VMIN,VMAX,AINS,VINS)
      CALL UTP4B (CA,VMN,NP,2)
      CALL UTP4B (CA,VMX,NP,2)
      CALL UTP4A(0.0,720.,0.0,SDMX,8.,5.,23H CRANK ANGLE  (DEGREES),3,24
     *HSTANDARD DEVIATION M/SEC,3)
      CALL GRID(0.0,720.,0.0,SDMX,8.,5.0)
      CALL UTP4B(CA,SD,NP,2)
      CALL UTP4A(0.0,720.,0.0,SMMX,8.,5.,23H CRANK ANGLE  (DEGREES),3,24
     *HCOEFF.OF VAR. S(U)/U*100,3)
      CALL GRID(0.0,720.,0.0,SMMX,8.,5.0)
      CALL UTP4B (CA,SDM,NP,2)
   10 CONTINUE
      CALL UTPCL
  111 FORMAT(2X,6I3)
  222 FORMAT(6F0.0)
  333 FORMAT(10A8)
  444 FORMAT(2X,10F7.3)
  555 FORMAT(1H1,'                        STATISTICAL ANALYSIS OF GAS MOTION
     * INSIDE A CYLINDER OF A S.I. ENGINE '/
     *'                    *******************************************
     ***************************'/
     *'                 ',10A8/'                    ',10A8/
     *'                 ',10A8//
     *'   C.A.     MEAN VEL  MAX VEL CY NO   MIN VEL CY NO  S.D.   MEAN S
     *.D.%   SKEW       KURT   COEF OF VAR%')
  666 FORMAT(2X,F6.2,3X,F7.3,2X,F7.3,2X,I3,5X,F7.3,2X,I3,2X,F7.3,2X,F7.3
     *,3X,F8.4,3X,F8.4,3X,F8.4)
      STOP
      END
```

```
      SUBROUTINE MAXIMUM (X,NP,XMAX)
      DIMENSION X(200)
      XMAX = X(1)
      DO 1 I=1,NP
      IF(XMAX.GT.X(I)) GO TO 1
      XMAX = X(I)
    1 CONTINUE
      XMAX = (NINT(XMAX/5.)+1.)*5.
      RETURN
      END


      SUBROUTINE GRID(XMIN,XMAX,YMIN,YMAX,XINS,YINS)
C     DRAWS A GRID ON A SET OF AXES PROVIDED BY UTP4A IN THE MASTER .
      DIMENSION X(2),Y(2)
      NX= IFIX(XINS)
      NY= IFIX(YINS)
      X(1)= XMIN
      Y(1)= YMIN
      Y(2)= YMAX
      DX= (XMAX-XMIN)/XINS
      DO 1 I=1,NX
      X(1)= X(1)+DX
      X(2)= X(1)
    1 CALL UTP4B(X,Y,2,3)
      X(1)= XMIN
      DY= (YMAX-YMIN)/YINS
      DO 2 I=1,NY
      Y(1)= Y(1)+DY
      Y(2)= Y(1)
    2 CALL UTP4B(X,Y,2,3)
      RETURN
      END
      FINISH
```

APPENDIX B5

TURBULENCE ANALYSIS I
Program

The objective of this program is to calculate the characteristics of the turbulence signal at some particular crank angle of interest during the engine cycle. These turbulence characteristics include the following parameters:

a) Fluctuating velocity components, (u'):

b) Intensities of turbulence, Int = ($\frac{u'}{\bar{U}}$). 100.

c) Time micro-scales of turbulence, (λ_t).

d) Length micro-scales of turbulence, (λ_y).

e) Length macro-scales of turbulence, (L_x).

The mean gas velocities and the mean bridge voltages, over the number of cycles considered ($\bar{U}$ and $\bar{E}$), are calculated as intermediate steps in the program and are, therefore, produced on the output results.

It is obvious that this program requires feeding with the output results obtained from the SPECTRAL ANALYSIS program discussed in Appendix B2. This includes the following variables.

a) Values of the mean square of the fluctuating voltage components as given by $R_t(o)$ equation (B-14) calculated over a large number of cycles.

b) Values of the second derivative of the auto-correlation coefficient at zero time delay.

$$\left[\frac{\partial^2 R'_t (t)}{\partial t^2} \right]_{t = 0}$$

c) Values of the integral time scale

$$L_t = \int_0^{\infty} R'_t \, (dt) \qquad \text{(B20)}$$

This program requires also the digitized signal of the mean bridge voltage for a number of consecutive cycles, the characteristics of the hot wire anemometer used in collecting the signal and finally the fluid properties at the different crank angles considered in the program.

A listing of the MASTER segment of the TURBULENCE ANALYSIS I program is given at the end of this appendix. All the subroutines and functions required for this program are the same as for the VELOCITY PREDICTION program and are not repeated, therefore, in this appendix.

INPUT DATA

AX(I)	String of characters used for the graph plot.
VC(I)	Coefficients of the dynamic viscosity function.
CPAC(I)	Coefficients of the specific heat at constant pressure function.
NS	Number of individual tests considered.
CASE(I)	Description of each test condition.
N CYL	Firing order of any particular cylinder, relative to the reference cylinder, used in setting the timing mark.
NANG(K)	Number of crank angles at which turbulence analysis are required.
NC	Number of complete consecutive cycles from the mean bridge voltage trace.
NP	Number of samples per cycle.
N	Total number of samples on the continuous data record of mean bridge voltage.
NEQ	A control variable for the selection of the appropriate anemometer system current equation. NEQ = 1 For DISA AoI system (100Ω top resistance) NEQ = 2 For DISA M system (50Ω " ") NEQ = 3 For DISA M system (5Ω " ")
N GRAPH	A control variable for calling the graph plotter section of the program if its input value = 9.
ANGLE (I,K)*	Values of crank angles at which turbulence analyses are required.

VMS(I,K)	Mean square values of fluctuating voltage components.
MICRO (I,K)	Second derivative of auto-correlation coefficient at zero time delay.
MACRO (I,K)	Integral time scale of turbulence $= \int_0^\infty R_t' (t)\, dt$
P(I)	Gas pressures (N/m^2)
T(I)	Gas temperatures (^oC)
A	Biased DC level from mean bridge voltage trace.
B	Attenuation factor on the recorded mean bridge voltage trace.
G	Attenuation factor on the recorded turbulence signal.
X(I)	Digitized values of mean bridge voltage.

(RW, RC, RL, TW, TO, PO, D, Z, ALPHA, BETA, These groups of variables have the same meaning as in the VELOCITY PREDICTION program, Appendix B3).

(*) Subscripts I refer to a particular crank angle index and K to the particular test considered.

OUTPUT DATA

ANGLE (J,K)	Values of crank angles at which turbulence analysis are carried out (degrees).
BVM	Mean value of the bridge voltage at a particular crank angle (volts).
INTENSITY (J,K)	Turbulence intensities, (%).
MICRO (J,K)	Time micro-scale of turbulence (sec).
MICROL (J,K)	Length micro-scale of turbulence (mm).
MACRO (J,K)	Time macro-scale of turbulence (sec).
MACROL (J,K)	Length macro-scale of turbulence (mm).
VMS (J,K)	Mean square value of fluctuating voltage component (volts).
U (J,K)	Fluctuating velocity component (m/sec).
VM (J,K)	Mean gas velocity over a number of cycles (m/sec).

Subscripts, J the particular crank angle index.

K the particular test index.

```
JOB N250,N,NS1505
JORCORE 32000
LUFORTRAN
RUN ,,1500
DCUMENT SOURCE
      LIBRARY (ED,SUBGROUPGRAF)
      LIBRARY (ED,SUBGROUPUSUB)
      LIBRARY(ED,SUBGROUPNAGF)
      PROGRAM(N250)
      COMPACT
      INPUT 1 = CRO
      OUTPUT2 =LPO
      TRACE 2
      END


      MASTER    TURBULENCE ANALYSIS I
C               *********************
      REAL INTENSITY(12,10),MICRO(12,10),MICROL(12,10),MACRO(12,10),
     *MACROL(12,10)
      DIMENSION T(12),P(12),BETA(12),RG(12),VM(12,10),
     *ANGLE(12,10),VMS(12,10),U(12,10),X(7500),Y(12),NANG(12)
      DIMENSION AX(20),CASE(10),XX(12),YY(12)
      COMMON/PROP/VC(9),CPAC(9)
      READ(1,1000) (AX(I),I=1,20)
      READ(1,666) (VC(I),I=1,9)
      READ(1,666) (CPAC(I),I=1,9)
      READ(1,111) NS

      DO 40 K=1,NS
      READ (1,888) (CASE(I),I=1,10)
      READ(1,111) NCYL,NANG(K),NC,NP,N,NEQ,NGRAPH
      READ(1,222) RW,RC,RL,TW,TO,PO,D,Z,ALPHA,BETO,E
      READ(1,222)(ANGLE(I,K),I=1,NANG(K))
      READ(1,222) (VMS(I,K),I=1,NANG(K))
      READ(1,222)(MICRO(I,K),I=1,NANG(K))
      READ(1,222)(MACRO(I,K),I=1,NANG(K))
      READ(1,222) (P(I),I=1,NANG(K))
      READ(1,222) (T(I),I=1,NANG(K))
      READ(1,222) A,B,G
      READ(1,333) (X(I),I=1,N)
      WRITE(2,889) (CASE(I),I=1,10)
      WRITE(2,444)

      DO 30 J=1,NANG(K)
      DO 10 I 1,NANG(K)
      BETA(I) = BETO*(1+ALPHA*(T(I)-TO))
      RG(I)   = RC* ( 1+ALPHA*(T(I)-TO))
   10 CONTINUE
      NSHIFT = NINT(FLOAT(NP*NCYL)/3.)
      SV,SBV=0.0
      DO 20 I=1,NC
      NX = NSHIFT +(I-1)*NP+NINT(ANGLE(J,K)*FLOAT(NP)/720.)
      Y1= (X(NX-1)+X(NX)+X(NX+1))/3.
      BV = A*Y1+B
      SBV = SBV+BV
```

```
      IF(NEQ.EQ.1) CUR = BV/(100.+RW+RL)
      IF(NEQ.EQ.2) CUR = BV/(50. +RW+RL)
      IF(NEQ.EQ.3) CUR = BV/(5.0 +RW+RL)
      CALL DF(T(J),TW,CUR,RW,RG(J),BETA(J),Z,D,ALPHA,P(J),VE,H,M)
      SV = SV+VE
   20 CONTINUE
      BVM = SBV/NC
      VM(J,K)= SV/NC
      VMS(J,K) = VMS(J,K)*G   *G
      INTENSITY (J,K) = SQRT(ABS(VMS(J,K)))*6./BVM*100.
      U(J,K) = VM(J,K)*INTENSITY(J,K)/100.
C     MICROL(J,K) &MACRO(J,K)  ARE CALCULATED IN (MM)
      MICROL(J,K) =MICRO(J,K)*VM(J,K)*5/(10**2)
      MACROL(J,K) =MACRO(J,K)*VM(J,K)*(1000)
      WRITE(2,555) ANGLE(J,K),BVM,VMS(J,K),VM(J,K),INTENSITY(J,K),U(J,K)
     *,MACROL(J,K),MICROL(J,K)
   30 CONTINUE
   40 CONTINUE
      IF(NGRAPH.NE.9) STOP
      CALL UTPOP
      VMAX = 40.
      SFX = 0.02
      CALLUTP4A(80. ,380.,0.0,VMAX,6.,5.,11HCRANK ANGLE,2,20HTURBULENCE
     *INTENSITY,3)
      SFY= 5./VMAX
      DO 60 K=1,NS
      DO 50 J=1,NANG(K)
      XX(J) =ANGLE(J,K)
      YY(J) = INTENSITY(J,K)
      X(J) = ANGLE(J,K)*SFX-1.6
      Y(J) = INTENSITY(J,K)*SFY
      CALL UTP3(AX(K),X(J),Y(J),2)
   50 CONTINUE
      CALL UTP4B(XX,YY,NANG(K),2)
   60 CONTINUE
      CALLUTP4A(80. ,380.,0.0, 6.0,6.,6.,11HCRANK ANGLE,2,19HTURBULENT
     *VELOCITY,3)
      DO 80 K=1,NS
      DO 70 J=1,NANG(K)
      YY(J) = U(J,K)
      X(J) = ANGLE(J,K)*SFX-1.6
      Y(J) = U(J,K)
      CALL UTP3(AX(K),X(J),Y(J),2)
   70 CONTINUE
      CALL UTP4B(XX,YY,NANG(K),2)
   80 CONTINUE
      CALL UTP4A(80.,380.,0.0,4.,6.,5.,11HCRANK ANGLE,2,24HMICROSCALE OF
     * TURBULENCE,3)
      SFY = 1.25
      DO100 K=1,NS
      DO 90 J=1,NANG(K)
      XX(J) =ANGLE(J,K)
      YY(J) = MICRO(J,K)
      X(J) = ANGLE(J,K)*SFX-1.6
      Y(J) = MICRO(J,K)*SFY
      CALL UTP3(AX(K),X(J),Y(J),2)
   90 CONTINUE
```

```
      CALL UTP4B(XX,YY,NANG(K),2)
  100 CONTINUE
      CALLUTP4A(80.,380. ,0.0,VMAX,6.,5.,11HCRANK ANGLE,2,20HMEAN VELOCT
     *Y (M/SEC),3)
      SFY = 5./VMAX
      DO 120 K=1,NS
      DO110 J=1,NANG(K)
       XX(J) =ANGLE(J,K)
      YY(J) = VM(J,K)
      X(J) = ANGLE(J,K)*SFX-1.6
      Y(J) = VM(J,K)*SFY
      CALL UTP3(AX(K),X(J),Y(J),2)
  110 CONTINUE
      CALL UTP4B(XX,YY,NANG(K),2)
  120 CONTINUE
      CALLUTP4A(80. ,380.,0.,2.,6.,5.,11HCRANK ANGLE,2,19HSCALE OF TURBU
     *LENCE,3)
      SFY = 2.5
      DO 140 K=1,NS
      DO130 J=1,NANG(K)
       XX(J) =ANGLE(J,K)
      YY(J) = MICROL(J,K)
      X(J) = ANGLE(J,K)*SFX-1.6
      Y(J) = MICROL(J,K)*SFY
      CALL UTP3(AX(K),X(J),Y(J),2)
  130 CONTINUE
      CALL UTP4B(XX,YY,NANG(K),2)
  140 CONTINUE
  111 FORMAT(10I4)
  222 FORMAT(12F0.0)
  333 FORMAT(2X,10F7.3)
  444 FORMAT(  X,'    CRANK ANGLE     MEAN B.V.          VMS           MEAN V
     *EL.    INTENSITY    TURBULENT VEL.    MACRO-            MICRO')
  555 FORMAT(2X,E13.5,2X,E13.5,1X,6(1X,E13.5))
  666 FORMAT(3E20.12)
  888 FORMAT(10A8)
  889 FORMAT(10X,10A8)
  999 FORMAT(6F0.0)
 1000 FORMAT(20A1)
 2000 CONTINUE
      CALL UTPCL
      STOP
      END
```

APPENDIX B6

TURBULENCE ANALYSIS II
Program

The main operations carried out by this program could be summarised as follows:

1. Calculations of the spatial micro-scale of turbulence from the normalised power spectrum curves as given by

$$\frac{1}{\lambda_x^2} = \frac{4 \pi^2}{\bar{U}^2} \int_0^\infty F(n)\, n^2\, d\, n \qquad \text{(B21)}$$

2. Calculations of the macro-scale of turbulence by integrating the positive part of auto-correlation coefficient curve and by approximating the auto-correlation curve by an exponential function as given by the following relations

$$L_t = \int_0^\infty R'_t\,(t)\ dt \qquad \text{(B20)}$$

$$L_x = \bar{U}\ L_t \qquad \text{(B22)}$$

and

$$R'_t\,(t) = e^{-t/Lt} \qquad \text{(B23)}$$

3. Calculations of the percentage of energy content in the signal at different frequencies as given by

$$\frac{\overline{u_1^2}}{\overline{u'^2}} = \int_0^{n_1} F(n)\ dn \qquad \text{(B24)}$$

4. Producing the power spectrum, auto-correlation coefficient and the second derivative of the auto-correlation coefficients in terms of absolute values at different frequencies and time delays, respectively.

INPUT DATA

NT	Number of individual graphs required with the following sequence IT = 1 for normalised power spectrum curve. IT = 2 for auto-correlation coefficient curve. IT = 3 for the second derivative of auto-correlation coefficient.
BS	Number of samples in the original data block on the FOURIER ANALYSER.
U	Mean gas velocity at the particular crank angle of interest.
VARIABLE(I)	Description of test conditions for each graph.
NAMEX(I)	The title which appears on the x-axis of a graph.
NAMEY(I)	The title which appears on the y-axis of a graph.
N1	Total number of data words on each tape.
NP	Number of samples per cycle.
SR	Sampling interval of the digitized data (μ sec/sample).

OUTPUT DATA

A(I)	Absolute values of the variable considered.
MAX	The location of maximum value of ordinates on the tape.
AMAX	The value of the maximum ordinate on a trace.
MACROSCALE	Macro-scale of turbulence.

OUTPUT DATA (continued)

SCALE	Micro-scale of turbulence.
FREQ(I)	Minimum frequency for a certain percentage of energy content in the signal.

```
JOB N390,N,NS1505
LUFORTRAN
IN TRO(NON-STANDARD),ONLINE
RUN
CARDLIST
DOCUMENT SOURCE
      LIBRARY (ED,SUBGROUPUSUB)
      LIBRARY (ED,SUBGROUPGRAF)
      LIBRARY (ED,SUBGROUPNAGF)
      PROGRAM(N390)
      COMPACT
      INPUT 1=CRO
      INPUT 3= TRO
      OUTPUT 2 = LPO
      OUTPUT 4=CPO
      TRACE 2
      END


C     MASTER     TURBULENCE ANALYSIS II
C                ***********************
      INTEGER SR
      REAL MACROSCALE (500)
      REAL NAMEX(4),NAMEY(4)
      DIMENSION A(2100),IA(8),VARIABLE(10),Z(11)
      COMMON/B1/X(1100),Y(1100),FREQ(11),N11,U,BS,FMAX
      COMMON/B1/X(1100),Y(2100),FREQ(11),N11,U,BS,FMAX
      DATA Z(1) Z(2),Z(3),Z(4),Z(5),Z(6),Z(7),Z(8),Z(9),Z(10),Z(11)/0.0,
     *0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1.0/
      READ(1,10) NT
      READ(1,20) U,BS,FMAX
      CALL UTPOP
      DO 1000 IT =1,NT
      READ(1,80) (VARIABLE (I),I=1,10)
      READ(1,80) ( NAMEX(I),I=1,4)
      READ(1,80) ( NAMEY(I),I=1,3)
      READ(1,70) N1,NP,SR
      CT = 32767.0*32767.
      SS=720./FLOAT(NP)
      RPM=120.*(10.**6)/FLOAT(NP*SR)
      WRITE(2,90) (VARIABLE(I),I=1,10),RPM,NP,SS
      NPP =N1/8
      NPC =NPP *8
      IF((IT.EQ.1).OR.(NRP.EQ.0)) READ(3,100)N2,N3
      IF(( IT.GT.1).AND.(NRP.GT.0))READ(3,101)N2,N3
      WRITE(2,100) N2,N3
      IF(N2.GT.0) SF = FLOAT(10**N2)*N3/CT
      IF(N2.EQ.0)SF = FLOAT(N3)/CT
      IF(N2.LT.0)  SF   FLOAT(N3)/((10.**IABS(N2))*CT)
      WRITE(2,500) SF
      DO 300 L=1,NPP
      READ (3,200) ( IA(I),I =1,8)
       K = (L-1) *8
      DO 300 J= 1,8
       M=J+K
      A(M) = FLOAT(IA(J)) * SF
  300 CONTINUE
```

```
      NRP = N1- NPC
      IF(NRP.EQ.0) GO TO 75
      READ(3,200) (IA(II) II=1,NRP)
      DO 75 II =1,NRP
      K = NPC +II
      A(K) = FLOAT(IA(II))*SF
   75 CONTINUE

      IF(IT.EQ.1) GO TO 520
      IF(IT.NE.3) GO TO 506
      DO 505 IF=1,N1
      Y(IF) =-A(IF)
  505 CONTINUE
  506 CONTINUE
      IF(IT.NE.2) GO TO 508
      DO 507 IF =1,N1
      Y(IF) = A(IF)
  507 CONTINUE
  508 CONTINUE
      CALL MAXIMUM (Y,N1,AMAX,MAX)
      WRITE(2,10) MAX
      WRITE(2,700) AMAX
      DO 510 IF =1,N1
      X(IF)=FLOAT((IF-MAX)*SR)/(10.**6)
      IF(Y(IF).EQ.1) GO TO 510
      MACROSCALE(IF) = X(IF)/ALOG(ABS(Y(IF)))
  510 CONTINUE
      WRITE(2,700) (X(II),MACROSCALE(II),II=1,N1)
      XMIN = X(1)
      XMAX = X(N1)
      YMIN - 0.5*AMAX
      WRITE(2,700) XMAX
      WRITE(2,700) YMIN
      WRITE(2,700) (X(II),Y(II),II=1,N1)
      CALL UTP4A(XMIN,XMAX,YMIN,AMAX,5.,5.,NAMEX,3,NAMEY,3)
      CALL UTP4B(X,Y,N1,2)
      GO TO 1000
  520 N11 = N1/2
      X(1) = 0.0
      DO 530 IF =2,N11
  530 X(IF) = IF*10000./2048.
      IF = 1
      DO 540 IF2=1,N1,2
      Y(IF) = A(IF2)*2048/10000.*2.
      IF = IF+1
  540 CONTINUE
      CALL MAXIMUM (Y,N11,YMAX,MAX)
      WRITE(2,10) MAX
      WRITE(2,700) YMAX
      WRITE(2,700) (X(II),Y(II),II=1,N11)
      CALL UTP4A( 0.0,5000.,.0,YMAX,5.,5.,NAMEX,3,NAMEY,3)
      CALL UTP4B(X,Y,N11,2)
      CALL ENERGY DISTRIBUTION
      CALL UTP4A(0.0,5000.,0.0,1.0,5.,5.,16HFREQUENCIES (HZ),2,8HENERGY
     *%,1)
      CALL UTP4B(FREQ,Z,11,2)
 1000 CONTINUE
```

```
 10 FORMAT(I3)
 20 FORMAT(4F0.0)
 70 FORMAT(3I4)
 80 FORMAT(10A8)
 90 FORMAT(1H1,10X,21HDIGITIZED DATA FOR    ,10A8//
   *8X,14HENGINE SPEED =,F7.2,19H   NO. OF SAMPLES =,I3,16H   SAMPLE S
   *IZE =,F5.2,9H(DEGREES)//)
100 FORMAT(2X,I7,14X,I7,/)
101 FORMAT (1X,/,2X,I7,14X,I7,/)
200 FORMAT(10X,8I7,1X,/)
500 FORMAT(2X,5E15.9,I3)
700 FORMAT(8(2X,E12.5))
    CALL UTPCL
    STOP
    END



    SUBROUTINE ENERGY DISTRIBUTION
               *******************
    COMMON/B1/X(1100),Y(2100),FREQ(11),N11,U,BS,FMAX
    DF=2.*FMAX/BS
    AREA,AREA1=0.0
    J = 0
    DO 1 I=1,(N11-1)
    AREA = AREA+(Y(I)+Y(I+1))/2.*DF
    AREA1=AREA1+(Y(I)+Y(I+1))*(X(I)**2)*DF/2.
    IF(AREA.LE.0.1) FREQ(2)  = X(I)
    IF(AREA.LE.0.2) FREQ(3)  = X(I)
    IF(AREA.LE.0.3) FREQ(4)  = X(I)
    IF(AREA.LE.0.4) FREQ(5)  = X(I)
    IF(AREA.LE.0.5) FREQ(6)  = X(I)
    IF(AREA.LE.0.6) FREQ(7)  = X(I)
    IF(AREA.LE.0.7) FREQ(8)  = X(I)
    IF(AREA.LE.0.8) FREQ(9)  = X(I)
    IF(AREA.LE.0.9) FREQ(10)= X(I)
    IF(AREA.LE.1.0) FREQ(11) = X(I)
    IF(J.GT.100) J =0
    IF(J.EQ.100) WRITE(2,3) X(I),AREA,AREA1
    J=J+1
    J  =  J +  1
  1 CONTINUE
    SCALE = SQRT((U**2)*(10.**6)/(39.478416*AREA1))
    WRITE(2,2) (FREQ(I),I=2,11)
    WRITE(2,4) SCALE
  4 FORMAT(2X,'MICRO-SCALE OF TURBULENCE =',F7.4,'(MM)')
  2 FORMAT(2X,' MINIMUM FREQUENCIES FOR PERCENTAGES OF TOTAL ENERGY'/
   *'     10%    20%    30%    40%    50%    60%    70%    80%    90%    100%'/
   *10(2X,F8.3))
  3 FORMAT(3(2X,F8.4))

    RETURN
    END
```

```
      SUBROUTINE MAXIMUM (X,NP,XMAX,J)
                 ********************
      DIMENSION X(2100)
      XMAX = X(1)
      J = 1
      DO 1 I=1,NP
      IF(XMAX.GT.X(I)) GO TO 1
      XMAX = X(I)
      J =I
    1 CONTINUE
      RETURN
      END
      FINISH
```

APPENDIX B7

TURBULENCE CYCLIC VARIATION
Program

The main objectives of this program could be outlined as follows:

1. Calculations of the turbulence characteristics for individual cycles at different crank angles during the engine cycle, e.g. fluctuating velocity components, micro-scales, intensities of turbulence and eddy diffusivities.

2. A test on the stationarity of the data at different confidence limits.

3. Estimation of the extent of cyclic variations in turbulence parameters, in terms of their standard deviations, coefficient of variation and ranges of variation.

The input data for such a program are, therefore, the output results of the Spectrum Analysis program for individual cycles (data records) at any particular crank angle of interest during the engine cycle.

INPUT DATA

NANG	Number of crank angles during the engine cycle, for which turbulence analysis are carried out.
NCYC	Number of cycles analysed at each crank angle.
G	Attenuation factor on the recorded turbulence signal.
ANGLE(I)	Values of crank angles at which turbulence analysis is carried out.
N EU(I)	Values of the kinematic viscosity at different crank angles.
BV(I)	Mean values of the bridge voltage at different crank angles.
VM(I)	Mean values of gas velocity at different crank angles.
VMS(I,J)	Mean square values of the fluctuating voltage component at the crank angle index (J) and for the particular cycle number (I).
MICRO(I,J)	The values of the second derivative of the auto-correlation coefficient at zero time delay for the crank angle of index (J) and the particular cycle number (I).
MACRO(I,J)	The value of the integral time scale at the crank angle of index (J) and for the cycle number (I).

OUTPUT DATA

The output data of this program are the calculated values of turbulence characteristic parameters for the number of cycles analysed.

These calculated parameters are:

1. Fluctuating velocity component (u').
2. Intensity of turbulence (Int = $\frac{u'}{\bar{U}} \cdot 100$).
3. Micro-scale of turbulence λ_y.
4. Macro-scale of turbulence L_x.
5. Micro-eddy diffusivity. ε_λ
6. Macro-eddy diffusivity. ε_L

Meanings of the symbols used for all the output parameters are as follows:

Y(I)	Value of a particular parameter for the cycle number I.
YM	Mean value of the parameter Y.
SD	Standard deviation of the parameter Y.
SDM	Coefficient of variation of the parameter Y = $\frac{SD}{YM}$.
ST INDEX	Stationarity index which provides the number of sign changes for the values of a particular parameter over a number of cycles (NCYC) which is compared with standard values for the "RUN TEST" of stationarity at different confidence limits as given in Table (B4).

TABLE (B4) Test of Stationarity

Percentage Points of Run Distribution (118).

Values of $r_{n,\alpha}$ such that $\left[r_n > r_{n,\alpha}\right] = \alpha$ where $n = N/2$

n = N/2	α					
	0.99	0.975	0.95	0.05	0.025	0.01
5	2	2	3	8	9	9
6	2	3	3	10	10	11
7	3	3	4	11	12	12
8	4	4	5	12	13	13
9	4	5	6	13	14	15
10	5	6	6	15	15	16
11	6	7	7	16	16	17
12	7	7	8	17	18	18
13	7	8	9	18	19	20
14	8	9	10	19	20	21
15	9	10	11	20	21	22
16	10	11	11	22	22	23
18	11	12	13	24	25	26
20	13	14	15	26	27	28
25	17	18	19	32	33	34
30	21	22	24	37	39	40
35	25	27	28	43	44	46
40	30	31	33	48	50	51
45	34	36	37	54	55	57
50	38	40	42	59	61	63
55	43	45	46	65	66	68
60	47	49	51	70	72	74
65	52	54	56	75	77	79
70	56	58	60	81	83	85
75	61	63	65	86	88	90

```
JOB N290,N,NS1505
LUFORTRAN
RUN
CARDLIST
DOC SOURCE
      LIBRARY(ED,SUBGROUPNAGF)
      LIBRARY (ED,SUBGROUPUSUB)
      LIBRARY (ED,SUBGROUPGRAF)
      PROGRAM(N290)
      COMPACT
      INPUT 1 = CRO
      OUTPUT 2 = LPO
      TRACE 2
      END


      MASTER TURBULENCE CYCLIC VARIATION
C           ***************************
      REAL MICRO(100,12),MACRO(100,12),NEU(12)
      DIMENSION ANGLE(12),BV(12),VM(12),VMS(100,12),X(100),Y(100)
      DIMENSINN TE(100),Y1(100),TITLE(10,12)
      READ(1,111) NANG,NCYC
      WRITE(2,111) NANG,NCYC
      READ(1,222) G
      READ(1,222) (ANGLE(I),I=1,NANG)
      READ(1,222) (NEU(I),I=1,NANG)
      READ(1,222) ( BV  (I),I=1,NANG)
      READ(1,222) ( VM  (I),I=1,NANG)
      DO 100 J=1,NANG
      READ(1,1010) (TITLE(I,J),I=1,10)
      READ(1,222) (VMS(I,J),I=1,NCYC)
      WRITE(2,444)(VMS(I,J),I=1,NCYC)
      READ(1,222) (MICRO(I,J),I=1,NCYC)
      WRITE(2,444)(MICRO(I,J),I=1,NCYC)
  100 CONTINUE
      DO 200 I=1,NCYC
  200 X(I)=FLOAT(I)
      DO 250 J=1,NANG
      DO 250 I=1,NCYC
      MICRO(I,J)=MICRO(I,J)/(10.**4)
      VMS(I,J)=VMS(I,J)*G*G/(10.**5)
  250 CONTINUE
      CALL UTPOP
      XMIN=0.0
      XMAX=FLOAT(NCYC)
      YMIN=0.0
      YMAX=40.
      DO 400 J=1,NANG
      WRITE(2,1010) (TITLE(IW,J),IW=1,10)
      CALL UTP4A(XMIN,XMAX,YMIN,YMAX,5.,5.,12HCYCLE NUMBER,2,
     *22HTURBULENCE INTENSITY %,3)
      YM,SYS=0.0
      STINDEX =0.0
      DO 300 I=1,NCYC
      Y(I)=6.*SQRT(VMS(I,J))/BV(J)*100.
      YM =YM+Y(I)
      SYS =SYS+Y(I)*Y(I)
  300 CONTINUE
      YM=YM/FLOAT(NCYC)
      DO 350 I=1,NCYC
```

```
      DO 350 I=1,NCYC
      TE(I)=Y(I)-YM
      IF(I.EQ.1) GO TO 350
      T =TE(I)/TE(I-1)
      IF(T.LT.0.0) STINDEX =STINDEX+1.
  350 CONTINUE
      YY =YM*YM*FLOAT(NCYC)
      VAR =(SYS-YY)/FLOAT(NCYC-1)
      SD=SQRT(VAR)
      SDM =SD/YM
      WRITE(2,555) NCYC
      WRITE(2,333) ANGLE(J),YM,VAR,SD,SDM,ST INDEX
      WRITE( ,444) (X(I),Y(I),I=1,NCYC)
      CALL UTP4B(X,Y,NCYC,2)
  400 CONTINUE
      YMAX=0.2
      DO 600 J=1,NANG
      WRITE(2,1010) (TITLE(IW,J),IW=1,10)
      CALL UTP4A(XMIN,XMAX,YMIN,YMAX,5.,5.,12HCYCLE NUMBER,2,
     *16HMICRO-SCALE (MM),2)
      YM,SYS=0.0
      STINDEX =0.0
      DO 500 I=1,NCYC
      Y(I)=VM(J)*0.05/SQRT(MICRO(I,J))
      SYS =SYS+Y(I)*Y(I)
      YM=YM+Y(I)
  500 CONTINUE
      YM=YM/FLOAT(NCYC)
      DO 550 I=1,NCYC
      TE(I)=Y(I)-YM
      IF(I.EQ.1) GO TO 550
      T =TE(I)/TE(I-1)
      IF(T.LT.0.0) STINDEX =STINDEX+1.
  550 CONTINUE
      YY =YM*YM*FLOAT(NCYC)
      VAR =(SYS-YY)/FLOAT(NCYC-1)
      SD=SQRT(VAR)
      SDM =SD/YM
      WRITE(2,666) NCYC
      WRITE(2,333) ANGLE(J),YM,VAR,SD,SDM,ST INDEX
      CALL UTP4B(X,Y,NCYC,2)
      WRITE(2,444) (X(I),Y(I),I=1,NCYC)
  600 CONTINUE
      YMAX=0.5
      DO 800 J=1,NANG
      WRITE(2,1010) (TITLE(IW,J),IW=1,10)
      CALL UTP4A(XMIN,XMAX,YMIN,YMAX,5.,5.,12HCYCLE NUMBER,2,
     *15HFLUCT VEL M/SEC,2)
      YM,SYS=0.0
      STINDEX =0.0
      DO 700 I=1,NCYC
      Y(I) =6.*SQRT(VMS(I,J))*VM(J)/BV(J)
      YM=YM+Y(I)
      SYS =SYS+Y(I)*Y(I)
  700 CONTINUE
```

```
      YM=YM/FLOAT(NCYC)
      DO 750 I=1,NCYC
      TE(I)=Y(I)-YM
      IF(I.EQ.1) GO TO 750
      T =TE(I)/TE(I-1)
      IF(T.LT.0.0) STINDEX =STINDEX+1.
  750 CONTINUE
      YY =YM*YM*FLOAT(NCYC)
      VAR =(SYS-YY)/FLOAT(NCYC-1)
      SD=SQRT(VAR)
      SDM =SD/YM
      WRITE(2,777) NCYC
      WRITE(2,333) ANGLE(J),YM,VAR,SD,SDM,ST INDEX
      WRITE(2,444) (X(I),Y(I),I=1,NCYC)
      CALL UTP4B(X,Y,NCYC,2)
  800 CONTINUE
      YMAX=0.0001
      DO 1000 J=1,NANG
      WRITE(2,1010) (TITLE(IW,J),IW=1,10)
      CALL UTP4A(XMIN,XMAX,YMIN,YMAX,5.,5.,12HCYCLE NUMBER,2,
     *22HMICRO EDDY DIFUSSIVITY,3)
      YM,SYS=0.0
      STINDEX =0.0
      DO 900 I=1,NCYC
      Y(I)=SQRT(VMS(I,J)/MICRO(I,J))*3./((10.**4)*BV(J))
      SYS =SYS+Y(I)*Y(I)
      YM=YM+Y(I)
  900 CONTINUE
      YM=YM/FLOAT(NCYC)
      DO 950 I=1,NCYC
      TE(I)=Y(I)-YM
      IF(I.EQ.1) GO TO 950
      T =TE(I)/TE(I-1)
      IF(T.LT.0.0) STINDEX =STINDEX+1.
  950 CONTINUE
      YY =YM*YM*FLOAT(NCYC)
      VAR =(SYS-YY)/FLOAT(NCYC-1)
      SD=SQRT(VAR)
      SDM =SD/YM
      CALL UTP4B(X,Y,NCYC,2)
      WRITE(2,888) NCYC
      WRITE(2,333) ANGLE(J),YM,VAR,SD,SDM,ST INDEX
      WRITE(2,444) (X(I),Y(I),I=1,NCYC)
 1000 CONTINUE
      DO 1400 J=1,NANG
      WRITE(2,1010) (TITLE(IW,J),IW=1,10)
      STINDEX,STINDEX1=0.0
      YM,SYS=0.0
      YM1,SYS1=0.0
      DO 1100 I=1,NCYC
        U   =6.*SQRT(VMS(I,J))*VM(J)/BV(J)
      Y(I)=VM(J)*MACRO(I,J)*1000.
      Y1(I)=Y(I)*U/(10**3)
      SYS=SYS+Y(I)*Y(I)
```

```
      SYS1 =SYS1+Y1(I)*Y1(I)
      YM =YM+Y(I)
      YM1 =YM1+Y1(I)
 1100 CONTINUE
      YM=YM/FLOAT(NCYC)
      YM1 =YM1/FLOAT(NCYC)
      DO 1150 I=1,NCYC
      TE(I)=Y(I)-YM
      IF(I.EQ.1) GO TO 1150
      T=TE(I)/TE(I-1)
      IF(T.LT.0.0) STINDEX =STINDEX +1.
 1150 CONTINUE
      DO 1350 I =1,NCYC
      TE(I)=Y1(I)-YM1
      IF(I.EQ.1) GO TO 1350
      T=TE(I)/TE(I-1)
      IF(T.LT.0.0) STINDEX1=STINDEX1+1.
 1350 CONTINUE
      YY =YM*YM*FLOAT(NCYC)
      VAR =(SYS-YY)/FLOAT(NCYC-1)
      SD=SQRT(VAR)
      SDM=SD/YM
      YY =YM1*YM1*FLOAT(NCYC)
      VAR1=(SYS1-YY)/FLOAT(NCYC-1)
      SD1 =SQRT(VAR1)
      SDM1=SD1/YM1
      YMIN=0.0
      YMAX=1.
      WRITE(2,887) NCYC
      WRITE(2,333) ANGLE(J),YM,VAR,SD,SDM,ST INDEX
      WRITE(2,444) (X(I),Y (I),I=1,NCYC)
      CALL UTP4A(XMIN,XMAX,YMIN,YMAX,5.,5.,12HCYCLE NUMBER,2,
     *16HMACRO-SCALE (MM),2)
      CALL UTP4B(X,Y,NCYC,2)
      YMAX=0.0004
      WRITE(2,889) NCYC
      WRITE(2,333) ANGLE(J),YM1,VAR1,SD1,SDM1,ST INDEX1
      WRITE(2,444) (X(I),Y1(I),I=1,NCYC)
      CALL UTP4A(XMIN,XMAX,YMIN,YMAX,5.,5.,12HCYCLE NUMBER,2,
     *16HEDDY DIFUSSIVITY,2)
      CALL UTP4B(X,Y1,NCYC,2)
  400 CONTINUE
  111 FORMAT(10I3)
  222 FORMAT(10F0.0)
  333 FORMAT(2X,'CRANK ANGLE  ',F5.1 ,'MEAN VALUE =',E14.6,'VARIANCE  ',
     *E14.6,'STANDARD DEVIATION =',E14.6/ 'COEFFICIENT OF VARIATION =',
     *E14.6,'STATIONARITY INDEX =',F4.0)
  444 FORMAT(6(2X,E14.6))
  555 FORMAT(2X,'TURBULENCE INTENSITIES FOR A NUMBER OF CYCLES NC=',I4)
  666 FORMAT(2X,'MICRO-SCALE OF TURBULENCE FOR A NUMBER OF CYCLES NC=',I
     *4)
  777 FORMAT(2X,'FLUCTUATING VEL. COMONENT FOR A NUMBER OF CYCLES NC=',I
     *4)
```

```
 889 FORMAT(2X;'MACRO EDDY DIFFUSIVITY FOR A NUMBER OF CYCLES NC=',I4)
 888 FORMAT(2X,'MICRO EDDY DIFFUSIVITY FOR A NUMBER OF CYCLES NC=',I4)
 999 FORMAT(20A1)
 337 FORMAT(2X,'MACRO-SCALE OF TURBULENCE FOR A NUMBER OF CYCLES NC=',I
    *4)
1010 FORMAT(10A8)
     CALL UTPCL
     STOP
     END
     FINISH
```

APPENDIX B8

PIPE FLOW CORRELATION
Program

The main objectives of this program could be divided into two items:

1. Establishment of the best relationship between the ratio of Eulerian/Lagrangian scales and other fluid properties such as fluctuating velocity components or the turbulence Reynolds numbers, R_{e_λ} and R_{e_L}.
2. Estimation of the coefficient of correlation between the measured values of eddy diffusivities and the predictions from pipe flow empirical relations.

The main operation in the program consists, therefore, of iteration procedures to establish the best values in an assumed model of relations as given by:

$$\frac{\mathcal{L}_L}{L_x} = a_1 + b_1 \, Re_L^{E_1} \tag{B25}$$

$$\frac{\mathcal{L}_L}{L_x} = a_2 + b_2 \, R_{e_\lambda}^{E_2} \tag{B26}$$

$$\frac{\mathcal{L}_L}{L_x} = a_3 + b_3 \, u'^{E_3} \tag{B27}$$

The values of the constants a_1 and b_1 are calculated by a least square errors regression between ($\mathcal{L}_L/L_x$) and $R_{e_L}^{E_1}$, $R_e^{E_2}$ or u'^{E_3}.

INPUT DATA

NC	Number of correlation models investigated.
N	Number of experimental points used for establishing the correlation.
NE	Maximum number of iteration loops in the program.
CASE(I)	Description of the particular model equation.
ERE	Initial value of Reynolds number exponent.
DERE	Increment in Reynolds number exponent.
EU	Initial value of fluctuating velocity component exponent.
DEU	Increment in fluctuating velocity component exponent.
U(I)	Values of the fluctuating velocity components for different experimental points.
RE(I)	Values of the turbulence Reynolds number Re_L or Re_λ.
EDI(I)	Eddy diffusivities based on Eulerian scales.

$$\varepsilon_\lambda = u' \cdot \lambda_y , \qquad (B28)$$

$$\varepsilon_L = u' \cdot L_x \qquad (B29)$$

EDM(I)	Values of eddy diffusivities obtained from pipe flow data at comparable fluid conditions.

OUTPUT DATA

E	Exponent of the Reynolds number of fluctuating velocity component.
A,B	Constants in equations (B25) - (B27).
X(I)	Values of $Re^E(I)$ or $U^E(I)$.

OUTPUT DATA (continued)

Y(I)	Values of ED1(I)/EDM(I).
YC(I)	Values of (corrected eddy diffusivity/EDM(I)), corrected eddy diffusivity = ED1.$\mathcal{L}/L_x$. (B30)
R	Coefficient of correlation between $\mathcal{L}/L_x$ and R_e^E or $\mathcal{L}/L_x$ and U^E.
ER	Square root of the summation of errors between Y(I) and YC(I).

```
JOB N270,N,NS1505
LUFORTRAN
RUN

DOCUMENT SOURCE
       LIBRARY(ED,SUBGROUPNAGF)
       LIBRARY (ED,SUBGROUPUSUB)
       PROGRAM(N270)
       COMPACT
       INPUT 1 =CRO
       OUTPUT 2 =LPO
       TRACE 2
       END

       MASTER          PIPE FLOW CORRELATION
C                      *********************
       DIMENSION ED1(200),EDM(200),U(200),RE(200),CASE(10)
       COMMON /B1/ X(200),Y(200),YC(200),A,B,N
       READ(1,111)NC
       DO 400 L=1,NC
       READ(1,666) (CASE(I),I=1,9)
       READ(1,111) N,NE
       READ(1,222) ERE,DERE,EU,DEU
       READ(1,222)  (U(I),I=1,N)
       READ(1,222)  (RE(I),I=1,N)
       READ(1,222)  (ED1(I),I=1,N)
       READ(1,222)  (EDM(I),I=1,N)

       DO 300 K=1,2
       IF(K.EQ.1) E=ERE
       IF(K.EQ.1) DE=DERE
       IF(K.EQ.2) E=EU
       IF(K.EQ.2)DE=DEU
       DO 200 J=1,NE
       IF(E.EQ.0.0) GO TO 150
       DO 100 I=1,N
       Y(I)=EDM(I)/ED1(I)
       IF(K.EQ.1) X(I)=RE(I)**E
       IF(K.EQ.2) X(I)=U(I)**E
 100   CONTINUE
       CALL   LEAST SQUARES
       WRITE(2,666) (CASE(II),II=1,9)
       IF(K.EQ.1) WRITE(2,333) A,B,E
       IF(K.EQ.2) WRITE(2,444) A,B,E
       WRITE(2,555) (X(I),Y(I),YC(I),I=1,N)
 150   CONTINUE
       E=E-DE
 200   CONTINUE
 300   CONTINUE
 400   CONTINUE
 111   FORMAT(5I3)
 222   FORMAT(12F0.0)
 333   FORMAT(2X,'CORRELATION BASED ON REYNOLDS NUMBER'/
      *5X,'X=',E14.L),' +',E14.6,'RE**',F5.3)
 444   FORMAT(2X,'CORRELATION BASED ON THE FLUCTUATING VELOCITY (U)'/
      *5X,'X=',E14.6 ,' +',E14.6,'U **',F5.3)
```

```
555 FORMAT(6(2X,E14.6))
666 FORMAT(10A3)
    STOP
    END


    SUBROUTINE   LEAST SQUARES
C                *************
    COMMON /B1/ X(200),Y(200),YC(200),A,B,N
    SX,SX2,SY,SXY =0.0
    DO 1 I=1,N
    SX = SX + X(I)
    SX2== SX2 + X(I)*X(I)
    SY = SY +Y(I)
    SXY= SXY +X(I)*Y(I)
  1 CONTINUE
    D = SX2*FLOAT(N)-(SX*SX)
    A = (SY*SX2-SX*SXY)/D
    B = (FLOAT(N)*SXY-SX*SY)/D
    ERS = 0.0
    DO 2 I=1,N
    YC(I) = A + B*X(I)
    ERS = ERS + ABS(YC(I)-Y(I))**2.
  2 CONTINUE
    ER = SQRT (ERS)
    WRITE(2,111) ER
    CALL COEFF OF CORR
111 FORMAT(2X,'LEAST SQUARE ERROR =',E20.6)
    RETURN
    END


    SUBROUTINE   COEFF OF CORR
C                *************
    COMMON /B1/ X(200),Y(200),YC(200),A1,B1,N
    SX,SY,SX2,SY2,SXY =0.0
    DO 100 I =1,N
    SX = SX + X(I)
    SY = SY + Y(I)
    SX2 = SX2 + X(I)*X(I)
    SY2 = SY2 + Y(I)*Y(I)
    SXY = SXY + X(I)*Y(I)
100 CONTINUE
    CXX = SX2-(SX*SX/FLOAT(N))
    CYY = SY2-(SY*SY/FLOAT(N))
    CXY = SXY-(SX*SY/FLOAT(N))
    B = CXX*CYY
    R = CXY/SQRT(B)
    WRITE(2,111) CXX,CYY,CXY,B,R
111 FORMAT (2X,' VALUES OF CXX,CYY,CXY,B,R  ARE :',5(2X,E14.6))
    RETURN
    END
    FINISH
```

APPENDIX B9

EDDY DIFFUSIVITY Program

This program is concerned with comparing the variations in eddy diffusivities with different expressions proposed for the friction factor in pipe flow and flow over flat plates. These expressions are given by the following relations:

$$f = 0.02296/R_{e_D}^{0.139}$$
$$f = 0.0262/R_{e_D}^{0.148257}$$
Flat plate Data

$$f = 0.046/R_{e_D}^{0.2} \tag{B31}$$
and
$$f = 0.0014 + (0.125/R_{e_D}^{0.32})$$
Pipe Flow Data

where $R_{e_D} = U.D/\nu$

The definition of different terms are given in Chapter 7. The eddy diffusivities were calculated from the Spalding expression given by

$$\mathcal{E}_m = 0.0407 \quad (e^C - 1 - C - \frac{C^2}{2} - \frac{C^3}{6}) \tag{B32}$$

where $C = 0.407\ U+$ (B33)

The input data for this program is some values of gas velocities between 0.5 and 5 m/sec and the kinematic viscosity of gas at TDC, while the output results consist of sets of graphs showing the relations between the following variables:

1. Eddy diffusivity versus non-dimensional velocity U^+.
2. Eddy diffusivity versus friction factor.
3. Eddy diffusivity versus Reynolds number.
4. Friction factor versus Reynolds number.

```
JOB N380,N,NS1505
LUFORTRAN
RUN
CARDLIST
DOCUMENT SOURCE
      LIBRARY(ED,SUBGROUPNAGF)
      LIBRARY (ED,SUBGROUPUSUB)
      LIBRARY (ED,SUBGROUPGRAF)
      PROGRAM(N380)
      COMPACT
      INPUT 1 = CRO
      OUTPUT 2 = LPO
      TRACE 0
      END


      MASTER      EDDY DIFFUSIVITY
C                 ****************
      REAL NEU(10)
      DIMENSION RE(100),CF(100),UP(100),ED(100)
      READ(1,222) N,N1,N2
      READ(1,111) (NEU(I),I=1,N1)
      READ(1,111) X,U
      CALL UTPOP
      DO 300 J=1,N1
      DO 250 K1=1,4
      DO 200 K=1,4
      WRITE(2,222) N,N1,N2,J,K,K1
      WRITE(2,444) NEU(J),X
      U=0.5
      DO 100 I=1,N
      RE(I)=X*U/NEU(J)
      IF(K.EQ.1) CF(I)=0.02296/(RE(I)**0.139)
      IF(K.EQ.2)CF(I)=0.0262/(RE(I)**0.148257)
      IF(K.EQ.3) CF(I)=0.046/(RE(I)**0.2)
      IF(K.EQ.4) CF(I)=0.0014+0.125/(RE(I)**0.32)
      UP(I)=1/((CF(I)*0.5)**0.5)
      C=UP(I)*0.407
      ED(I)=0.0407*(EXP(C)-1.-C-(C*C)/2.-(C*C*C)/6.)*NEU(J)
      WRITE(2,333) U,RE(I),CF(I),UP(I),ED(I)
      U=U+0.5
100   CONTINUE
      IF(K1.NE.1) GO TO 110
      XMIN=15000.
      XMAX=160000.
      YMIN=0.004
      YMAX=0.008
      IF(K.EQ.1)  CALL UTP4A(XMIN,XMAX,YMIN,YMAX,6.,6.,15HREYNOLDS NUMBE
     *R,2,15HFRICTION FACTOR,2)
      CALL UTP4B(RE,CF,N,2)
110   CONTINUE
      IF(K1.NE.2) GO TO 120
      XMIN=15.
      XMAX=24.
```

```
      YMIN=0.00005
        YMAX=0.0011
      IF(K.EQ.1) CALL UTP4A(XMIN,XMAX,YMIN,YMAX,6.,6.,2HU+,1,21HEDDY DIF
     *FUSIVITY (   ),3)
      CALL UTP4B(UP,ED,N,2)
  120 CONTINUE
      IF(K1.NE.3) GO TO 130
      XMIN=0.004
      XMAX 0.008
      YMIN=0.00005
        YMAX=0.0011
      IF(K.EQ.1)  CALL UTP4A(XMIN,XMAX,YMIN,YMAX,6.,6.,15HFRICTION FACTO
     *R,2,21HEDDY DIFFUSIVITY (   ),3)
      CALL UTP4B(CF,ED,N,2)
  130 CONTINUE
      IF(K1.NE.4) GO TO 140
      XMIN=15000.
       XMAX=160000.
      YMIN=0.00005
        YMAX=0.0011
      IF(K.EQ.1)  CALL UTP4A(XMIN,XMAX,YMIN,YMAX,6.,6.,15HREYNOLDS NUMBE
     *R,2,21HEDDY DIFFUSIVITY (   ),3)
      CALL UTP4B(RE,ED,N,2)
  140 CONTINUE
  200 CONTINUE
  250 CONTINUE
  300 CONTINUE
  111 FORMAT(6F0.0)
  222 FORMAT(10I3)
  333 FORMAT(5(2X,E14.6))
  444 FORMAT(2X,'CASE NO: NEU =' E14.6,'CHARACTERISTIC LENGTH =',E14.6 )
      CALL UTPCL
      STOP
      END
      FINISH
```

APPENDIX B10

CORRELATION II
Program

This program is concerned with comparing the measured turbulence characteristics inside the combustion chambers of engines with predictions of the semi-empirical relations established from the experimental data of pipe flow. It also serves the purpose of correcting the measured turbulence parameters for the effect of finite wire length assuming exponential correlation functions. Plotting facilities of these turbulence parameters for different tests are also provided.

The theoretical analysis of the correlation with pipe flow was discussed in Chapter 7 and it is sufficient here to discuss the INPUT/OUTPUT DATA manipulated by the program. Obviously the INPUT DATA are the results of the turbulence analysis at different crank angles in the cycle as discussed earlier in Appendix B5. These include the following data:

1. Variations of gas mean velocities with crank angles.
2. Variations of fluctuating velocity components with crank angles.
3. Variations of micro-scales with crank angles.
4. Variations of macro-scales with crank angles.
5. Values of dynamic and kinematic viscosities at different crank angles in the cycle.

and 6. Cylinder diameter and hot wire length.

The output results of the program could be summarised as follows:

i) The variation of corrected turbulence intensities and fluctuating velocity components with crank angles.

ii) The variation of the ratio u'/U^* with crank angles.

iii) Values of turbulence Reynolds number Re_L and Re_λ for different crank angles.

iv) Values of micro- and macro-eddy diffusivities as given by:

$$\varepsilon_{micro} = u' \left(\frac{\mathcal{L}_L}{\lambda_y} \right) \lambda_y \qquad (B34)$$

and

$$\varepsilon_{macro} = u' \left(\frac{\mathcal{L}_L}{L_x} \right) L_x \qquad (B35)$$

v) Predicted values of eddy diffusivities from pipe flow data.

Graph plots showing the variation of turbulence characteristics with crank angle as well as general plots of eddy diffusivities versus Reynolds numbers Re_L and Re_λ and the friction factor are provided. Moreover a comparison between measured and predicted eddy diffusivities is also provided.

INPUT DATA

NS	Number of experiments considered.
A_1, A_2, B_1, B_2	Constants in equations of the ratio between Lagrangian and Eulerian scales $\mathcal{L}_L/L_x$ and $\mathcal{L}_L/\lambda_y$

$$\mathcal{L}_L/L_x = A_1 + B_1 \ Re_L^{E_1} \qquad (B36)$$

$$\mathcal{L}_L/\lambda_y = A_2 + B_2 \ Re^{E_2} \qquad (B37)$$

LW	Length of hot wire (m).
Lx	Engine cylinder diameter (m)
CASE(J,K)*	Description of test conditions.
NANG(K)	Number of crank angles considered in test number (K).
ANGLE(J,K)	Values of crank angles considered in the test number (K), (degrees).
VM(J,K)	Values of mean velocities for test number (K), (m/sec).
INTENSITY(J,K)	Values of turbulence intensities for test number (K). (%).
U(J,K)	Values of fluctuating velocity components for the test number (K), (m/sec).
MICRO(J,K)	Values of time micro-scales for the test number (K), (sec).
MICROL(J,K)	Values of spatial micro-scales for the test number (K), (mm).
MACRO(J,K)	Values of the spatial macro-scales of turbulence for the test number (K). (mm).
NEU (J,K)	Values of the kinematic viscosity for the test number (K).
AX(I)	A string of alphanumeric characters used for identifying individual tests.

* The index J defines the particular crank angle in the test number (K).

OUTPUT DATA

UC(J,K)	Values of the fluctuating velocity components after correction for the effect of finite wire length on measurements.
INTENSITY(J,K)	Corrected values of turbulence intensities.
REO(J,K)	Reynolds number based on gas mean velocity and cylinder diameter.
RE(J,K)	Reynolds number of turbulence $Re_\lambda = \frac{u' \lambda_y}{\nu}$
RE1(J,K)	Reynolds number of turbulence $Re_L = \frac{u' L_x}{\nu}$
REO1(J,K)	Reynolds number based on boundary layer thickness over a flat plate under similar flow conditions in engine.
DELTA(J,K)	Boundary layer thickness, (mm).
UR(J,K)	Values of friction velocities (u*) (m/sec).
UP(J,K)	Values of the non-dimensional velocity $U+ = \frac{U}{u^*}$
EPS(J,K)	Rate of energy dissipation.
RATIO(J,K)	Ratio between fluctuating velocity components and friction velocities = u'/u^*.
ED(J,K)	Eddy diffusivities based on micro-scales of turbulence.

<u>OUTPUT DATA</u> (continued)

ED1(J,K)	Eddy diffusivities based on macro-scales of turbulence.
EDM(J,K)	Eddy diffusivities calculated from Spalding's expression for pipe flow. (B32).
CF (J,K)	Values of the friction factor.

```
JOB N260,N,NS1505

LUFORTRAN
RUN
JOBCORE 30000
CARDLIST
DOCUMENT SOURCE
      LIBRARY (ED,SUBGROUPNAGF)
      LIBRARY (ED,SUBGROUPUSUB)
      LIBRARY (ED,SUBGROUPGRAF)
      PROGRAM(N260)
      COMPACT
      INPUT 1 = CRO
      OUTPUT 2 = LPO
      TRACE 0
      END


      MASTER          CORRELATION II
C                     **************
      REAL MICRO(12,20),MICROL(12,20),INTENSITY(12,20),NEU(12,20)
      REAL MEU(12,20),MACRO(12,20),INT(12,20),LX ,LW
      DIMENSION ED(12,20),CF(12,20),UT(12,20),CASE(12,20)
      DIMENSION UP(12,20),ED1(12,20),EDM(12,20)  ,RE1(12,20)
      DIMENSION ANGLE(12,20),U(12,20),VM(12,20),UR(12,20),REO(12,20),
     *REO1(12,20),DELTA(12,20),RATIO(12,20),EPS(12,20),RE(12,20),X(20),
     *Y(12),XX(12),YY(12),NANG(20),AX(20),UC(12,12)
C     ANGLE = CRANK ANGLE DEGREES.
C     VM    = GAS MEAN VELOCITY.
C     MICRO= MICRO SCALE OF TURBULENCE9
C     MACRO   MACRO SCALE OF TURBULENCE.
C     NEU = KINEMATIC VISCOSITY.
C     A,B&E ARE THE CONSTANTS AND EXPONENT VALUES FOR THE RATIO BETWEEN
C            THE LAGRANGIAN AND EULERIAN SCALES OF TURBULENCE.
C     U     =MEASURED FLUCTUATING VELOCITY COMPONENTS.
C     UC=   = CORRECTED FLUCTUATING VELOCITY COMPONENTS FOR THE EFFECT
C           OF WIRE LENGTH ON TIRBULENCE MEASUREMENTS.
C     LX    = CYLINDER DIAMETER.
C     LW    = LENGTH OF WIRE (MM).
C     RE   =TURBULENT REYNOLDS NUMBER BASED ON MICRO-SCALE.
C     RE1  =TURBULENT REYNOLDS NUMBER BASED ON MACRO-SCALE.
C     REO   = REYNOLDS NUMBER BASED ON MEAN VELOCITY AND CYLINDER DIAMETE
C     EPS   = RATE OF ENERGY DISSIPATION BY SMALL SCALE EDDIES9
C     ED    = MICRO-EDDY DIFFUSIVITY.
C     ED1   = MACRO-EDDY DIFFUSIVITY.
C     EDM   = SPALDING EXPRESSION FOR EDDY DIFFUSIVITY.
      READ(1,333) (AX(I),I =1,20)
      READ(1,111 )NS
      READ(1,222) A1,A2,B1,B2,E1,E2,LX ,LW
      DO 1000 K=1,NS
      READ (1,9000)  (CASE(J,K),J =1,9)
      READ(1,111 ) NANG(K)
      READ(1,222) (ANGLE(J,K),J =1,NANG(K))
      READ(1,222)(VM(J,K),J =1,NANG(K))
      READ(1,222) INTENSITY(J,K),J=1,NANG(K))
      READ(1,222) (U(J,K),J =1,NANG(K))
      READ(1,222) (MICRO(J,K),J=1,NANG(K))
      READ(1,222)(MICROL(J,K),J =1,NANG(K))
```

```
      READ(1,222) (MACRO(J,K),J=1,NANG(K))
      READ(1,222) (NEU(J,K),J=1,NANG(K))
 1000 CONTINUE

      DO 500 K=1,NS
      DO 400 J=1,NANG(K)
      EPS(J,K) =15.*(10.**6)*MEU(J,K)*((U(J,K)/MICROL(J,K))**2)
      SCALE=MACRO(J,K)
      CX=LW*2./SCALE
      CX1=CX/(SQRT(2.*(1/EXP(CX)-1.+CX)))
      UC(J,K)=CX1*U(J,K)
      WRITE(2,555) RA,SCALE,CX,CX1,U(J,K),UC(J,K)
      RE(J,K)=UC(J,K)*MICROL(J,K)/(NEU(J,K)*(10.**3))
      RE1(J,K)=UC(J,K)*MACRO(J,K)/(NEU(J,K)*(10.**3))
      REO(J,K)=LX*VM(J,K)/NEU(J,K)
      DELTA(J,K) = 0.1285*LX/(REO(J,K)**0.148257)
      REO1(J,K)= VM(J,K)*DELTA(J,K)/NEU(J,K)
      INTENSITY(J,K)=INTENSITY(J,K)*UC(J,K)/U(J,K)
      RA1=A1+B1*(RE(J,K)**E1)
      RA2=A2+B2*(RE1(J,K)**E2)
      ED(J,K)=MICROL(J,K)*UC(J,K)/(10.**3) *RA1
      ED1(J,K)=UC(J,K)*MACRO(J,K)/(10.**3) *RA2
      CF(J,K)=0.0262/(REO(J,K)**0.148257)
      UP(J,K)=1/((CF(J,K)*0.5)**0.5)
      UR(J,K)=VM(J,K)/UP(J,K)
      RATIO(J,K)=UC(J,K)/UR(J,K)
      C= UP(J,K)*0.407
      EDM(J,K) = 0.0407*(EXP(C)-1.-C-(C*C)/2.-(C*C*C)/6.)*NEU(J,K)
  400 CONTINUE

      WRITE(2,9000)  (CASE(J,K),J=1,9)
      WRITE(2,444) K,IC,NANG(K),NC,NS
      WRITE(2,1001)
      WRITE(2,555) (ANGLE(J,K),J=1,NANG(K))
      WRITE(2,1002)
      WRITE(2,555) ( VM(J,K),J=1,NANG(K))
      WRITE(2,1003)
      WRITE(2,555) (INTENSITY(J,K),J=1,NANG(K))
      WRITE(2,1004)
      WRITE(2,555) (U(J,K),J=1,NANG(K))
      WRITE(2,555)(UC(J,K),J=1,NANG(K))
      WRITE(2,1005)
      WRITE(2,555) (MICRO(J,K),J=1,NANG(K))
      WRITE(2,1006)
      WRITE(2,555) (MICROL(J,K),J=1,NANG(K))
      WRITE(2,1007)
      WRITE(2,555)  (MACRO(J,K),J=1,NANG(K))
      WRITE(2,1008)
      WRITE(2,555) ( RE(J,K),J=1,NANG(K))
      WRITE(2,555)(RE1(J,K),J=1,NANG(K))
      WRITE(2,1009)
      WRITE(2,555) ( REO (J,K),J=1,NANG(K))
      VRITE(2,1010)
      WRITE(2,555) (REO1 (J,K),J=1,NANG(K))
      WRITE(2,1012)
      WRITE(2,555) (DELTA(J,K),J=1,NANG(K))
      WRITE(2,1013)
      WRITE(2,555) (   UR(J,K),J=1,NANG(K))
      WRITE(2,555) (UP(J,K),J=1,NANG(K))
      WRITE(2,1014)
      WRITE(2,555) (EPS(J,K),J=1,NANG(K))
```

```
      WRITE(2,1015)
      WRITE(2,555) (RATIO(J,K),J=1,NANG(K))
      WRITE(2,1016)
      WRITE(2,555) (ED(J,K),J=1,NANG(K))
      WRITE(2,555) (ED1(J,K),J=1,NANG(K))
      WRITE(2,555) (EDM(J,K),J=1,NANG(K))
      WRITE(2,1017)
      WRITE(2,555) (CF(J,K),J=1,NANG(K))
  500 CONTINUE
 2000 CONTINUE

C          ********PLOTTING OF TURBULENCE CHARACTERISTIC PARAMETERS*****
      CALL UTPOP
      SFX = 0.02
      YMAX =2000.
      SFY =.0025
      CALL UTP4A(80.,380.,0.0,YMAX,6.,5.,11HCRANK ANGLE,2,19HRATE OF DIS
     *SIPATION,3)
      DO 40 K=1,NS
      DO 30 J =1,NANG(K)
      XX(J) =ANGLE(J,K)
      YY (J) =EPS(J,K)
      X(J) = ANGLE(J,K)*SFX-1.6
       Y (J) =EPS(J,K)*SFY
      CALL UTP3(AX(K),X(J),Y(J),2)
   30 CONTINUE
      CALL UTP4B(XX,YY,NANG(K),2)
   40 CONTINUE
      CALLUTP4A(80. ,380.,0.0,VMAX,6.,5.,11HCRANK ANGLE,2,20HTURBULENCE
     *INTENSITY,3)
      SFY= 5./VMAX
      DO 60 K=1,NS
      DO 50 J 1,NANG(K)
      XX(J) =ANGLE(J,K)
      YY(J) = INTENSITY(J,K)
      X(J) = ANGLE(J,K)*SFX-1.6
      Y(J) = INTENSITY(J,K)*SFY
      CALL UTP3(AX(K),X(J),Y(J),2)
   50 CONTINUE
      CALL UTP4B(XX,YY,NANG(K),2)
   60 CONTINUE
      CALLUTP4A(80. ,380.,0.0,6.0,6.0,6.,11HCRANK ANGLE,2,19HTURBULENT
     *VELOCITY,3)
      DO 80 K=1,NS
      DO 70 J=1,NANG(K)
      XX(J) =ANGLE(J,K)
      YY(J) = U(J,K)
      X(J) = ANGLE(J,K)*SFX-1.6
      Y(J) = U(J,K)
      CALL UTP3(AX(K),X(J),Y(J),2)
   70 CONTINUE
      CALL UTP4B(XX,YY,NANG(K),2)
   80 CONTINUE
      CALL UTP4A(80.,380.,0.0,4.,6.,5.,11HCRANK ANGLE,2,24HMICROSCALE OF
     * TURBULENCE,3)
```

```
      SFY =1.25
      DO100 K=1,NS
      DO 90 J =1,NANG(K)
      XX(J) =ANGLE(J,K)
      YY(J) = MICRO(J,K)
      X(J) = ANGLE(J,K)*SFX-1.6
      Y(J) = MICRO(J,K)*SFY
      CALL UTP3(AX(K),X(J),Y(J),2)
   90 CONTINUE
      CALL UTP4B(XX,YY,NANG(K),2)
  100 CONTINUE
      CALLUTP4A(80.,380. ,0.0,VMAX,6.,5.,11HCRANK ANGLE,2,20HMEAN VELOCT
     *Y (M/SEC),3)
      SFY = 5./VMAX
      DO 120 K=1,NS
      DO 110 J =1,NANG(K)
       XX(J) =ANGLE(J,K)
      YY(J) = VM(J,K)
      X(J) = ANGLE(J,K)*SFX-1.6
      Y(J) = VM(J,K)*SFY
      CALL UTP3(AX(K),X(J),Y(J),2)
  110 CONTINUE
      CALL UTP4B(XX,YY,NANG(K),2)
  120 CONTINUE
      CALLUTP4A(80. ,380.,0.,3.,6.,6.,11HCRANK ANGLE,2,19HSCALE OF TURBU
     *LENCE,3)
      SFY =2.
      DO 140 K=1,NS
      DO 130 J =1,NANG(K)
       XX(J) =ANGLE(J,K)
      YY(J) = MICROL(J,K)
      X(J) = ANGLE(J,K)*SFX-1.6
      Y(J) = MICROL(J,K)*SFY
      CALL UTP3(AX(K),X(J),Y(J),2)
  130 CONTINUE
      CALL UTP4B(XX,YY,NANG(K),2)
  140 CONTINUE
  200 CONTINUE

C     ********     CORRELATION    PLOTS       *******
      VMAX =50.
      XMIN=400.
      XMAX=4000.
      YMAX=8.
       YMIN =0.0
      CFY =5./(YMAX-YMIN)
      CFX =5./(XMAX-XMIN)
      CALL UTP4A(XMIN,XMAX,YMIN,YMAX,5.,5.,21HREYNOLDS NUMBER (RE ),3,23
     *HFLUCT. VEL/FRICTION VEL,3)
      DO 3000 K=1,NS
      DO 3000 J=1,NANG(K)
      IF(ANGLE(J,K).LT.250) GO TO 3000
      Z =CFX*(RE01(J,K)-XMIN)
      H = CFY*(RATIO(J,K)-YMIN)
      CALL UTP3(AX(K),Z,H,2)
 3000 CONTINUE
```

```
      XMAX =120000
      XMIN =1000
      YMIN =0.0
      CFY =5./(YMAX-YMIN)
      CFX =5./(XMAX-XMIN)
      CALL UTP4A(XMIN,XMAX,YMIN,YMAX,5.,5.,21HREYNOLDS NUMBER (REX),3,23
     *HFLUCT. VEL/FRICTION VEL,3)
      DO 3100 K=1,NS
      DO 3100 J=1,NANG(K)
      IF(ANGLE(J,K).LT.250) GO TO 3100
      Z=CFX*(REO(J,K)-XMIN)
      H = CFY*(RATIO(J,K)-YMIN)
      CALL UTP3(AX(K),Z,H,2)
 3100 CONTINUE
      XMAX=120000
      YMIN=0.0
      XMIN =1000
      YMAX =40.
      CFY =5./(YMAX-YMIN)
      CFX =5./(XMAX-XMIN)
      CALL UTP4A(XMIN,XMAX,YMIN,YMAX,5.,5.,21HREYNOLDS NUMBER (REX),3,20
     *HTURBULENCE INTENSITY,3)
      DO 3200 K=1,NS
      DO 3200 J=1,NANG(K)
      IF(ANGLE(J,K).LT.250) GO TO 3200
      Z=CFX*(REO(J,K)-XMIN)
      H =CFY*(INTENSITY(J,K)-YMIN)
      CALL UTP3(AX(K),Z,H,2)
 3200 CONTINUE
      XMIN=400.
      XMAX=4000.
      YMAX =40.
      CFY =5./(YMAX-YMIN)
      CFX =5./(XMAX-XMIN)
      CALL UTP4A(XMIN,XMAX,YMIN,YMAX,5.,5.,21HREYNOLDS NUMBER (RE ),3,20
     *HTURBULENCE INTENSITY,3)
      DO 3300 K=1,NS
      DO 3300 J=1,NANG(K)
      IF(ANGLE(J,K).LT.250) GO TO 3300
      Z =CFX*(REO1(J,K)-XMIN)
      H =CFY*(INTENSITY(J,K)-YMIN)
      CALL UTP3(AX(K),Z,H,2)
 3300 CONTINUE
      XMAX=120000
      XMIN =1000
      YMAX=0.0004
      YMIN =0.0
      CFX =5./(XMAX-XMIN)
      CFY =5./(YMAX-YMIN)
      CALL UTP4A(XMIN,XMAX,YMIN,YMAX,5.,5.,21HREYNOLDS NUMBER (RE ),3,15
     *HMICRO-ED. DIFF.,2)
      DO 3400 K=1,NS
      DO 3400 J=1,NANG(K)
      IF(ANGLE(J,K).LT.250) GO TO 3400
      Z=CFX*(REO(J,K)-XMIN)
      H=CFY*(ED(J,K)-YMIN)
```

```
      CALL UTP3(AX(K),Z,H,2)
 3400 CONTINUE
      XMIN=400.
      XMAX=4000.
      YMIN =0.0
      CFY =5./(YMAX-YMIN)
      CFX =5./(XMAX-XMIN)
      CALL UTP4A(XMIN,XMAX,YMIN,YMAX,5.,5.,21HREYNOLDS NUMBER (RE ),3,15
     *HMICRO-ED. DIFF.,2)
      DO 3500 K=1,NS
      DO 3500 J=1,NANG(K)
      IF(ANGLE(J,K).LT.250) GO TO 3500
      Z =CFX*(REO1(J,K)-XMIN)
      H=CFY*(ED(J,K)-YMIN)
      CALL UTP3(AX(K),Z,H,2)
 3500 CONTINUE
      YMAX=0.002
      YMIN =0.0
      XMAX=120000
      XMIN =1000
      CFX =5./(XMAX-XMIN)
      CFY =5./(YMAX-YMIN)
      CALL UTP4A(XMIN,XMAX,YMIN,YMAX,5.,5.,21HREYNOLDS NUMBER (RE ),3,15
     *HMACRO-ED. DIFF.,2)
      DO 3800 K=1,NS
      DO 3800 J=1,NANG(K)
      IF(ANGLE(J,K).LT.250) GO TO 3800
      Z=CFX*(REO(J,K)-XMIN)
      H=CFY*(ED1(J,K)-YMIN)
      CALL UTP3(AX(K),Z,H,2)
 3800 CONTINUE
      XMIN=400.
      XMAX=4000.
      CFX =5./(XMAX-XMIN)
      CALL UTP4A(XMIN,XMAX,YMIN,YMAX,5.,5.,21HREYNOLDS NUMBER (RE ),3,15
     *HMACRO-ED. DIFF.,2)
      DO 3900 K=1,NS
      DO 3900 J=1,NANG(K)
      IF(ANGLE(J,K).LT.250) GO TO 3900
      Z =CFX*(REO1(J,K)-XMIN)
      H=CFY*(ED1(J,K)-YMIN)
      CALL UTP3(AX(K),Z,H,2)
 3900 CONTINUE
      XMAX=0.007
      XMIN=0.004
       YMIN =0.0
      YMAX=0.002
      CFY =5./(YMAX-YMIN)
      CFX =5./(XMAX-XMIN)
      CALL UTP4A(XMIN,XMAX,YMIN,YMAX,5.,5.,17HCOEFF OF FRICTION,3,15HMAC
     *RO-ED. DIFF.,2)
      DO 4100 K=1,NS
      DO 4100 J=1,NANG(K)
      IF(ANGLE(J,K).LT.250) GO TO 4100
      Z =CFX*(CF(J,K)-XMIN)
      H=CFY*(ED1(J,K)-YMIN)
      CALL UTP3(AX(K),Z,H,2)
 4100 CONTINUE
```

```
      YMAX=0.0004
      CFY =5./(YMAX-YMIN)
      CALL UTP4A(XMIN,XMAX,YMIN,YMAX,5.,5.,17HCOEFF OF FRICTION,3,15HMIC
     *RO-ED. DIFF.,2)
      DO 3600 K=1,NS
      DO 3600 J=1,NANG(K)
      IF(ANGLE(J,K).LT.250) GO TO 3600
      Z =CFX*(CF(J,K)-XMIN)
      H=CFY*(ED(J,K)-YMIN)
      CALL UTP3(AX(K),Z,H,2)
 3600 CONTINUE
      XMIN,YMIN=0.0
      XMAX=0.001
      CFX =5./(XMAX-XMIN)
      CALL UTP4A(XMIN,XMAX,YMIN,YMAX,5.,5.,17HSPALDING ED. DIFF,3,15HMIC
     *RO-ED. DIFF.,2)
      DO 3700 K=1,NS
      DO 3700 J=1,NANG(K)
      Z =CFX*(EDM(J,K)-XMIN)
      H=CFY*(ED(J,K)-YMIN)
      CALL UTP3(AX(K),Z,H,2)
 3700 CONTINUE
      YMAX=0.002
      CFY =5./(YMAX-YMIN)
      CALL UTP4A(XMIN,XMAX,YMIN,YMAX,5.,5.,17HSPALDING ED. DIFF,3,15HMAC
     *RO-ED. DIFF.,2)
      DO 4000 K=1,NS
      DO 4000 J=1,NANG(K)
      IF(ANGLE(J,K).LT.250) GO TO 4000
      Z =CFX*(EDM(J,K)-XMIN)
      H=CFY*(ED1(J,K)-YMIN)
      CALL UTP3(AX(K),Z,H,2)
 4000 CONTINUE
      CALL  UTPCL
  111 FORMAT(10I3)
  222 FORMAT(12F0.0)
  220 FORMAT(6F0.0)
  333 FORMAT(20A1)
  444 FORMAT(2X,10I3)
  555 FORMAT(2X,9E12.4)
 1001 FORMAT(2X,'CRANK ANGLES ')
 1002 FORMAT(2X,'MEAN VELOCITY:')
 1003 FORMAT(2X,'TURBULENCE INTENSITY % .')
 1004 FORMAT(2X,'FLUCTUATING VELOCITY COMPONENT U:')
 1005 FORMAT(2X,'TIME MICRO-SCALE :')
 1006 FORMAT(2X,'MICRO-SCALE (MM) :')
 1007 FORMAT(2X,'MACRO-SCALE (MM) :')
 1008 FORMAT(2X,'REYNOLDS NUMBER (   ) :')
 1009 FORMAT(2X,'REYNOLDS NUMBER (   ) :')
 1010 FORMAT(2X,'REYNOLDS NUMBER (   ) :')
 1012 FORMAT(2X,'BOUNDARY LAYER THICKNESS (CM) :')
 1013 FORMAT(2X,'FRICTION VELOCITY (UR): ')
 1014 FORMAT(2X,'RATE OF ENERGY DISSIPATION :')
 1015 FORMAT(2X,'FLUCTUATING VEL./FRICTION VEL. :')
 1016 FORMAT(2X,'EDDY DIFFUSIVITY :')
 1017 FORMAT(2X,'COEFFICIENT OF FRICTION :')
 9000 FORMAT(2X,9A8)
      STOP
      END
      FINISH
```

APPENDIX B11

ISOTROPIC PORT AREA
Program

This program is concerned with calculating the variation of isotropic port area with valve lift. It enables a comparison between the effect of different valve shapes on restricting the port area of the combustion chamber. The isotropic area is calculated by the following equation:

$$\frac{\dot{m}}{A^*} = \left[\frac{P_c}{P_o}\right]^{\frac{1}{\gamma}} \sqrt{\frac{2\gamma}{\gamma-1} \; P_o \; \rho_o \left[1 - \left[\frac{P_c}{P_o}\right]^{\frac{\gamma-1}{\gamma}}\right]} \qquad \text{(B38)}$$

The input data for this program consists of the variation of pressure drop across the port with the rate of mass flow across the port. The latter variable is calculated from the measured pressure drop across a metering orifice in the blowing rig circuit and the calibration of this orifice.

INPUT DATA

NC	Number of experiments.
N	Number of experimental data points at each valve lift.
PVALVE	Pressure drop across the port (inches H_2O).
PRIG	Pressure drop across the blowing rig metering orifice (inches H_2O).
LIFT	Valve lift.
TITLE(I)	Description of experimental conditions.

OUTPUT DATA

AMEAN	Mean value of isotropic port area at a particular valve lift.
DM(I)	Rate of mass flow for different experimental points at each valve lift.
A(I)	Isotropic port area for different experimental points at each valve lift.

```
JOB N300,N,NS1505
LUFORTRAN
RUN
DOCUMENT SOURCE
      PROGRAM(N300)
      COMPACT
      INPUT 1=CRO
      OUTPUT 2 - LPO
      TRACE 2
      END


      MASTER         ISOTROPIC PORT AREA
C                    ********************
C     THIS PROGRAM CALCULATES THE ISOTROPIC PORT AREA IN (MT**2)
C     THE CORRESPONDING VALUES FOR EACH EXPERIMENTAL POINT IS CALCULATED
C     AND PRINTED OUT, AS WELL AS, THE MEAN VALUE FOR THE NUMBER OF
C     EXPERIMENTAL POINTS CONSIDERED.
C     PVALVE = THE PRESSURE DROP ACROSS THE INLET PORT.
C     PRIG = THE PRESSURE DROP ACROSS THE ORIFICE OF THE BLOWING RIG.
      REAL LIFT
      DIMENSION Q(20),Q1(20),H(20),PRIG(20) PVALVE(20),P1(20),P2(20),
     *V2(20),DM(20),A(20),TITLE(10),COMP(20)
      E1=1.4285714
      E2=1.7142857
      CT=0.000472
      READ(1,111) NC
      READ(1,222) ( (I),I=1,16)
      READ(1,222) (H(I),I=1,16)
      DO 500 JC=1,NC
      READ(1,555) (TITLE(I),I=1,5)
      READ(1,222) LIFT
      READ(1,1 1) N
      READ(1,222) (PVALVE(I),I=1,N)
      READ(1,222) (PRIG(I),I=1,N)
      DO 100 I=1,N
      PRIG(I)=PRIG(I)*2.54
      PVALVE(I)=PVALVE(I)*2.54
      P1(I)=98.*PRIG(I)
      P2(I)=98.*PVALVE(I)
      V2(I)=SQRT(P2(I)*2.44)
      R=1-(P2(I)/101300.)
      COMP(I)=SQRT(((R**E1)-(R**E2))*3.5/(1-R))
      V2(I)=V2(I)*COMP(I)
  100 CONTINUE
      AMEAN =0.0
      DO 400 J=1,N
      DO 300 I= ,16
      DP=PRIG(J)-H(I)
      IF(DP)150,200,300
  150 Q1(J)=Q(I-1)+(PRIG(J)-H(I-1))*(Q(I)-Q(I-1)) (H(I)-H(I-1))
      GO TO 250
  200 Q1(J)=Q(I)
  250 DM(J)=Q1(J)*CT
      A(J)=DM(J)/V2(J)
       AMEAN =AMEAN +A(J)
      GO TO 400
  300 CONTINUE
  400 CONTINUE
      AMEAN =AMEAN/N
```

```
      WRITE(2,333)(TITLE(L),L=1,5),LIFT,AMEAN
      WRITE(2,444)(DM(I),A(I),PRIG(I),PVALVE(I),P1(I),P2(I),COMP(I),I=1,
     *N)
  500 CONTINUE
  111 FORMAT(5I3)
  222 FORMAT(10F0.0)
  333 FORMAT(2X,5A8,/'VALVE LIFT=',F8.4,'MM','MEAN ISOTROPIC AREA =',E20
     *.6)
  444 FORMAT(7(1X,E13.4))
  555 FORMAT(5A8)
      STOP
      END
      FINISH
```

APPENDIX B12

MODEL OF CYCLIC VARIATION
Program

This program is concerned with verifying the assumptions used in developing the theoretical model of cyclic variation as discussed in Chapter 8. The program compares the theoretical predictions of the model for cyclic variations in the burning times with their measured values. The former values are calculated using measured gas velocities and their cyclic variations, while the experimental values of burning times and their variations were represented by values of the angle of occurrence of maximum cylinder pressure for Barton's data (10) and with burning times for Winsor's data (23).

The output results of these analyses consist of the ratio between the predictions of the theoretical model and the experimental values of burning times and the standard variation of these ratios relative to their mean value. The input/output data for this program could be summarised as follows:

INPUT DATA

U	Gas velocity at the time of ignition.
S(U)	Standard deviation of gas velocity.
THETA	Characteristic parameter representing the burning time, e.g. angle of occurrence of maximum pressure.
STHETA	Standard deviation of the burning time or the corresponding parameter used.

INPUT DATA (continued)

AF	Air/fuel ratio.
T	Temperature.
P	Pressure.
SL	Laminar flame speed.
RPM	Engine speed.

OUTPUT DATA

SST	Theoretical prediction of variations in burning time assuming a constant value of the critical flame kernel radius.
SSTT	Theoretical prediction of variations in burning time assuming a critical radius of the flame kernel of some multiple ratio of small scale eddies.
RATIO, RATIO 1	Ratio between theoretical and experimental values of variations in burning time assuming a constant value of the critical radius and a radius of some multiple ratio of small scale eddies respectively.
YM, YM1	Mean values of RATIO and RATIO 1 over the total number of experimental points respectively.
SD, SD1	Standard deviation in RATIO and RATIO 1 respectively.
SDM, SDM1	Coefficient of variation of RATIO and RATIO 1 respectively.

$$SDM = SD/YM$$
$$SDM1 = SD1/YM \qquad (B39)$$

```
JOB N370,N,NS1505
HPFORTRAN N370,,,EXT
DOCUMENT SOURCE

      MASTER          MODEL OF CYCLIC VARIATION
C                     *************************
      REAL NEU,MEU
      DIMENSION X(100),X1(100),X2(100),Y(100),VC(9)
       READ(1,444) (VC(I),I=1,9)
      A1= 0.0165649
      A=0.65938047
      D=0.0968375
      DO 200 J=1,6
      WRITE(2,666)
      READ(1,111) NP
      SY,SY1,SYS,SYS1=0.0
      DO 100 I=1,NP
      READ(1,222) U,SU,THETA,STHETA,AF,T,P ,RPM
      U=U*0.3048
      SU=SU*0.3048
      IF((J.EQ.3).OR.(J.EQ.4))GO TO 10
      P=P*101300/14.7
   10 CONTINUE
      RHO=P*28.93/(8314.3*T)
      TO=T-273.
      MEU=VT(VC,0.00001717,0.0,TO,-139.5)
      NEU=MEU/RHO
       RE=U*D/NEU
      CF=0.046/(RE**0.2)
      IF((J.EQ.2).OR.(J.EQ.4).OR.(J.EQ.6)) CF=CF/((323./T)**0.1)
      UP=1/SQRT(CF*0.5)
      C=UP*0.407
      SUP=A*((D/NEU)**0.1)/(U**0.9)*SU
      EPS=NEU*0.0407*(EXP(C)-1-C-(C*C)/2.-(C*C*C)/6.)
      DEPS=NEU*A1*(EXP(C)-1-UP-(UP*UP)/2.)
      EDT=EPS+NEU
      SEPS=DEPS*SUP
      DEPSU=SEPS/SU
      YH=EDT/DEPSU
      XH=YH-U
      IF(J.GT.2) READ(1,222) SL
      IF(J.GT.2) GO TO 20
      HAF=16.25-0.22*((AF-14.35)**2.)
      SL=(T**1.4)/(P**0.4) *HAF
   20 CONTINUE
      SST=(NEU**0.25)*(T**0.66)*(AF**0.33)*SEPS/(4*SL*(EDT**1.25))
      SSTT=SST*XH
      COEF=SST/SEPS
      COEF1 =SSTT/SEPS
      SST1 =STHETA/(6.*RPM)
      IF((J.EQ.3).OR.(J.EQ.4)) SST1 =STHETA
      RATIO =SST/SST1
      RATIO1 =SSTT/SST1
      WRITE(2,555)
      WRITE(2,333)U,RE,UP,EPS,SST1,SST,SSTT,RATIO,RATIO1
      WRITE(2,777)
      WRITE(2,333) U,YH,XH,COEF,COEF1,SEPS,DEPS,DEPSU
```

```
      SY=SY+RATIO
      SY1=SY1+RATIO1
      SYS=SYS+RATIO*RATIO
      SYS1=SYS1+RATIO1*RATIO1
    X(I)=SST
    X1(I)=SSTT
    Y(I)=SST1
100 CONTINUE
    N=NP
     YM=SY/FLOAT(NP)
     YM1=SY1/FLOAT(NP)
      YY=YM*YM*FLOAT(NP)
     YY1=YM1*YM1*FLOAT(NP)
     VAR=(SYS-YY)/FLOAT(NP)
     VAR1=(SYS1-YY1)/FLOAT(NP)
    SD=SQRT(VAR)
     SDM=SD/YM
     SD1=SQRT(VAR1)
     SDM1=SD1/YM1
     WRITE(2,333)YM,SD,SDM
     WRITE(2,333)YM1,SD1,SDM1
200 CONTINUE
111 FORMAT(10I3)
222 FORMAT(10F0.0)
333 FORMAT(9(1X,E12.5))
444 FORMAT(3E20.12)
555 FORMAT(1X,/,'   VELOCITY      RE NO.              U+              EDDY  DIF
  *      S(O-PMAX)        S(ST)         S(ST*)        RATIO             RATIO*')
666 FORMAT(40X,'MODEL  OF  CYCLIC  VARIATIONS'/)
777 FORMAT(2X,'   VELOCITY    YH        XH        COEF        COEF1      SEPS
  *      DEPSU     DEPSU')
    STOP
    END
    FUNCTION VT(CF,VO,TC,TT,TC)
    DIMENSION CF(9),X(2),F(2)
    TR1= (TO+273)/(TC+273)
    TR2= (TT+273)/(TC+273)
    X(1)= 1.33*TR1
    X(2)= 1.33*TR2
    DO 2 I=1,2
    F(I)= 0.0
    DO 1 J=1,9
  1 F(I)= F(I)+CF(J)*(X(I)**(J-1))
  2 CONTINUE
    VT= VO*F(2)/F(1)
    RETURN
    END
    FINISH
```

APPENDIX B13

Miscellaneous Programs used in the Data Acquisition System

B13-1 TEMPERATURE COEFFICIENT Program

This program is concerned with calculating the correct value of the temperature coefficient of resistance ($\cdot$) for the wire material by a least square error linear regression.

The input data are the measured values of: wire resistance at various temperatures during the heating up and cooling down processes, the wire cold resistance and the lead resistance.

The output data are the calculated value of α as given by:

$$\alpha = \left[(R_H/R_C) - 1 \right] / \Delta T \qquad \text{(B40)}$$

Denoting $\left[(R_H/R_C) - 1\right]$ as x and ΔT as y the least square line approximating the set of points (x_1, y_1), (x_2, y_2), ... (x_N, y_N) has the equation

$$Y = a_0 + a_1 x \qquad \text{(B41)}$$

where a_0 and a_1 are given by the following relations

$$a_0 = \frac{(\Sigma Y)(\Sigma X^2) - (\Sigma X)(\Sigma XY)}{N \Sigma X^2 - (\Sigma X)^2} \qquad \text{(B42)}$$

and

$$a_1 = \frac{N \Sigma XY - (\Sigma X)(\Sigma Y)}{N \Sigma X^2 - (\Sigma X)^2} \qquad \text{(B43)}$$

The value of the temperature coefficient α is given therefore by the calculated value of a_1 while a_0 equals zero for the straight line passing through the origin.

The output results are usually obtained as a graph showing the experimental results and the calculated value of α.

```
JOB N410,N,NS1505
LUTORTRAN
RUN
DOCUMENT SOURCE
      LIBRARY(ED,SUBGROUPNAGF)
      LIBRARY (ED,SUBGROUPGRAF)
      LIBRARY (ED,SUBGROUPUSUB)
      PROGRAM(N410)
      COMPACT
      INPUT 1 = CRO
      OUTPUT 2 = LPO
      TRACE 2
      END


      MASTER     TEMPERATURE COEFFICIENT
C                **************************
      DIMENSION R(100),T(100),ALPHA(100)
      COMMON/B1/DT(100),Y(100),L,A,B
      CALL UTPOP
      READ(1,222) NS
      DO 200 K=1,NS
      READ(1,222) N
      READ(1,111) RL
      READ(1,111) (T(I),I=1,N)
      READ(1,111) (R(I),I=1,N)
      DO 200 J=1,(N-1)
      M = N-J+1
      RC =R(M)-RL
      TC =T(M)
      SALPHA =0.0
      DO 100 I=1,(N-J)
      DT(I) =(T(I)-TC)*.55555
      Y(I) =((R(I)-RL)/(RC-RL)) 1.
      ALPHA(I)= Y(I)/DT(I)
      SALPHA = SALPHA+ALPHA(I)
  100 CONTINUE
      L = N-J
      CALL LEAST SQUARE
      SALPHA = SALPHA /(N-J)
      TC =(TC-32)*0.55555
      WRITE(2,333) RC,TC,SALPHA,A,B
      WRITE(2,444) (DT(I),ALPHA(I),I=1,(N-J) )
      WRITE(2,444) (DT(I),     Y(I),I=1,(N-J) )
      XMIN =0.0
      YMIN =0.0
      YMAX=0.3
      XMAX = 300.
      CALL UTP4A(XMIN,XMAX,YMIN,YMAX,5.,5.0,16HDT-(TH-TC)  (   ),2,9H(RH/
     *RC)-1,2)
      SFX = 5./(XMAX-XMIN)
      SFY = 5./(YMAX-YMIN)
      DO 250 IP =1,N-J
      XX =SFX*(DT(IP)-XMIN)
```

```
      YY = SFY*(Y(IP)-YMIN)
      CALL UTP3(1H*,XX,YY,2)
  250 CONTINUE
  200 CONTINUE

  111 FORMAT(10F0.0)
  222 FORMAT(10I3)
  333 FORMAT(2X,'RC =',F8.3,'OHMS  TC=',F8.3,' OC  MEAN VALUE OF ALPHA =
     *',F10.7,'A=',F10.7,'B= ',F10.7/
     *'  DT          ALPHA        DT        ALPHA        DT        ALPHA        DT
     *ALPHA       DT        ALPHA        DT        ALPHA'/)
  444 FORMAT(2X,6(1X,F7.3,1X,F9.7))
  555 FORMAT(5(1X,F7.3,1X,F7.6))
      CALL UTPCL
      STOP
      END


      SUBROUTINE LEAST SQUARE
                 ************
      COMMON /B1/ X(100),Y(100),N,A,B
      SX,SX2,SY,SY2,SXY=0.0
      DO 1 I=1,N
      SX = SX+X(I)
      SX2 =SX2+X(I)*X(I)
      SXY = SXY +X(I)*Y(I)
      SY = SY +Y(I)
    1 CONTINUE
      D = SX2*FLOAT(N)-(SX*SX)
      A = (SY*SX2-SX*SXY)/D
      B = (FLOAT(N)*SXY-SX*SY)/D
      RETURN
      END
      FINISH
```

B13-2 - CYLINDER-TO-CYLINDER VARIATION Program

This program is concerned with estimating the extent of cylinder-to-cylinder variations in the turbulent field characteristics. It consists of a simplified version of the general program (STATISTICAL ANALYSIS) discussed in Appendix B4.

The input data for this program are the variation of turbulence characteristic parameters with crank angles for different cylinders. These data are usually obtained from the output results of the TURBULENCE ANALYSIS I program discussed in Appendix B5.

```
      MASTER  CYLINDER TO CYLINDER VARIATIONS
C             ********************************.
      COMMON /B1/X(12,10),CA(10),NANG,NC
      READ(1,111) NC,NANG,NS
      READ(1,222) G
      READ(1,222) (CA(I),I=1,NANG)
      DO 10 IS=1,NS
      DO 1 J=1,NC
      READ(1,222)(X(I,J),I=1,NANG)
    1 CONTINUE
      IF((IS.EQ.1).OR.(IS.EQ.4)) GO TO 3
      DO 2 J=1,NC
      DO 2 I=1,NANG
      X(I,J)=X(I,J)*G
    2 CONTINUE
    3 CONTINUE
      CALL STATISTICAL ANALYSIS
   10 CONTINUE
  111 FORMAT(10I3)
  222 FORMAT(10F0.0)
      STOP
      END


      SUBROUTINE STATISTICAL ANALYSIS
      DIMENSION SD(10),SDM(10),SKEW(10),VMN(10),VMX(10),CVR(10),VM(10)
      REAL KURT(10)
      COMMON /B1/V(12,10),CA(10),NANG,NC
      DO 4 J=1,NANG
      SV=0.0
      DO 5 I=1,NC
    5 SV =SV+V(J,I)
      VM(J) = SV/NC
      SVS,DV3,DV4 =0.0
      DO 1 I=1,NC
      SVS = SVS+V(J,I)*V(J,I)
      DV =V(J,I)-VM(J)
      DV3 = DV*DV*DV+DV3
      DV4 = DV3*DV
    1 CONTINUE
      Y = VM(J)*VM(J)*NC
      VAR = (SVS-Y)/(NC-1)
      SD(J) = SQRT(VAR)
      SDM(J) = SD(J)/VM(J)
      SD3 = SD(J)*VAR
      SD4 = VAR*VAR
      SKEW(J)= DV3/(SD3*(NC-1))
      KURT(J) = DV4/(SD4*(NC-3))
      VMN(J),VMX(J)=V(J,1)
      DO 2 I=1,NC
      IF(VMN(J).LT.V(J,I)) GO TO 2
      VMN(J) = V(J,I)
      MN =I
    2 CONTINUE
      DO 3 I=1,NC
      IF(VMX(J).GT.V(J,I)) GO TO 3
      VMX(J) = V(J,I)
      MX =I
    3 CONTINUE
```

```
      CVR(J) = (VMX(J)-VMN(J))/VM(J)*100.
      WRITE(2,333) CA(J),VM(J),VMX(J),VMN(J),CVR(J),SD(J),SDM(J),SKEW(J)
     *,KURT(J)
    4 CONTINUE
  333 FORMAT (9(1X,E12.4))
      RETURN
      END
      FINISH
```

B13-3 - TABULATED DATA Program

The main purpose of this program is to generate some tabulated data required for the SPECTRAL ANALYSIS program. It calculates the exact sample number of a data block for any crank angle during the cycle, the required shift of the signal in the data block and the maximum number of cycle samples in the block.

It calculates also the sample size (crank angle degrees) and the exact value of engine speed for the particular test considered.

The input data for this program could be summarised as follows:

1. The minimum and maximum values of engine speeds in the Table.
2. The width of cycle sample (crank angle degrees).
3. The sampling rate on the ADC (μ sec/sample).

and 4. The size of the data block used in storing the digitized data.

```
JOB N280,N,NS1505
LUFORTRAN
RUN
VOLUME 7500
CARDLIST
DOCUMENT SOURCE
      LIBRARY (ED,SUBGROUPFSCE)
      LIBRARY (ED,SUBGROUPGRAF)
      LIBRARY (ED,SUBGROUPUSUB)
      PROGRAM(N280)
      COMPACT
      INPUT 1 = CRO
      OUTPUT 2 = LPO
      TRACE 0
      END


      MASTER               TABULATED DATA
C                          **************
C     FOR CALCULATING THE CORRECT ENGINE SPEED AND THE SAMPLE NUMBER
C     FOR THE AUTO-CORRELATION AND POWER SPECTRUM ANALYSIS
      INTEGER SR
      DIMENSION ANGLE(100),NA(100),ND(100)
      MAX RPM =3900.
      MIN RPM =500.
      DO 1200 IT=1,NT
      READ(1,111)NANGLE,NT,NS,SR,NB
  111 FORMAT(4I4)
      READ(1,113) (ANGLE(I),I=1,NANGLE )
  113 FORMAT(12F0.0)
      DO 1100 IW=6,10,2
      J =0
      NSI= 120.*(10.**6)/(MAX RPM *FLOAT(SR))
      DO 1000 NP=NSI,NS,5
      RPM=120.*(10.**6)/FLOAT(NP*SR)
      IF(RPM.LT.MIN RPM) GO TO 1100
      SS=720./NP
      X= FLOAT(IW)/SS
      NW= NINT(X)
      NW2= NINT (X/2.)
      NCOUNT = NINT( FLOAT(NB)/X)
      NDI=NB-NW
      IF(J.EQ.18) J=0
      IF(J.GT.0) GO TO 800
      WRITE(2,222) SR,IW
      WRITE(2,333) (ANGLE(I),I 1,NANGLE )
      WRITE(2,444)
  800 CONTINUE
      DO 900 I=1,NANGLE
      NA(I) = NINT(ANGLE(I)/SS)
      ND(I) =NA(I)  NW2
  900 CONTINUE
      WRITE(2,555) NP,RPM,SS,(NA(I),I=1,NANGLE ),NW,NDI
      WRITE(2,666) (ND(I),I=1,NANGLE ),NCOUNT
      J=J+1
```

```
1000 CONTINUE
1100 CONTINUE
1200 CONTINUE
 222 FORMAT(1H1,30X,61H TABULATED DATA FOR CALCULATING THE CORRECT ENGI
    XNE SPEED(RPM)/,30X,71HAND SAMPLE NUMBER FOR THE AUTO-CORRELATION
    XAND POWER SPECTRUM ANALYSIS//,20X,16HSAMPLING RATE = ,I5  ,27H(MIC
    XRO-SEC.), CHUNK WIDTH =,I4,9H(DEGREES))
 333 FORMAT(120H*****************************************************
    X***************************************************************/
    X4X,2HNP,4X,3HRPM,2X,11HSAMPLE SIZE,21X,32HSAMPLE  NUMBER/SAMPLE DI
    *FFERENCE,20X/,25X,12(2X,F4.0))
 555 FORMAT(2X,I4,2X,F6.1,2X,F6.3,3X,12(2X,I4),2X,11HCLEAR FROM ,I2,4H
    *TO ,I4)
 444 FORMAT(120H-----------------------------------------------------
    *---------------------------------------------------------------/
    *)
 666 FORMAT(25X,12(2X,I4),5X,11HCOUNT NO.  =,I4/)
     STOP
     END
     FINISH
```