COMPUTER PROGRAM FOR DETERMINING SURFACE ROUGHNESS AND DISPLACEMENT HEIGHT FROM WIND SPEED AND AIR TEMPERATURE PROFILES

by

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A computer program in Fortran IV language was written to determine d and z_o for wind speed and air temperature profiles collected at Davis, California during the April-May 1967, Cooperative Field Experiment sponsored by the U.S. Army, Department of Meteorology, Fort Huachuca, Arizona. The program is written with several subroutines each of which perform closely related parts of the program. Many of the subroutines can be used without alteration for other data sets in computers that can use Fortran IV, V or 63.

The logical unit code used in the read/write statements is one parameter which may need to be changed for a particular computer whether the input data is on cards or tape and the output is desired on cards, tape or printer. The read/write statement format, for example, is Read/Write (N,M) (data list) where N is the logical unit number (cards, tape, printer typewriter) and M is the format statement used for the data list. N will depend upon the particular computer system used. The initial program statement is a common statement which is also contained in most of the subprograms. This makes the call statements for the subroutines shorter and reduces the possibilities of interchanging variables. The definitions of all variables in the mainline program and subroutines are listed and are somewhat related to the variables used in the theory so that the remembering of meaningless symbols is reduced.

The theoretical profile structure is contained in the subroutines LOM1, LOM2, PHI, CAPPH, and DUET and can easily be altered to other concepts about profile structure.

The performance of the program depends on initial guess for z_o and d. If the initial guess differ greatly then a fatal error may be indicated. Then another initial set of guesses at z_o and d must be tried. An error may be returned using one set of measurements but not another. It depends upon the manner in which $\Sigma\varepsilon_i^2 = \Sigma\{V_i - V^*k^{-1}[\ln(z_i + d + z_o) - \ln z_o + \Phi_i]^2$ varies with d and z_o. There may not be a minimum value of $\Sigma\varepsilon_i^2$ within the requirement that $d + z_o$ not be greater in absolute value than the height of the lowest measurement level. It might be desirable to vary d in increments of one cm or so, then vary z_o in increments of 10% of the expected value for a given value of d, call the subroutine ZFIX modified to calculate $\Sigma\varepsilon_i^2$ and then print out d, z_o, V*, and $\Sigma\varepsilon_i^2$ to see if there is a minimum present in $\Sigma\varepsilon_i^2$. If so, then two initial estimates of d and z_o could be based on the values of d and z_o which bracketed the minimum for $\Sigma\varepsilon_i^2$.

The tolerance on d and z_o would be dependent on the desired accuracy in the friction velocity V* and can readily be determined from the results above by determining the change in V* with respect to d and z_o. A rough estimate for the tolerance for d would be 0.1 cm since this is less than the error in the height determination for the profile levels. An estimated tolerance for z_o would be 1% of the expected value.

SYMBOL LIST -- COMMON

N	Number of measurement levels on mast
J	Mast number
I	Index for measurement level on mast
Z(J,I)	Height of measurement level
K	Index for height of gradient measurement
DZ(K)	Height difference for gradient measurement
ZZ(K)	Height of gradient measurement
D	Displacement height d
ZO	Surface roughness
ZZD(K)	ZZ(L) + D + ZO
V(I)	Wind speed at I level
VD(K)	Wind speed shear at K level
T(I)	Temperature at I level
TD(K)	Temperature gradient at K level
S(I)	Specific humidity at I level
SD(K)	Specific humidity gradient at K level
RI(K)	Richardson number at K level
CPV(I)	Integral diabatic influence function for wind at I level
CPT(I)	Integral diabatic influence function for temperature at I level
TM	Mean profile temperature
VST	V*, the shearing velocity
CLM	L^{-1}, Lettau - Obukov - Monin length scale
ZD(I)	ZD(I) = Z(J,I) + D + ZO

MAINLINE DAVIS PRO

The mainline program calls the subroutines as needed and selects the number of levels of wind speed and air temperature which will be used to determine z_o and d. This is carried out in the DO loop (DO 611 L = N, M, P) where N is the number of measurement levels used for the first trial, M the number of levels for the last trial and P is the increase in the number of levels for the next trial. In the listing of the program N = 5, M = 9, P = 2 so that for the first trial the lowest five levels of wind speed and air temperature are used then seven levels and finally nine. The parameter LL selects the assumption about profile structure such that if LL = 0 then $K_h K_m^{-1} = 1$ and if LL = 1 then $K_h K_m^{-1} = \phi^{-1/2}$.

If the subprogram ZZero returns a value of V* = VST = 0, which means that a determination of d and z_o was not made, then the output subroutine TAVT is not called.

If the Richardsons number is greater than 1/B where B is usually taken as 18, then the subroutine LOM1, which uses the assumption that $K_h K_m^{-1} = 1$, will not be able to determine 1/L. The assumption that $K_h K_m^{-1}$ is bypassed and only the assumption that $K_h K_m^{-1} = \phi^{-1/2}$ will be used.

SYMBOL LIST - MAINLINE PROGRAM

B	KEYPS equation constant (18)
IDAY	Date
ITS	Start time
ITE	Stop time
LL	Key to assumption about $K_h K_m^{-1}$
L	Number of profile levels to be used
N	Number of profile levels
NN	Number of gradient levels on mast

```
      DIMENSION WD(9),HF(9)
      DIMENSION Z(3,9),DZ(8),ZZ(8),ZZD(8).V(9),VD(8),T(9),TD(8),S(9),SD(18),
      RI(8),CPV(9),CPT(9),ZD(9)
      COMMON Z,DZ,ZZ,ZZD,V,VD,T,TD,S,SD,RI,CPV,CPT,TM,VST,ZO,D,OLM,J,ZD
      CALL ZMAST
      B=18.
      L=0
      N=9
      NN=N-1
3     CALL DATUM(IDAY,ITS,ITE,L,WD,HF)
      LL=0
      IF(IDAY)99,99,12
12    IF(RI(9)-1.0/B -.005)31,611,611
31    CONTINUE
220   CONTINUE
      ZO=0.9

      CALL ZZERO (N,NN,LL,B,JIJ)
      IF(VST)7,7,13
13    CALL TAVT (N,NN,LL,IDAY,ITS,ITE,B)
7     D=0.0
      ZO=0.9
      CALL ZFIX(N,NN,LL,B)
      CALL TAVT (N,NN,LL,IDAY,ITS,ITE,B)
611   LL=LL+1
      IF(LL-1) 99,220,3
99    STOP
      END
```

```
'FOR,SIZ MAIN
      DIMENSION WD(9),HF(9)
      DIMENSION Z(3,9),DZ(8),ZZ(8),ZZD(8),V(9),VD(8),T(9),TD(8),S(9),SD(
     18),RI(8),CPV(9),CPT(9),ZD(9)
      COMMON Z,DZ,ZZ,ZZD,V,VD,T,TD,S,SD,RI,CPV,CPT,TM,VST,ZO,D,OLM,J,ZD
      CALL MFTCH
      CALL ZMAST
      B=18.
   50 FORMAT(1H1)
      PRINT 50
    3 CALL DATUM(IDAY,ITS,ITE,L,WD,HF)
      IF(IDAY)99,99,12
   12 CONTINUE
    7 D=0.0
      N=9
      NN=N-1
      ZO=0.9
      IF(RI(1).GT.0.0) LL=1
      IF(RI(1).LT.0.0) LL=0
      CALL ZFIX(N,NN,LL,B)
      CALL TAVT (N,NN,LL,IDAY,ITS,ITE,B)
      GO TO 3
   99 STOP
      END
```

SUBROUTINE ZMAST

The Davis, California data consisted of nine levels of wind speed, air temperature and moisture, and 5 levels of wind direction on three masts at the corners of an equilateral triangle 100 m on a side, ZMAST reads data cards which refer to a particular mast and the heights of each successive level on the mast starting with the lowest level. The heights may be included in the subprogram rather than read from card input.

```
       SUBROUTINE ZMAST
       DIMENSION Z(3,9),DZ(8),ZZ(8),ZZD(8),V(9),VD(8),T(9),TD(8),S(9),SD(18),
       RI(8),CPV(9),CPT(9),ZD(9)
       COMMON Z,DZ,ZZ,ZZD,V,VD,T,TD,S,SD,RI,CPV,CPT,IM,VST,ZO,D,OLM,J,ZD
       M=5
       DO 2 L=1,3
500    FORMAT (I2,9F6.3)
2      READ (M,500)J,(Z(J,I),I=1,9)
       DO 4 I=1,9
4      Z(3,I)=Z(3,I)+2.
       RETURN
       END
```

```
'FOR,SIZ ZMAST
      SUBROUTINE ZMAST
      DIMENSION Z(3,9),DZ(8),ZZ(8),ZZD(9),V(9),VD(8),T(9),TD(8),S(9),SD(
     18),PI(9),CPV(9),CPT(9),ZD(9)
      COMMON Z,DZ,ZZ,ZZD,V,VD,T,TD,S,SD,PI,CPV,CPT,TM,VST,ZC,D,OLM,J,ZD
      Z(1,1)=18.7
      Z(1,2)=38.7
      Z(1,3)=79.3
      Z(1,4)=119.3
      Z(1,5)=159.8
      Z(1,6)=200.5
      Z(1,7)=240.9
      Z(1,8)=280.5
      Z(1,9)=320.9
      Z(2,1)=20.9
      Z(2,2)=40.9
      Z(2,3)=80.9
      Z(2,4)=122.2
      Z(2,5)=162.2
      Z(2,6)=201.9
      Z(2,7)=244.3
      Z(2,8)=283.6
      Z(2,9)=322.4
      Z(3,1)=21.1
      Z(3,2)=40.9
      Z(3,3)=81.1
      Z(3,4)=121.1
      Z(3,5)=161.4
      Z(3,6)=201.0
      Z(3,7)=241.6
      Z(3,8)=282.3
      Z(3,9)=321.8
      RETURN
      END
```

SUBROUTINE DATUM

The Davis, California half hour mean data recorded on tab cards was identified by mast number (J = 1,2,3), item number (1-wind speed, 2-air temperature, 3-specific humidity, 4-heat budget results, and 5-wind direction), date, start time, stop time, then the data for the particular item starting at the lowest level on the mast. The potential air temperature calculation at each level replaces in storage the actual air temperature initial read from the cards.

Occasionally a wet bulb sensor was dry so a check is included to see if the specific humidity is close to the saturation specific humidity of the air ($\pm$ 0.2 gm/kg). If close to saturation, the specific humidity at that level are also set to 0.

Upon completing the data reading and the above operations the results are printed under a heading giving date, time and mast number.

The desired wind speed, potential temperature and specific humidity gradients are determined together with their geometric height and printed. The selection of the intervals over which the gradients are calculated will determine the degree of smoothing applied to the gradients and should be done carefully.

Initially, adjacent levels were used for the Davis, California, profiles, but the maximum separation was 40 cm and the determination of a gradient for height differences of 40 cm, particularly between 280 and 320 cm for moisture, resulted in large and unrealistic values do to the inaccuracy with which small differences could be determined. The smoothing used may be seen in the subroutine. The gradients are printed so that they may be readily examined.

Richardson number is calculated and checked to see if it is in the range of 0.2 to -1.0. If outside the range, RI is set to the limits of the range. The reason for this is that if the gradients are not smoothed, as was initially the case, RI values outside the above limits consume large amounts of computer time attempting to determine values of ϕ which are unrealistically large. The initial mistake cost one hour of time on the CDC 1604 computer.

Richardson number is printed and control is returned from the subroutine to the main program.

The profile data necessary for determining d and z_o is now in storage and available in common.

SYMBOL LIST-DATUM

A(I)	Input data
K	Identifier for input data
B	Specific humidity for saturation at air temperature
HF(I)	Heat flux data from heat budget
WD(I)	Wind direction
M	Logical unit number for reading or writing

```
      SUBROUTINE DATUM(IDAY,ITS,ITE,L,WD,HF)
      DIMENSION Z(3,9),DZ(8),ZZ(8),ZZD(8),V(9),VD(8),T(9),ID(8),S(9),SD(
     18),RI(8),CPV(9),CPT(9),ZD(9)
      DIMENSION A(9),HF(9),WD(9)
      COMMON Z,DZ,ZZ,ZZD,V,VD,T,ID,S,SD,RI,CPV,CPT,TM,VST,ZO,D,OLM,J,ZD
  501 FORMAT(2I2,I3,2I5,9F7.3)
  502 FORMAT(2I2,I3,2I5,6F10.6,/17X,3F10.6)
      DO 1 I=1,9
      V(I)=0.0
      T(I)=0.0
      S(I)=0.0
      HF(I)=0.0
    1 WD(I)=0.0
      DO 2 I=1,8
    2 SD(I)=0.0
      TM=0.0
  100 CONTINUE
      READ501,   J,K,IDAY,ITS,ITE,(A(I),I=1,9)
      IF (J-10) 101,1001,99
 4099  FORMAT(1H1)
 1001  PRINT 4099
      GO TO 100
  101 IF (K-1) 100,102,103
  102 DO 1022 I=1,9
 1022 V(I)=A(I)
 5021 FORMAT(1H ,5HAPRIL,I3,5H,1967,5X,5HSTART,I5,5X,4HSTOP,I5,10X,7HMAS
     1T NO,I3)
      IF(IDAY - 25)203,99,202
  202 PRINT5021,   IDAY,ITS,ITE,J
      GO TO 204
 5022 FORMAT(1H ,3HMAY  ,I3,5H,1967,5X,5HSTART,I5,5X,4HSTOP,I5,10X,7HMAS
     1T NO,I3)
  203 PRINT5022,   IDAY,ITS,ITE,J
  204 PRINT503,    (Z(J,I),I=1,9)
  503 FORMAT(1H0,11HHEIGHT (CM),12X,1X,9F9.1)
  504 FORMAT(1H ,19HWIND SPEED (CM/SEC),5X,9F9.1)
      PRINT504,    (V(I),I=1,9)
      GO TO 100
  103 IF (K-2) 99,104,106
  104 DO 105 I=1,9
      T(I)=A(I)+273.16                  -.0001*Z(J,I)
  105 TM=TM+T(I)
      TM=TM/9.
      GO TO 100
  106 IF (K-3) 99,107,109
  107 DO 108 I=1,9
      S(I)=A(I)
      B=25.22*(T(I)-273.16)/T(I)
      B=ALOG(6.105)+B-5.31*ALOG( T(I)/273.16)
      B=EXP(B)*0.622
      IF(B-S(I)-0.02)1071,1071,108
 1071 S(I)=0.0
  108 CONTINUE
      GO TO 100
  109 IF(K-4) 99,1091,110
 1091 DO 1092 I=1,9
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```
1092  HF(I)=A(I)
      GO TO 100
110   IF (K-5) 99,111,99
111   DO 201 I=1,8
201   WD(I)=A(I)
5012  FORMAT(1H ,21HWIND DIRECTION (DEG)    ,3X,9F9.1)
      PRINT5012,    (WD(I),I=1,6)
505   FORMAT(1H ,23HAIR TEMPERATURE (DEG K),1X,10F9.3)
      PRINT505,   (T(I),I=1,9),TM
      IF (IDAY-25) 257,99,258
506   FORMAT(1H ,25HSPECIFIC HUMIDITY (GM/KG)                    ,9F9.4)
257   PRINT506,   (S(I),I=1,9)
5011  FORMAT(1H ,19HHEAT FLUX (LY/MIN) 5X,9F9.3)
      PRINT5011,    (HF(I),I=1,7)
258   CONTINUE
      DO 602 I=1,2
      DZ(I)=Z(J,I+1)-Z(J,I)
      ZZ(I)=SQRT(Z(J,I+1)*Z(J,I))
      VD(I)= (V(I+1)-V(I))*100./DZ(I)
602   TD(I)=(T(I+1)-T(I))*100./DZ(I)
      DO 6021 I=3,8
      DZ(I)=Z(J,I+1)-Z(J,I-1)
      ZZ(I)=SQRT(Z(J,I+1)*Z(J,I-1))
      VD(I)=(V (I+1)-V (I-1)) *100./DZ(I)
6021  TD(I)=(T(I+1)-T(I-1))*100./DZ(I)
507   FORMAT(1H0,11HHEIGHT (CM)  ,18X,8F9.1)
C     PRINT507,   (ZZ(I),I=1,8)
508    FORMAT(1H ,27HWIND SPEED GRAD. (CM/SEC/M)  ,2X,8F9.2)
C     PRINT508,   (VD(I),I=1,8)
C     PRINT509,   (TD(I),I=1,8)
509   FORMAT(1H ,26HPOT. TEMP. GRAD. (DEG K/M)  ,3X,8F9.2)
      IF (IDAY-25) 255,99,255
255   DO 603 I=1,8
      IF(I-2)6031,6031,6032
6031   AX=S(I)
      BX=S(I+1)
      GO TO 2501
6032  AX  =S(I-1)
      BX=S(I+1)
2501  IF(AX)252,252,251
251   IF(BX)252,252,253
252   SD(I)=0.0
      GO TO 603
 253   CONTINUE
      SD(I)= (BX-AX) *100. /DZ(I)
603   CONTINUE
510   FORMAT(34H SPECIFIC HUMIDITY GRAD (G/KG/M)  ,8F9.3)
C     PRINT510,   (SD(I),I=1,8)
256   DO 209 I=1,8
      IF(V(I).LE.1.0) GO TO 100
209   RI(I)=980./TM*TD(I)/VD(I)/VD(I)*100.
      DO 210 I=1,8
      IF(RI(I)+12.0)211,212,212
211   RI(I)=-12.0
      GO TO 210
212   IF(RI(I)-0.2)210,210,213
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213   RI(I)=0.2
210   CONTINUE
      L=0
      PRINT511,    (RI(I),I=1,8)
511   FORMAT(1H ,17HRICHARDSON NUMBER ,12X,8F9.4)
99    RETURN
      END
```

SUBROUTINE DATE

Heading information containing date, start and stop time, mast no. and the assumption about $K_h K_m^{-1}$ is printed before a determination of z_o and d are made.

```
      SUBROUTINE DATE(IDAY,ITS,ITE,LL,B)
      COMMON Z(3,9),DZ(8),ZZ(8),ZZD(8),V(9),VD(8),T(9),TD(8),S(9),SD(8),
      1RI(8),CPV(9),CPT(9),TM,VST,ZO,D,OLM,J,ZD(9)
5021  FORMAT(1H1,5HAPRIL,I3,5H,1967,5X,5HSTART,I5,5X,4HSTOP,I5,10X,7HMAS
      1NO,I3)
      M=6
4     IF (IDAY-25) 2037,5 ,2027
2027  WRITE(M,5021)IDAY,ITS,ITE,J
      GO TO 5307
2037  WRITE(M,5022)IDAY,ITS,ITE,J
530   FORMAT(1H ,7HKH/KM=1)
531   FORMAT(1H ,18HKH/KM=1/SQRTF(PHI))
5307  IF (LL-1) 4073,4074,5
4073  WRITE(M,530)
      GO TO 5
4074  WRITE(M,531)
5     RETURN
      END
```

SUBROUTINE ZZERO

The determination of d and z_o are made within the desired tolerance. Two values of d and z_o are initially chosen to start the approximation process. The initial selections for obtaining the first estimate of d and z_o should be as near the expected value as possible and preferably one slightly above and the other below. An error is indicated if the value of $|d + z_o|$ = z(J,I) the height of the lowest sensor or if more than 20 trials are required to estimate d or z_o. The tolerance on z_o is .01 cm and on d 0.1 cm. If more than 20 trials are required for estimating z_o or if the estimated $z_o < 0$ the results of the previous trial are used for estimating a new value of d. If the routine is terminated with a fatal error then the condition that V* = 0 is set and used as a test in the main program to determine if a solution was obtained.

If d and z_o are determined within the above tolerances then a return is made to the main program with the resulting values of d, z_o and V*.

Given a value of d, the subroutine uses the two initial estimates of z_o to calculate a third estimate, continuing to cycle until the new estimate of z_o differs from the previous estimate of z_o by the tolerance of .01 cm. Then, using the second estimate of d a new z_o is obtained as above and used to estimate a new d. The program cycles until the new estimate of d differs from the previous estimate of d by less than 0.1 cm. A new estimate of z_o is made for each value of d.

The subroutine LOM1 is called with the assumption that $K_h K_m^{-1} = 1$ to obtain the value of L^{-1} for the several values of Ri determined from the initial data for the number of levels used. If the assumption that $K_h/K_m = \varphi^{-1/2}$ is used, then subroutine LOM2 is called to obtain L^{-1}. It is in these two subroutines that the nominal height z_n of each level is replaced by $z_n + d + z_o$.

The integral diabatic influence functions Φ and Φ_T are determined in the subroutine CAPPH. Given the value of L^{-1} obtained from subroutine LOM1 or LOM2, ϕ is determined in the subroutine PHI called by CAPPH. Since ϕ cannot be solved for directly from $(z_n + d + z_o)L^{-1}$, an approximation is made until the error in L^{-1} is less than .0001. Given the value of ϕ a value of Φ and Φ_T are determined. The subroutine ZZERO then solves for V* using the value of Φ determined at each level where wind speed is measured.

SYMBOL LIST ZZERO

M	Logical unit number for reading or writing
I	Index for level of measurement
JD	Number of cycles required for displacement height determination
DO	First estimate of displacement height
D1	Second estimate of displacement height
D2	Third estimate of displacement height
SD	Selection of initial estimates of displacement height
Z00	First estimate of surface roughness
Z01	Second estimate of surface roughness
Z02	Third estimate of surface roughness
JZ	Number of cycles for surface roughness determination
SZ	Selection of initial estimates of surface roughness
P	Value of ϕ at the I level

```
      SUBROUTINE ZZERO (N,NN,LL,B)
      DIMENSION Z(10),DZ(10),ZZ(10),ZZD(10),V(10),VD(10),T(10),TD(10),
     1(10),CPV(10),CPT(10),ZD(10)
      DIMENSION P(9)
      COMMON Z,DZ,ZZ,ZZD,V,VD,T,TD,RI,CPV,CPT,IM,VST,Z0,D,OLM,ZD
      M=6
      JD=0.0
      D0=0.0
      D=D0
      D1=5.0
      SSD=0.0
  400 CONTINUE
      Z00=1.0
      Z0=1.0
 31   Z01=2.
      IF(ABS(D+Z0)-Z(1)   )401,408,408
 401  CONTINUE
      JZ=0
      SZ=0
 4    CONTINUE
      DO 44 I=1,N
      ZD(I)=Z(I)   +D+Z0
 44   CONTINUE
      DO 45 I=1,NN
      ZZD(I)=SQRT((Z(I)+D)*(Z(I+1)+D))+Z0
 45   CONTINUE
      IF(LL)12,14,15
  14   CALL LOM1(NN,B)
      GO TO 415
 15    CALL LOM2 (NN,B)
 415  CALL CAPPH(N,B,P)
      V1=0
      V2=0.0
      V3=0.0
      V4=0.0
      V5=0.0
      V6=0.0
      DO 1 I=1,N
      AX=(ZD(I)      )/Z0
      IF(AX)408,408,4072
 4072 AX=ALOG(AX)+CPV(I)
      BX=P(I)/ZD(I)-1./Z0
      V1=V1+V(I)*AX
      V2=V2+V(I)/AX/AX*BX
      V3=V3+V(I)/AX
      V4=V4+V(I)*BX
      V5=V5+AX*BX
   1  V6=V6+AX*AX
      W=N
      G=V3*V4-V1*V2+V2*V3*V6/W-V3*V3*V5/W
      IF(SZ)2,2,3
 2    GZ0=G
      Z0=Z01
      SZ=SZ+1.
      GO TO 4
 3    JZ=JZ+1
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```
      IF(JZ-20)5,5,6
5     GZ1=G
      Z02=(Z00*GZ1-Z01*GZ0)/(GZ1-GZ0)
      IF(Z02)6,6,61
61    IF(ABS(Z02-Z01)-.001) 8,8,7
7     Z00=Z01
      GZ0=GZ1
      Z01=Z02
      Z0=Z02
      GO TO 4
6     CONTINUE
50    FORMAT(1H ,8HERROR AT,I5,38H ITERATION IN DETERMINING Z0 AND VS
     1)
      WRITE(M,50)JZ
8     VST=V3*.428/W
      V2=0.0
      V4=0.0
      V5=0.0
      DO 20 I=1,N
      AX=ALOG((ZD(I)     )/Z0)+CPV(I)
      CX=P(I)/ZD(I)
      V2=V2+V(I)/AX/AX*CX
      V4=V4+V(I)*CX
20    V5=V5+AX*CX
      G=V3*V4-V1*V2+V2*V3*V6/W-V3*V3*V5/W
      IF(SSD) 403,402,403
402   GD0=G
      D=D1
      SSD=1.
      GO TO 400
403   JD=JD+1
      IF(JD-20) 4031,4031,408
4031  GD1=G
      D2=(D0*GD1-D1*GD0)/(GD1-GD0)
      IF(ABS(D2-D1)-.01) 11,11,404
404   D0=D1
      GD0=GD1
      D1=D2
      D=D2
      GO TO 400
408   WRITE(M,520) JD
520   FORMAT(1H ,14HFATAL ERROR AT,I5,27H ITERATION IN DETERMINING DI
      VST=0.0
11    CONTINUE
12    RETURN
      END
```

SUBROUTINE LOM1

Given values of $\underline{Ri}_i$ and $z_i + d + z_o$ subroutine LOM1 determines $L^{-1} = \sum_{i=1}^{n} \phi_i \underline{Ri}_i (zz_i+d+z_o)^{-1}$ assuming $K_h K_m^{-1} = 1$ where $\phi_i = (1-B\ \underline{Ri}_i)^{-1/4}$ and zz_i is the geometric height of the levels at which $\underline{Ri}$ was determined. A check is included to see if $\underline{Ri} > B^{-1}$ which would result in a negative value for $1 - B\ \underline{Ri}$ and the fourth root could not be taken by the computer.

The return is made to the main program with an average value of OLM = L^{-1} for the number of measurement levels used.

SYMBOL LIST LOM1

PP	ϕ estimated from $\underline{Ri}$

```
      SUBROUTINE LOM1 (NN,B)
      DIMENSION Z(3,9),DZ(8),ZZ(8),ZZD(8),V(9),VD(8),T(9),TD(8),S(9),SD(18),
      RI(8),CPV(9),CPT(9),ZD(9)
      DIMENSION RT(8)
      COMMON Z,DZ,ZZ,ZZD,V,VD,T,TD,S,SD,RI,CPV,CPT,TM,VST,ZO,D,OLM,J,ZD
      OLM=0.0
      DO 1 I=1,NN
      IF(I-2)4,4,5
4     RT(I)=RI (I)*ZZD(I)*ALOG(ZD(I+1)/ZD(I ))/DZ(I)
      GO TO 6
5     RT(I)=RI (I)*ZZD(I)*ALOG(ZD(I+1)/ZD(I-1 ))/DZ(I)
6     IF( RT(I)-1./B)2,3,3
3     PP =1.0
      OLM=0.0
      GO TO 1
2     PP =SQRT (SQRT (1./(1.-B *RT(I))))
      OLM=OLM-PP *RT(I)/ZZD(I)
1     CONTINUE
      WW=NN
      OLM=OLM/WW
      RETURN
      END
```

```
      SUBROUTINE LOM1 (NN,B)
      DIMENSION Z(10),DZ(10),ZZ(10),ZZD(10),V(10),VD(10),T(10),TD(10),RI
     1(10),CPV(10),CPT(10),ZD(10)
      DIMENSION RT(8)
      COMMON Z,DZ,ZZ,ZZD,V,VD,T,TD,RI,CPV,CPT,TM,VST,Z0,D,OLM,ZD
      OLM=0.0
      DO 1 I=1,NN
 4    RT(I)=RI(I)*ZZD(I)*ALOG(ZD(I+1)/ZD(I))/DZ(I)
6     IF( RT(I)-1./B)2,3,3
3     PP  =1.0
      OLM=0.0
      GO TO 1
2     PP  =SQRT (SQRT (1./(1.-B  *RT(I))))
      OLM=OLM-PP  *RT(I)/ZZD(I)
1     CONTINUE
      WW=NN
      OLM=OLM/WW
      RETURN
      END
```

SUBROUTINE LOM2

Given values of $\underline{Ri}_i$ and $zz_i + d + z_o$ where zz_i is the geometric height of the levels at which $\underline{Ri}_i$ was determined subroutine LOM2 determines L^{-1} assuming $K_h K_m^{-1} = \phi^{-1/2}$. The equation solved is

$$L^{-1} = \sum_{i=1}^{n} \phi_i \ \underline{Ri}_i (zz_i + d + z_o)^{-1}.$$

Since $\underline{Ri} = \phi^{-1/2} (1-\phi^{-4})B^{-1}$ cannot be solved for ϕ in terms of $\underline{Ri}$ easily an initial guess is made on ϕ based on $\phi_i = (1-B\ \underline{Ri}_i)^{-1/4}$ for lapse conditions and $\phi = 1 + 22\ \underline{Ri}_i$ for inversion conditions. Then additional approximation to ϕ are made until the difference between $\underline{Ri}_i$ and $\phi^{-1/2} (1-\phi^{-4})B^{-1}$ is less than 0.0001. Then the value of ϕ_i is used to determine L^{-1}.

Return is made to the main program with L^{-1} = OLM average for the number of levels used.

SYMBOL LIST LOM2

PP	estimation of ϕ
PP2	estimated value of $\underline{Ri}$ based on PP
E	differences between $\underline{Ri}$ determined from profile data and estimation of $\underline{Ri}$ from PP

```
      SUBROUTINE LOM2 (NN,B)
      DIMENSION Z(10),DZ(10),ZZ(10),ZZD(10),V(10),VD(10),T(10),TD(10),RI
     1(10),CPV(10),CPT(10),ZD(10)
      DIMENSION RT(9)
      COMMON Z,DZ,ZZ,ZZD,V,VD,T,TD,RI,CPV,CPT,TM,VST,ZO,D,OLM,ZD
      OLM=0.0
      DO 1 I=1,NN
      RT(I)=RI(I)*ZZD(I)*ALOG(ZD(I+1)/ZD(I))/DZ(I)
   61 IF(RT(I))2,2,3
    2 PP=SQRT (SQRT (1./(1.-B  *RT(I))))
      GO TO 4
    3 PP=1.+22.*RT(I)
    4 CONTINUE
      AA=SQRT(PP)
      AB=1./PP**4
      PP2=AA*(1.-AB)/B
      E=RT(I)-PP2
      IF(ABS(E)-.01*ABS(RT(I))) 5,5,6
    6 CONTINUE
      PP=PP+2.*E*B/(1./AA*(1.+7.*AB))
      GO TO 4
    5 OLM=OLM-SQRT (PP)*RT(I)/ZZD(I)
    1 CONTINUE
      WW=NN
      OLM=OLM/WW
      RETURN
      END
```

SUBROUTINE CAPPH

Given d, z_o, L^{-1} and z_i the subroutine CAPPH determines a new height $ZD_i = z_i + d + z_o$, calls the subroutine PHI to determine ϕ_i for each ZD_i. Then using ϕ_i the integral diabatic influence function Φ for the wind profile and Φ_T for the potential air temperature profile assuming $K_h K_m^{-1} = \phi^{-1/2}$ are determined in the following manner

$$\Phi = \int_1^{\phi} (\phi-1)(1+3\phi^{-4})\phi^{-1}(1-\phi^{-4})^{-1} d\phi \tag{1}$$

and

$$\Phi_T = \int_1^{\phi} (\phi^{3/2}-1)(1+3\phi^{-4})\phi^{-1}(1-\phi^{-4})^{-1} d\phi \tag{2}$$

where $\phi = 1$ at $z + d = 0$. Φ and Φ_T are determined by series expansion of the integrals then term by term integration. Sufficient terms are retained to determine Φ and Φ_T within the desired tolerance.

$$\text{If } \phi>1 \text{ then } (1-\phi^{-4})^{-1} = 1 + \phi^{-4} + \phi^{-8} + \ldots \tag{3}$$

$$\text{If } \phi<1 \text{ then } (1-\phi^{-4})^{-1} = - \phi^{4}(1+\phi^{4}+\phi^{8}+\ldots) \tag{4}$$

(3) and (4) are substituted in 1 then integrated term by term. Using as an example (3) one obtains the series

$$\Phi = \int_1^{\phi} \phi^{-1}(\phi-1)(1+3\phi^{-4})(1+\phi^{-4}+\phi^{-8}+\ldots)d\phi$$

$$= \int_1^{\phi}(1-\phi^{-1}+4\phi^{-4}-4\phi^{-5}+4\phi^{-8}-4\phi^{-9}\ldots)d\phi \tag{5}$$

Term by term integration of (5) with insertions of the limits yield

$$\Phi = (\phi-1) - \ln\phi + \xcancel{(\phi^{-4}-1)} - 4(\phi^{-3}-1)/3 + 4(\phi^{-4}-1)/4$$

$$- 4(\phi^{-7}-1)/7 + 4(\phi^{-8}-1)/8\ldots \tag{6}$$

A similar procedure is carried out for Φ_T when $\phi>1$ and for Φ and Φ_T when $\phi<1$. It can be readily seen that when $\phi=1$, $\Phi=0$ in (6). The term by term integration is carried out for 22 terms in the subroutine CAPPH. Since 22 terms did not actually reach a good limit rapidly a small residue (.016, .024) was added or subtracted from Φ or Φ_T to account for the discrepancy at values of ϕ differing appreciably from one. The error in Φ due to the residue of the series is insignificant compared to errors in $\ell n[(z+d+z_o)/z_o]$ and probably could have been neglected.

Return is made to either ZZERO or ZFIX with values of Φ_i and Φ_{T_i} at each level where ϕ has been determined. Φ and Φ_{T_i} are available in common for use by the subroutine TAVT.

SYMBOL LIST CAPPH

BB	Dummy variable for B used previously in other parts
P(I)	ϕ at the I level
A,AA,B,C,F,E,X	are all dummy variable used to represent recurring terms in the series expansion for Φ and Φ_T.

```
      SUBROUTINE CAPPH(N,BB,P)
      DIMENSION P(10)
      DIMENSION Z(10),DZ(10),ZZ(10),ZZD(10),V(10),VD(10),T(10),TD(10),RI
     1(10),CPV(10),CPT(10),ZD(10)
      COMMON Z,DZ,ZZ,ZZD,V,VD,T,TD,RI,CPV,CPT,TM,VST,Z0,D,OLM,ZD
      CALL PHI (P,N,ZD,OLM,BB)
      DO 5 I=1,N
      IF(P(I)-1.) 3,3,4
4     A=1./P(I)**3
      AA=A/P(I)
      B=AA
      C=A*SQRT(P(I))
      F=B-1.
      E=ALOG(P(I))
      CPV(I)=P(I)-1.-E+0.016
      CPT(I)=2./3.*(P(I)*C/A-1.)-E+.024
      X=1.
      DO 7 L=2,12
      CPV(I)=CPV(I)+F-4.*(A-1.)/(4.*X-1.)
      CPT(I)=CPT(I)+F-8.*(C-1.)/(8.*X-3.)
      A=A*AA
      B=B*AA
      C=C*AA
      X=X+1.
      F=(B-1.)/X
7      CONTINUE
      GO TO 5
3      AA=P(I)**4
      A=AA
      B=A*P(I)
      C=SQRT(P(I))
      C=B*C
      F=A-1.
      E=3.*ALOG(P(I))
      CPV(I)=E-3.*(P(I)-1.)-.016
      CPT(I)=E-2.*(C/A-1.)-.024
      X=1.
      DO 9 L=2,12
      CPV(I)=CPV(I)   +F-4.*(B-1.)/(4.*X+1.)
      CPT(I)=CPT(I)   +F-8.*(C-1.)/(8.* X+3.)
      A=A*AA
      B=B*AA
      C=C*AA
      X=X+1.
      F=(A-1.)/X
9      CONTINUE
5     CONTINUE
      RETURN
      END
```

SUBROUTINE PHI

Give a value of $z_i + \dot{\underline{d}} + z_o$ and 1/L the subroutine PHI determines ϕ_i to a tolerance of .0001 for $(z+d+z_o)L^{-1}$.

The expression $\phi(1-\phi^{-4})B^{-1} = (z_i+d+z_o)L^{-1}$ cannot be solved easily for ϕ. Therefore approximations are made to ϕ as $\phi_i = [1 + B(z_i+d+z_o)L^{-1}]^{-1/4}$ for lapse conditions and $\phi_i = 1 + 9.0(z+D+z_o)L^{-1}$ for inversion conditions. Then the estimated ϕ_i is used to determine $\phi_i(1-\phi_i^{-4})B^{-1}$. The error $(z_i+d+z_o)L^{-1} - \phi_i(1-\phi_i^{-4})B^{-1} = E$ is used to estimate a new ϕ_i and the cycle is repeated until the error is less than 0.0001.

When ϕ_i has been determined for all levels then a return is made to the calling program.

SYMBOL LIST PHI

NN	number of levels to be used
I	level
P(I)	ϕ at the level I
PR1	$(z_i+d+z_o)L^{-1}$
PP	estimated value of
PR2	estimate of PR1
E	error in PR1

```
          SUBROUTINE PHI (P,NN,AZD,OLM,B)
          DIMENSION P(9) ,AZD(9)
          DO 1 I=1,NN
          PR1= OLM*AZD(I)
          IF (OLM) 3,3,2
2         PP=SQRT (SQRT (1./(1.-B   *PRL)))
          GO TO 4
4         PR2=PP*(1.-1./PP**4)/B
          E=PR1-PR2
          IF(ABS(E)-.0001*ABS(PRL))5,5,6
6         PP=PP+E*B  /(1.+3./PP**4)
          GO TO 4
5         P(I)=PP
1         CONTINUE
          RETURN
          END
```

SUBROUTINE ZFIX

Upon occasion it may be desirable to select a value of displacement height and surface roughness to determine V*. Then the result may be used in the subroutine TAVT and DUET to determine the profile parameters.

The subroutine may be altered to determine the error squares for various values of d and z_o to see if there is a minimum error squares within the expected range of d and z_o.

```
      SUBROUTINE ZFIX (N,NN,LL,B)
      DIMENSION Z(10),DZ(10),ZZ(10),ZZD(10),V(10),VD(10),T(10),TD(10),RI
     1(10),CPV(10),CPT(10),ZD(10)
      DIMENSION P(9)
      COMMON Z,DZ,ZZ,ZZD,V,VD,T,TD,RI,CPV,CPT,TM,VST,Z0,D,OLM,ZD
      Z0=1.0
C     Z0=0.9
      D=0.0
      DO 409 I=1,N
  409 ZD(I)=Z(I)+D+Z0
      DO 411 I=1,NN
  411  ZZD(I)=SQRT((Z(I)+D)*(Z(I+1)+D))+Z0
 400  IF(LL-1)412,414,11
 412  CALL LOM1 (NN,B)
      GO TO 415
 414  CONTINUE
      CALL LOM2(NN,B)
 415  CALL CAPPH(N,B,P)
      V3=0.0
      DO 1 I=1,N
      AX=ALOG(ZD(I)/Z0)+CPV(I)
 1    V3=V3+V(I)/AX
      VNX=N
      V3=V3/VNX
      VST=V3*.428
 11   RETURN
      END
```

SUBROUTINE TAVT

The purpose of the subroutine is to print or punch the data in a desirable form based on the values of V*, L^{-1}, z_o and d from either subroutine ZZERO or ZFIX. The surface stress is calculated as $\tau_o = V*^2 T_m^{-1} P R_d^{-1}$ where T_m is the mean of the temperature over the profile, P (dynes cm^{-2}) is the surface pressure and R_d is the gas constant for dry air. In the program a surface pressure of 10^6dynes cm^{-2} is assumed. τ_o, V* and L^{-1} are written. From L^{-1} and V* an estimate of the sensible heat flux is made and written in units of ly min^{-1} and watts m^{-2}. A second estimate of the sensible heat flux may be made using the temperature gradients and the appropriate assumption about $K_h K_m^{-1}$. The results are written in the same form as the previous estimate of the sensible heat flux. Since several levels are used to obtain the sensible heat flux the standard deviation for the sample is calculated and written.

Since it is very likely that one or more measurement levels may be in error, a synthetic wind profile is calculated and compared to the original data as a percentage of the synthetic wind speed. This would then be the correction factor required if one anemometer were consistently in error by the same percentage. A standard deviation on wind speed error is calculated and written. The output sequence consists of height, synthetic wind speed, and V*, real wind speed, percent error on the real wind speed, and the standard deviation of the difference between the real and the synthetic wind speed. A similar procedure is followed with the temperature profile except that the difference between the measured and the synthetic potential temperature is written along with the standard deviation. The synthetic temperature profile is based on L^{-1} and the appropriate assumption about $K_h K_m^{-1}$. The surface potential temperature at the height $z_i + d = 0$ is obtained by extrapolating the temperature profile to the height z_o. The order of writing is surface synthetic potential temperature, synthetic potential temperature, and the standard deviation of the difference. Since two values of the sensible heat flux are available, two synthetic temperature profiles are calculated with the first utilizing the first estimate of the sensible heat flux densities.

Two estimates of latent heat flux are available: the first based on the assumption that $K_e K_m^{-1} = 1$ and the second based on $K_e K_Q^{-1} = 1$ utilizing the second estimate of sensible heat flux. The results are written in units of ly min^{-1} and watts m^{-2}.

An additional summary of the results is written and may be punched on cards or written on tape. The list includes, the mast number, date, start and stop time, number of levels used, the assumption about $K_h K_m^{-1}$ used, displacement height, surface roughness, surface stress and two estimates of the following; sensible heat flux, latent heat flux and the extrapolated temperatures at z_o.

SYMBOL LIST - TAVT

N	number of measurement levels
NN	number of gradient levels
TSI	T*
TAU	Surface stress
Q3	Sensible heat flux density in units of ly min^{-1}
Q4	Sensible heat flux density in units of watts m^{-2}
Q2	Standard deviation of sensible heat flux density in percent
VS(I)	Synthetic wind speed at the I level
A	Difference between synthetic and real wind speed
VM	ΣA
VMS	ΣA^2
VS(I)	percentage error in wind speed
VMS	standard deviation of wind speed error in units of cm sec^{-1}
T01	z_o temperature using sensible heat flux density
TT(I)	synthetic temperature profile
AB	standard deviation of air temperature difference from synthetic air temperature
E2	latent heat flux density assuming $K_e K_q^{-1} = 1$
E22	E2 in units of watts m^{-2}
E0	z_o specific humidity using latent heat flux density
SH(I)	synthetic specific humidity profile

```
      SUBROUTINE TAVT (N,NN,LL,IDAY,ITS,ITE.B)
      DIMENSION Z(3,9),DZ(8),ZZ(8),ZZD(8),V(9),VD(8),T(9),TD(8),S(9),SD(18),
     1RI(8),CPV(9),CPT(9),ZD(9)
      DIMENSION  P(9)
      DIMENSION VS(9),TT(9)
      DIMENSION SH(9)
      COMMON, Z,DZ,ZZ,ZZD,V,VD,T,TD,S,SD,RI,CPV,CPT,TM,VST,ZO,D,OLM,J,ZD
      M=6
      MM=1
      TS1=TM/0. 0.4/0.24*2.887/VST
      TS1=-TS1
      TAU=VST*VST/TM/2.887
      Q1=0.0
      Q2=0.0
      CALL PHI  (P,N,ZZD,OLM,B)
      DO1  I=1,NN
      Q11= TD(I)/100.*ZZD(I)/P(I)/TS1
      IF(LL-1)4,3,4
3     Q11=Q11/SQRT(P(I))
4     QL=Q1+Q11
1     Q2=Q2+Q11*Q11
      W=N
      WW=NN
      Q2=Q2-Q1*Q1/WW
      Q2=SQRT(Q2/(WW-1.))
      Q1=Q1/WW
      Q2=Q2/Q1*100.
      Q3=Q1*60.
      QT=Q3
      Q4=Q1*41850.
      WRITE(M,50) TAU,VAT,OLM,Q3,Q4,Q2
   50 FORMAT(7HOSTRESS,F6.3,15H DYNES/CM/CM     ,5HVSTAR,F6.1.10H CM/SEC
     1 ,6H 1/LOM,F8.6,8H 1/CM    ,9HSENS HEAT.F6.3/10H LY/MIN     ,F6.1,13H
     2 WATTS/M/M    ,6HSIGMA ,F7.2)
53    FORMAT(1H ,20HHEIGHT   (CM)          ,10F9.4)
      WRITE(M,53)ZO,(ZD(I),I=1,N)
      VM=0.0
      VMS=0.0
      DO 5 I=1,N
      AX=VST/0.40          *(ALOG(ZD(I)/ZO)+CPV(I))
      VM=VM+AX
      VMS=VMS+AX*AX
      VS(I)=AX/V(I)*100.
5     CONTINUE
      VMS=VMS-VM*VM/W
      VMS=SQRT(VMS/(W-1.))
56    FORMAT(1H ,29HSYNTHETIC/REAL WIND SPEED     ,10F9.4)
      WRITE(M,56)(VS(I),I=I,N),VMS
      TO1=0.0
      TS=TS1*QL
      DO 9 I=1,N
      IF(LL)24,77,8
77    TOL=TO1+T(I)-TS*(ALOG(ZD(I)/ZO     )+CPV(I))
      GO TO 9
```

```
8       TO1=TO1+T(I)-TS*(ALOG(ZD(I)/ZO     )+CPT(I))
9       CONTINUE
        TO1=TO1/W
        AC=0.0
        AB=0.0
        DO 10 I=1,N
        IF(LL)24,11,14
11      TT(I)=TO1+TS*(ALOG(ZD(I)/ZO    )+CPV(I))
         GO TO 13
14      TT(I)=TO1+TS*(ALOG(ZD(I)/ZO    )+CPT(I))
13      TT(I)=T(I)-TT(I)
        AC=AC+TT(I)
        AB=AB+TT(I)*TT(I)
10      CONTINUE
        AB=(AB-AC*AC/W)/(W-1.0)
        AB=SQRT(AB)
57      FORMAT(1H ,29HDIFFERENCE                          ,10F9.4)
        WRITE(M,57)(TT(I),I=1,N),AB
12      CONTINUE
17      TST=TO1-273.16
        IF(IDAY-25) 20,20,23
20      CONTINUE
        E2=0.0
        X=0.0
        A2=.6/.24*QT
        DO 22 I-1,NN
        IF(SD(I)) 21,22,21
21      X=X+1.
        E2=E2+A2*SD(I)/TD(I)
22      CONTINUE
        E2 =E2/X
        E22=E2 *697.2
589     FORMAT(1H ,29HLATENT HEAT KE/KQ=1  (LY/MIN),F10.3,10X,12H (WATTA/M
       1/M),F10.3,9X,12HSENS HT FLUX,F10.3)
        WRITE(M,589) E2 ,E22,Q3
        ES=E2*2.887*TM/(.600*.428*VST  )/60.
        X=0.0
        EO=).)
25       DO 26 I=1,N
        IF(S(I))24,26,27
27      X=X+1.
        IF(LL)24,28,29
28      EO=EO+S(I)=ES*(ALOG(ZD(I)/ZO)+CPV(I))
        GO TO 26
29      EO=EO+S(I)+ES*(ALOG(ZD(I)/ZO)+CPT(I))
26      CONTINUE
        EO=EO/X
        DO 30 I=1,N
        IF(LL) 24,31,32
31      SH(I)=EO-ES*(ALOG(ZD(I)/ZO+CPV(I))
        GO TO 30
32      SH(I)=EO-ES*(ALOG(ZD(I)/ZO)+CPT(I))
```

```
30      CONTINUE
54      FORMAT(31H SYNTHETIC SPECIFIC HUMIDITY.      ,10F8.3)
        WRITE(M,54)(SH(I),I=1,N),EO
        W=0.0
        AB=0.
        AC=0.0
        DO 33 I=1,N
        IF(S(I))35,35,34
35      SH(I)=0.0
        GO TO 33
34      W=W+1.
        SH(I)=SH(I)-S(I)
        AB=AB+SH(I)*SH(I)
        AC=AC+SH(I)
33      CONTINUE
        W=N
        AB=(AB-AC*AC/W)/(W-1.0)
        AB=SQRT(AB)
55      FORMAT(20H HUMIDITY DIFFERENCE  ,12X,10F8.3)
        WRITE(M,55)(SH(I),I=1,N)   ,AB
        GO TO 24
23      CONTINUE
        E2=0.
        EO=0.
24      CONTINUE
        K=6
59      FORMAT(2I2,I3,I1,I4,I1,I4,9F7.3)
        WRITE(MM,59) J,K,IDAY,N,ITS,LL,ITE,D,ZO,TAU,QT,TST,E2,EO
        WRITE( M,50) J,K,IDAY,N,ITS,LL,ITE,D,ZO,TAU,QT,TST,E2,EO
C       CALL DUET (N,LL,TS)
        RETURN
        END
```

SUBROUTINE DUET

The profile curvature for wind speed and potential air temperature, and Richardson's number are calculated and written along with the height. Theoretical values of the flux Richardson number, gradient Richardson number profile curvature for wind speed $\underline{DEU}$ and for potential air temperature DET are determined as

$$\underline{DEU} = \phi^{-4}(1+3\phi^{-4})^{-1}$$

and

$$\underline{DET} = 1.5\ \underline{DEU} - 0.5.$$

SYMBOL LIST - DUET

DEU(I)	Deacon number for wind speed profile
DET(I)	Deacon number for potential air temperature
BD(I)	Geometric height of DEU(I) and DET(I)
RQ(I)	Richardson number calculated for the height B2(I)
DEU(I)	Theoretical Deacon number
DET(C)	Theoretical Deacon number
RQ(I)	Theoretical gradient Richardson number

```
'FOR,SIZ DUET
      SUBROUTINE DUET(N,LL,TS)
      DIMENSION Z(10),DZ(10),ZZ(10),ZZD(10),V(10),VD(10),T(10),TD(10),RI
     1(10),CPV(10),CPT(10),ZD(10)
      DIMENSION DEU(8),DET(8),BD(8),RQ(8),BR(8),P(8),AKHM(8)
      COMMON Z,DZ,ZZ,ZZD,V,VD,T,TD,RI,CPV,CPT,TM,VST,Z0,D,OLM,ZD
49    FORMAT(10H HEIGHT BR,7F10.3)
50    FORMAT(10H HEIGHT BD,7F10.3)
51    FORMAT(7H DEU    ,7F10.3)
52    FORMAT(7H DET    ,7F10.3)
53    FORMAT(7H RI     ,7F10.3)
 54    FORMAT(7H KH/KM ,7F10.3)
      M=6
      B=18.
      K=0
      NM=N-2
      NN=N-1
      DO 3 I=1,NN
      ZZD(I)=SQRT((Z(I+1)+D)*(Z(I)+D))+Z0
      VD(I)=(V(I+1)-V(I))/ DZ(I)
      TD(I)=(T(I+1)-T(I))/DZ(I)
 3    CONTINUE
      DO 1 I=1,NM
      AA=ALOG(ZZD(I+1)/ZZD(I))
      DEU(I)=ALOG(VD(I)/VD(I+1))/AA
      DET(I)=ALOG(ABS(TD(I)/TD(I+1)))/AA
      BD(I)=SQRT((ZZD(I+1)-Z0)*(ZZD(I)-Z0))+Z0
 6    AZ=ZD(I+2)-ZD(I)
      BR(I)=SQRT((Z(I)+D)*(Z(I+2)+D))+Z0
      AT=T(I+2)-T(I)
      AV=V(I+2)-V(I)
 8    RQ(I)=980.*AT/(AV*AV*TM)*AZ
      AKHM(I)=.428*TS*AV/(VST*AT)
 1    CONTINUE
      WRITE(M,50)(BD(I),I=1,NM)
5     WRITE(M,51)(DEU(I),I=1,NM)
      WRITE(M,52) (DET(I),I=1,NM)
      WRITE(M,53)(RQ(I),I=1,NM)
      WRITE(M,54) (AKHM(I),I=1,NM)
      CALL PHI(P,NM,BD,OLM,B)
 13    CONTINUE
      DO 2 I=1,NM
      AA=1./P(I)**4
      DEU(I)=4.*AA/(1.+3.*AA)
      IF(LL)9,9,10
 9    DET(I)=DEU(I)
      RQ(I)=(1.-AA)/B
      AKHM(I)=1.
      GO TO 2
 10     AB=SQRT(P(I))
      RQ(I)=(1.-AA)/B*AB
      DET(I)=1.5*DEU(I)-.5
      AKHM(I)=1./AB
 2    CONTINUE
      WRITE(M,51)(DEU(I),I=1,NM)
      WRITE(M,52) (DET(I),I=1,NM)
      WRITE(M,53)(RQ(I),I=1,NM)
      WRITE(M,54) (AKHM(I),I=1,NM)
 12    RETURN
      END
```

Fatal error in determining z_o and d for five measurement levels by Subroutine ZZERO then Subroutine ZFIX is used with d = 0 and z_o = 0.90 cm then the printout from Subroutine TAVT and DUET.

```
MAY  3,1967      START     1      STOP   30            MAST NO  2
KH/KH=1
ERROR AT     1ITERATION IN DETERMINING ZO AND VSTAR    0   -5.00    -5.00     .00    2.76    2.00    1.00
ERROR AT     1ITERATION IN DETERMINING ZO AND VSTAR    0     .00    -5.00     .00    2.76    2.00    1.00
ERROR AT     1ITERATION IN DETERMINING ZO AND VSTAR    1    3.80      .00    3.80    3.80    2.00    1.00
ERROR AT     5 ITERATION IN DETERMINING D
    5    3   DISPLACEMENT HEIGHT (CM)-WIND PROFILE        73.47      1.00

SURFACE STRESS (DYNES/CM/CM)      .292     VSTAR (CM/SEC)     15.383     1/LOM [1/CM]        -.0010067123
SENSIBLE HEAT FLUX (LY/MIN)      -.044          (WATTS/M/M)   -30.4           TSTAR    .372155
SENSIBLE HEAT FLUX (LY/MIN)      -.030          (WATTS/M/M)   -21.0           SIGMA   -29.796570

HEIGHT (CM)                     .90    21.70    41.80    81.80   123.10   163.10
SYN. WIND SPEED (CM/SEC)               118.00   145.69   180.27   209.22   235.84    15.38
REAL WIND SPEED (CM/SEC)               122.40   152.45   182.47   203.19   220.02
SYN./REAL*100.                          96.40    95.57    98.80   102.97   107.19     9.25
AIR TEMP-KH/KH=1            278.31     279.53   279.82   280.17   280.47   280.75      .37
DIFFERENCE                                .16      .13      .04     -.09     -.25      .17
AIR TEMP-KH/KM=1            278.88     279.72   279.92   280.17   280.37   280.56      .26
DIFFERENCE                               -.03      .03      .05      .01     -.06      .04
LATENT HEAT KE/KH=1 -(LY/MIN)           -.023            -(WATTS/M/M)   -15.836     .292
LATENT HEAT KE/KO=1 -(LY/MIN)           -.019            -(WATTS/M/M)   -13.219    -.030
2   3   1   30 5 0     .0     .900     .292   -.044   -.030   -.023   -.019    5.148    5.719
HEIGHT      35.503     54.785     76.785
DEU          1.212       .880       .811
DET          1.099       .898      1.152
RI            .024       .038       .050
DEU           .779       .607       .401
DET           .668       .411       .102
RI            .030       .040       .048
RI            .032       .047       .061
```

Initial Print out from Subroutine DATUM

MAY 3,1967 START 1 STOP 29 MAST NO 2

HEIGHT (CM)	20.8	40.9	80.9	122.2	162.2	201.9	244.3	283.6	322.
WIND SPEED (CM/SEC)	122.4	152.5	182.5	203.2	220.0	223.4	243.2	253.8	262.
WIND DIRECTION (DEG)	195.7	195.9	192.2	192.5	195.4	194.3			
AIR TEMPERATURE (DEG K)	279.671	279.945	280.218	280.386	280.505	280.595	280.676	280.739	280.79
SPECIFIC HUMIDITY (G/KG)	5.8110	5.8680	5.9480	5.9850	6.0130	6.0230	6.0270	6.0550	6.078
HEAT FLUX (LY/MIN)	.006	-.074	-.036	-.025	-.025	-.013	-.013		

HEIGHT (CM)	29.2	41.0	70.7	81.4	127.8	140.6	186.2	228.7
WIND SPEED GRAD. (CM/SEC/M)	149.51	99.95	62.40	55.71	33.85	37.16	31.35	26.29
POT. TEMP. GRAD. (DEG K/M)	1.26	.88	.54	.46	.31	.28	.22	.18
SPECIFIC HUMIDITY GRAD(G/K/M)	.284	.228	.144	.120	.062	.048	.043	.031
RICHARDSON NUMBER	.0198	.0307	.0487	.0520	.0950	.0709	.0777	.0903

Printout from Subroutine Date, error indication from Subroutine ZZERO and the resulting solution from Subroutine TAVT and DUET.

```
MAY  3,1967        START    1        STOP   30             MAST NO  2
[illegible]
ERROR AT       ITERATION IN DETERMINING ZO AND VSTAR     0   -5.00   -5.00    .00    2.65    2.00    1.00
ERROR AT       ITERATION IN DETERMINING ZO AND VSTAR     0     .00   -5.00    .00    2.65    2.00    1.00
ERROR AT.      ITERATION IN DETERMINING ZO AND VSTAR     3    1.17    2.92   1.17    1.17    2.00    1.00

SURFACE STRESS (DYNES/CM/CM)        .276      VSTAR (CM/SEC)     14.951      1/LOM (1/CM)        -.00087258
SENSIBLE HEAT FLUX (LY/MIN)       -.035              (WATTS/M/M)     -24.2          TSTAR    .304664
SENSIBLE HEAT FLUX (LY/MIN)       -.036              (WATTS/M/M)     -25.0          SIGMA  -18.682977

HEIGHT (CM)                      .75     29.40    44.50    84.50   125.80
SYNT WIND SPEED (CM/SEC)                125.06   149.48   180.30   205.38    14.95
REAL WIND SPEED (CM/SEC)                122.40   152.45   182.47   203.19
[illegible]                             102.17    98.05    98.81   101.06     2.91
AIR TEMP-KH/KM=1              278.62    279.71   279.92   280.19   280.41      .30
DIFFERENCE                                -.02      .02      .03     -.03      .03
AIR TEMP-KH/KM=1              278.57    279.70   279.92   280.20   280.42      .31
DIFFERENCE                                -.01      .03      .02     -.04      .03
LATENT HEAT KE/KM=1 -(LY/MIN)           -.021             -(WATTS/M/M)   -14.986     .276
LATENT HEAT KE/KM=1 -(LY/MIN)           -.022             -(WATTS/M/M)   -15.617    -.036
2  2    1   30 4 0    2.8    .750    .276   -.035   -.036   -.021   -.022   5.460   5.412
HEIGHT       38.239      57.574
DEU           1.304        .924
DET           1.183        .943
RI             .024        .038
DEU            .758        .653
DET.           .696        .480
RI             .028        .038
RI             .031        .044
```

SUBROUTINE TEST

It is necessary to check all computer programs for punching and duplication errors. The purpose of subroutine TEST is to take a value of L^{-1}, calculate ϕ, Φ and Φ_T using subroutines CAPPH and PHI, determine Ri from ϕ, for $K_hK_m^{-1} = 1$, call subroutine LOM1 and see if the same value of L^{-1} is returned. Then, determine Ri for $K_hK_m^{-1} = \phi^{-1/2}$, call subroutine LOM2 and see if the same value of L^{-1} returns again. When first tried the subroutine revealed that the tolerance in subroutines LOM1 and LOM2 was not small enough and there were several errors in the subroutine CAPPH. It will also provide as output a set of profile parameters ϕ, Φ, Φ_T, RI, DEU, Ri, DET, and $K_hK_m^{-1}$ for each value of $(z+z_o)L^{-1}$.

The value of L^{-1} was changed slightly each time LOM1 or LOM2 was called.. The order was LOM1 then LOM2.

	LAPSE	INVERSION
Initial value of L^{-1}	0.0060000	-.00100
LOM1	0.0060043	-.00099
LOM2	0.0060036	-.00099
LOM1	0.0060066	-.00098
LOM2	0.0060062	-.00098

	LAPSE	INVERSION
Initial value of L^{-1}	0.0006000	-.000100
LOM1	0.0006002	-.000099
LOM2	0.0006006	-.000099
LOM1	0.0006008	-.000098
LOM2	-.0006008	-.000098

It was concluded that the error in estimating L^{-1} from Ri and $z + z_o$ of less than 1% was insignificant and the operation of the subroutines PHI, CAPPH, LOM1 and LOM2 was satisfactory.

```
'FOR,SI TEST
      .SUBROUTINE TEST
       COMMON Z(3,9),DZ(8),ZZ(8),ZZD(8),V(9),VD(8),T(9),TD(8),S(9),SD(8),
      1RI(8),CPV(9),CPT(9),TM,VST,Z0,D,OLM,J,ZD(9)
       DIMENSION P(9),DEU(9),DET(9)
       J=1
       B=20.
       OLM=.006
       D=0.0
       Z0=1.
       N=9
       A=10.
       DO 1 I=1,N
       A=A*SQRT(2.)
       ZZD(I)=A
1      Z(J,I)=A
4      CONTINUE
       CALL CAPPH(N,B,P)
50     FORMAT(1H ,9F10.3 ,F20.10)
       WRITE(6,50) (ZD(I),I=1,N),OLM
       WRITE(6,50) (P(I),I=1,N),B
       WRITE(6,50) (CPV(I),I=1,N),D
       WRITE(6,50) (CPT(I),I=1,N),Z0
       DO 2 I=1,N
       A=1./P(I)**4
       RI(I)=(1.-A)/B
  2    DEU(I)=4.*A/(1.+3.*A)
       CALL LOM1 (N,B)
       WRITE(6,50) (RI(I),I=1,N) ,OLM
       WRITE(6,50) (DEU(I),I=1,N)
       DO 3 I=1,N
       RI(I)=RI(I)*SQRT(P(I))
3      DET(I)=1.5*DEU(I)-.5
       CALL LOM2 (N,B)
       WRITE(6,50) (RI(I),I=1,N),OLM
       WRITE(6,50) (DET(I),I=1,N)
        B=B-2.
       IF(B-8.)5,4,4
5       IF(OLM) 6,7,7
7      OLM=-.001
       GO TO 4
6      RETURN
       END
```

```
C     SYNTHETIC WIND AND TEMPERATURE PROFILES
      DIMENSION P(10),VA(10),TA(10),TTA(10)
      DIMENSION Z(10),DZ(10),ZZ(10),ZZD(10),V(10),VD(10),T(10),TD(10),RI
     1(10),CPV(10),CPT(10),ZD(10)
      COMMON Z,DZ,ZZ,ZZD,V,VD,T,TD,RI,CPV,CPT,TM,VST,Z0,D,OLM,ZD
      B=18.
      N=9
      NN=N-1
      IDAY=0
      ITS=0
      ITE=0
 16   CONTINUE
      D=0.0
      Z0=1.0
      Z(1)=20.
      ZD(1)=Z(1)+Z0
      T(1)=0.0
      V(1)=0.0
      DO 1 I=2,N
      Z(I)=Z(I-1)*SQRT(2.)
      ZD(I)=Z(I)+Z0
      ZZ(I-1)=SQRT(Z(I)*Z(I-1))
      DZ(I-1)=Z(I)-Z(I-1)
      ZZD(I-1)=ZZ(I-1)+Z0+D
      T(I)=0.0
      V(I)=0.0
 1    CONTINUE
 555  FORMAT(1H1)
      PRINT555
      LK=0
 2    CONTINUE
 481  FORMAT(5F10.3)
      READ 481,TM,TAU,Q0
      IF(TAU) 99,99,3
 3    CONTINUE
      TO1=TM
      Q0=Q0/60.
 10   CONTINUE
      VST=SQRT(TAU*TM*2.887)
 11   CONTINUE
      TS=TM*2.887*Q0/(.428*.24*VST)
      TS=-TS
      OLM=980.*.428*2.887/(.24*VST*VST*VST)
      OLM=OLM*Q0
      Q1=Q0*60.
      Q2=Q0*41850.
 50   FORMAT(1H ,6HSTRESS,F10.3,9X,6H VSTAR,F10.3,9X,6H 1/LOM,F20.10)
      PRINT 50,TAU,VST,OLM
 51   FORMAT(1H ,20HSENS HT FLUX(LY/MIN),F10.3,9X,12H (WATTS/M/M),F10.1,
     19X,6H TSTAR,F10.6)
      PRINT 51,Q1,Q2,TS
 571  FORMAT(1H ,20HHEIGHT (CM)         ,10F 9.3)
      PRINT571,Z0,(ZD(I),I=1,N)
      CALL CAPPH(N,B,P)
      DO 4 K=1,N
      AA=ALOG(ZD(K)/Z0)
```

```
      VA(K)=VST/.428*(AA+CPV(K))
      TA(K)=TS*(AA+CPV(K))+TO1
      TTA(K)=TS*(AA+CPT(K))+TO1
4     CONTINUE
572   FORMAT(1H ,29HSYNTHETIC WIND SPEED (CM/SECD,10F 9.3)
101   FORMAT(1H ,20HAIR TEMP-KH/KM=1      ,10F9.3)
      PRINT 572,(VA(I),I=1,N)
      PRINT 101,TO1,(TA(I),I=1,N)
140   FORMAT(1H ,20HAIR TEMP-KH/KM=1/P    ,10F9.3)
      PRINT 140,TO1,(TTA(I),I=1,N)
      IF(QO) 5,6,6
 5    CONTINUE
      DO 9I=1,N
      T(I)=T(I)+TTA(I)*.5
      V(I)=V(I)+VA(I)*.5
 9    CONTINUE
      LL=1
      GO TO 8
 6    DO 12 I=1,N
      T(I)=T(I)+TA(I)*.5
      V(I)=V(I)+VA(I)*.5
 12   CONTINUE
      LL=0
 8    CONTINUE
      CALL DUET(N,LL,TS)
      IF(LK-1) 14,15,99
 14   LK=1
      GO TO 2
 15   CONTINUE
      DO 17 I=1,NN
      VD(I)=(V(I+1)-V(I))/DZ(I)
      TD(I)=(T(I+1)-T(I))/DZ(I)
      RI(I)=980.*(T(I+1)-T(I))*DZ(I)/(TM*(V(I+1)-V(I))**2)
 17   CONTINUE
      PRINT 572,(V(I),I=1,N)
      PRINT 101,TO1,(T(I),I=1,N)
C     CALL DUET(N,LL,TS)
      CALL ZZERO (N,NN,LL,B)
      IF(VST)7,7,13
13    CALL TAVT (N,NN,LL,IDAY,ITS,ITE,B)
7     D=0.0
      Z0=1.0
      CALL ZFIX(N,NN,LL,B)
      CALL TAVT (N,NN,LL,IDAY,ITS,ITE,B)
      GO TO 16
99    STOP
      END
```