A Rapid Method of Calculating Temperature increases along Mine Airways†

By A. M. STARFIELD*, Ph.D. (Rand) (Visitor)

SYNOPSIS

A description is given of a new computer programme that has been developed for the rapid computation of the changes in temperature and humidity of air passing through mine airways. The programme enables the ventilation engineer to calculate air temperature increases along airways with an ease that is comparable with that of looking up a set of graphs or tables in an engineering hand-book. The pertinent information for a particular airway can be fed to the computer either on a standard punched card, or by typing directly into the computer at a remote terminal teletype unit.

INTRODUCTION

In a recent paper by Starfield and Dickson[1] a computer model was developed for the study of heat transfer and moisture pick-up along mine airways. The results of this study were presented in the form of graphs showing the gradients of both wet and dry bulb temperatures at a cross-section of the airway. The paper indicated how these graphs could be used to calculate air temperatures at any point along the airway once the inlet air temperatures were known. However, new conditions of air velocity, virgin rock temperature, or the wetness of the footwall, for example, required the calculation of a completely new set of gradient graphs. Since each set was the result of some 50 minutes of digital computation (on an IBM System 360 Model 30 computer), the calculation of results for particular cases was a somewhat lengthy and expensive process.

A large number of these graphs have now been produced in a systematic way so as to cover the range of variables likely to be encountered in practice. A study of these graphs has shown that any particular airway situation can be calculated by interpolating between the graphs for the conditions most closely resembling that situation.

The simplest way of presenting these graphs is, in fact, to store them in a new computer programme which not only interpolates between the graphs but also performs the integration of temperatures along the length of the airway. The new programme thus calculates air temperatures along any length of airway under any likely set of conditions. The computation time for a single example is usually less than 30 seconds and the information pertaining to the example is easily prepared for the computer. This method of calculation enables the ventilation engineer to consider a wide range of alternatives simply and rapidly so as to arrive at the best method of ventilation in any given case.

A REVIEW OF THE STARFIELD-DICKSON MODEL

The model proposed by Starfield and Dickson considers an airway in cross-section as a square void in an infinite extent of rock. The hangingwall and sidewalls are assumed to be dry while the footwall is, in general, assumed to be wet. A 'wetness factor' f represents the footwall's resistance to evaporation. Thus $f = 1$ corresponds to a thoroughly wet footwall with actual pools of water on its surface, while $f = 0$ describes a perfectly dry footwall. It is felt that $f = 0 \cdot 2$ probably corresponds to a footwall that would subjectively be described as 'damp'.

The temperatures in the rock surrounding the airway are calculated at successive time intervals by a finite difference solution of the equation of heat conduction. Heat and moisture transfer from rock to air is assumed to depend on the rock surface temperatures and the heat and moisture content of the air and is controlled by coefficients of heat and mass transfer which are both functions of the air velocity and of the cross-sectional area of the airway.

The wet and dry bulb gradients are calculated from the heat and moisture transferred, using the appropriate psychrometric equations.

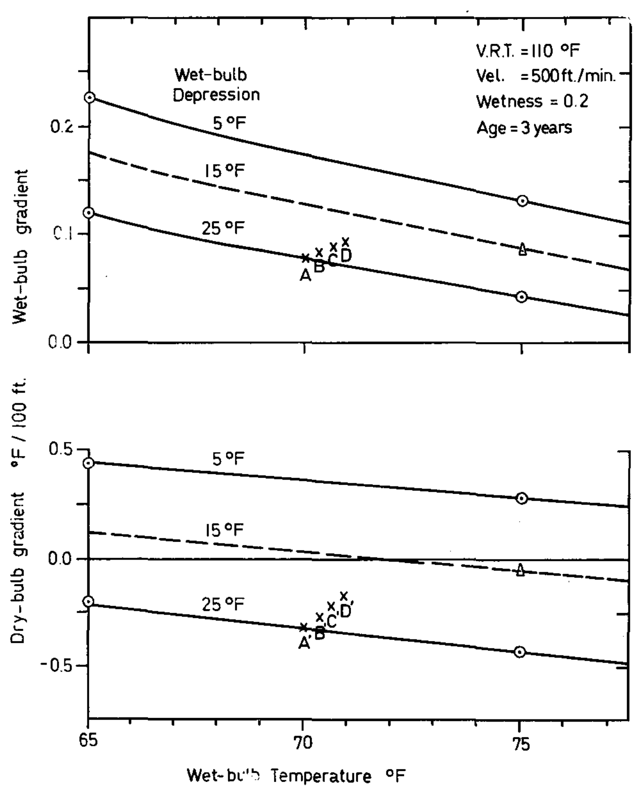


Fig. 1—Gradient graphs from the Starfield-Dickson model

*Professor in the School of Mineral and Metallurgical Engineering, University of Minnesota.

†Work done in Mining Research Laboratory, Chamber of Mines of South Africa.

The results are presented in graphs such as Fig. 1 in which wet and dry bulb gradients are plotted against the wet bulb temperature of the air, for different values of the wet bulb depression (the wet bulb depression is equal to the difference between the dry bulb temperature and the wet bulb temperature). If air enters the airway considered in Fig. 1 at 70/95°F (wet bulb/dry bulb), then points A and A′ would give the wet and dry bulb gradients at the beginning of the airway. These are 0·077°F/100 ft and −0·31°F/100 ft respectively. If it is assumed that these gradients are constant over, say, the first 400 ft of the airway, then after 400 ft the air temperatures will be 70·31/93·76°F and the points B and B′ would give the temperature gradients at the position 400 ft along the airway.

From these the air temperatures could be calculated a further 400 ft along the airway and C and C′ would then give the gradients at a point 800 ft from the beginning of the airway and so on. The shorter the distance calculated at each stage, the greater the accuracy of the answers.

A plot such as Fig. 1 applies only to certain fixed values of each of the following parameters:

Wetness of the footwall
Virgin rock temperature
Thermal conductivity of the rock
Air quantity (c.f.m.)
Perimeter of the airway
Age of airway and the thermal diffusivity of the rock.

It has been shown[1] that the tables of Goch and Patterson[2] provide a reasonably accurate correction factor for the age of the airway (and the rock diffusivity, which can be associated with age in the Goch-Patterson tables). With this exception, a change in any one of the parameters listed above requires the re-calculation of the graphs of Fig. 1. The intrinsic non-linearity of the psychrometric relations prevents the results from being simplified to any compact or dimensionless form.

THE RAPID COMPUTER PROGRAMME

The rapid method of calculation presented in this report is the result of an analysis of some 80 graphs such as Fig. 1. Further details of the analysis are given in Appendix A. The computer-programme based on the analysis has been designed to print-out air temperatures at specified intervals along an airway for virtually any specified conditions. This is accomplished by the following steps:

(i) The programme first stores the information from the analysis described in Appendix A. This information enables the computer to synthesize a whole series of graphs similar to Fig. 1.

(ii) Given the parameters which describe a particular airway, the computer interpolates between those graphs having parameters which most closely resemble those of the airway.

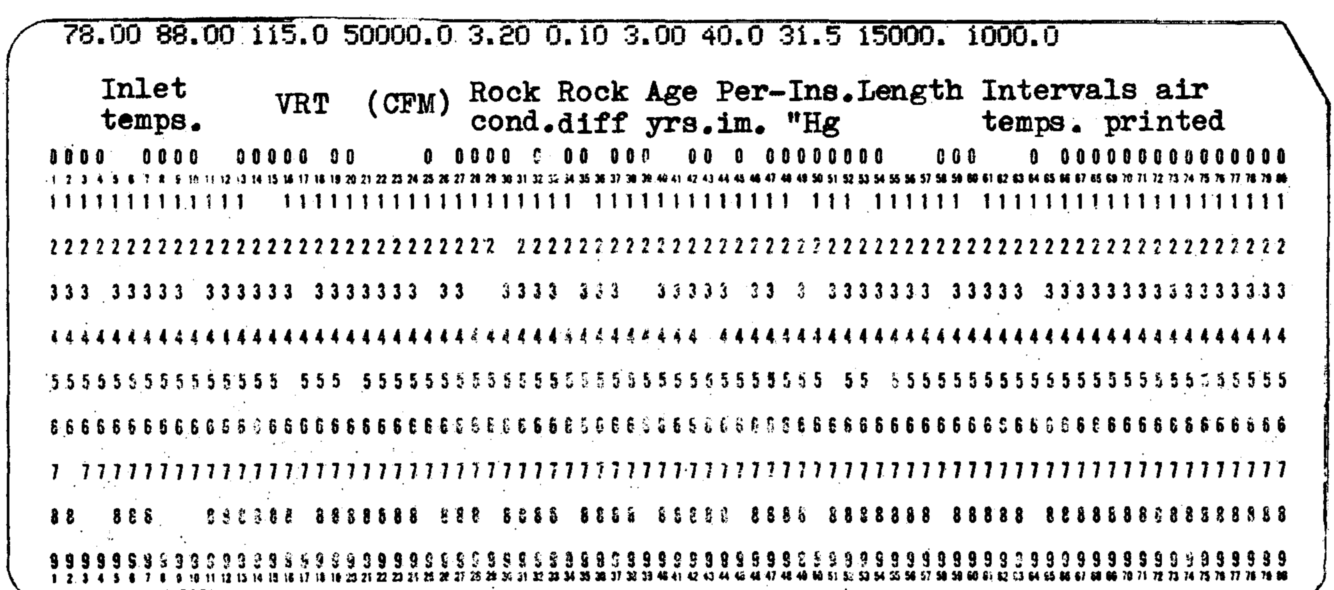
(iii) It then performs the step-by-step calculation of air temperatures along the airway in steps of about 250 ft.

(iv) If the age of the airway differs from that used in the synthesized graphs, the computer applies an age correction to the temperature gradients at each step of the calculation.

A listing of the Fortran programme is given in Appendix B. The only additional input that the programme requires are the parameters specifying the airway. These are punched on a single card in the following order:

Inlet wet and dry bulb temperatures (°F)
Virgin rock temperature (°F)
Air quantity (c.f.m.)
Thermal conductivity of rock (Btu/hr.ft°F)
Thermal diffusivity of rock (ft^2/hr)
Age of airway (years)
Perimeter of airway (ft)
Barometric pressure (in. Hg)
Length of airway (ft)
Intervals at which temperatures are to be printed (ft).

An example of the entries on an input card is the following:



The computer takes approximately 30 seconds to calculate and print the results, an example of the print-out being shown in Table I. By preparing the data for ten or 12 alternative sets of conditions, the engineer can have temperature increases for all of these conditions calculated in a period of four or five minutes.

TABLE I

THE COMPUTER PRINT-OUT

// EXEC

VRT= 115.0 AIR VEL= 50000.0 CFM ROCK COND= 3.20 DIFF= 0.10
AGE= 3.0 YRS PERIM= 40.0 FT PRES= 31.5

DISTANCE(FT)	DRY		DAMP		WET	
	WB	DB	WB	DB	WB	DB
0.0	78.00	88.00	78.00	88.00	78.00	88.00
1000.0	79.20	92.12	79.26	89.55	79.39	86.79
2000.0	80.17	95.50	80.42	90.81	80.80	86.81
3000.0	80.95	98.27	81.50	91.86	82.16	87.39
4000.0	81.57	100.55	82.50	92.76	83.46	88.23
5000.0	82.08	102.41	83.45	93.55	84.66	89.16
6000.0	82.49	103.94	84.35	94.25	85.84	90.11
7000.0	82.82	105.18	85.21	94.89	86.94	91.03
8000.0	83.09	106.20	86.03	95.48	87.98	91.92
9000.0	83.31	107.04	86.81	96.03	88.96	92.76
10000.0	83.49	107.72	87.56	96.55	89.90	93.57
11000.0	83.64	108.27	88.29	97.04	90.81	94.34
12000.0	83.76	108.72	88.99	97.51	91.67	95.08
13000.0	83.85	109.09	89.67	97.96	92.51	95.79
14000.0	83.93	109.40	90.33	98.40	93.31	96.47
15000.0	83.99	109.64	90.97	98.82	94.09	97.13

The programme is accurate for the following range of conditions:

Air quantities of 20,000 to 120,000 c.f.m.
Wet bulb temperatures of 65 to 95°F
Airways with perimeters of 30 to 50 ft
Virgin rock temperatures between 90 and 145°F
Rock conductivities between 2·0 and 4·0 Btu/hr ft°F
and airways older than about one year.

The scope of the computer programme is best illustrated by specific examples.

SOME EXAMPLES

The results of any set of calculations can be presented in a number of different ways depending on the purpose for which they are intended. Figs. 2a and 2b, for example, show the wet bulb temperature calculated along 14,000 ft of an airway in rock at a V.R.T. of 110°F. Two inlet conditions are considered, viz. 80/85°F and 80/100°F, and graphs are plotted for different air quantities and conditions of footwall wetness. Dry bulb temperatures are indicated at specific distances along the airway.

An alternative method of plotting results is that of Fig. 3. In this case the wet bulb temperatures at the end of a 10,000 ft airway with a cross-section of 100 ft², in rock at a V.R.T. of 125°F, are plotted against air quantity for different conditions of footwall wetnesss and different inlet air temperatures. The figure shows, for example, that a wet bulb temperature of 90°F at the end of the airway is attained:

(i) With a wet footwall, 80,000 c.f.m. and inlet temperatures of 80/85 to 80/100°F.

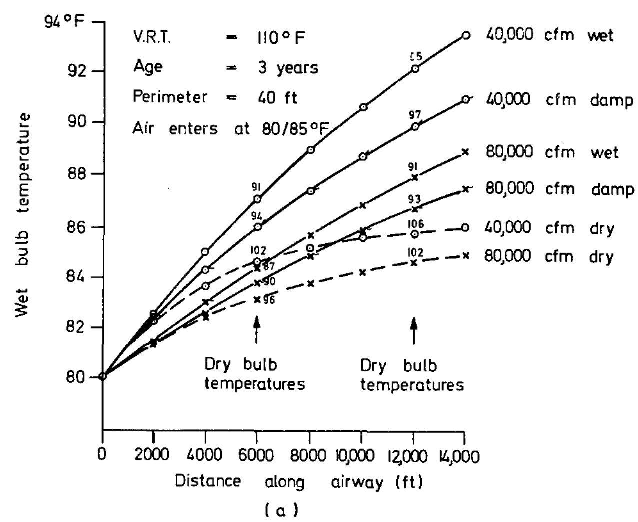
(ii) With a wet footwall, 60,000 c.f.m. and an inlet temperature of 75/85°F.

(iii) With a perfectly dry footwall, 20,000 c.f.m. and an inlet temperature of 80/85°F.

Yet another plot is that of Fig. 4, showing the wet bulb temperature at the end of an airway 10,000 ft long for different virgin rock temperatures (air enters at 80/85°F). Fig. 4 can be used to extrapolate from known conditions at lower rock temperatures to ventilation requirements at greater depths. If the ventilation engineer does not wish to rely on the actual magnitudes of the temperatures calculated by the computer programme, a graph such as Fig. 4 can still be used to compare results at a low V.R.T. with actual experience and then scale the results for a high V.R.T. in the light of this comparison.

Also shown in Fig. 4 are the predictions that would be obtained from the empirical analysis of Lambrechts[3]. It is interesting to note that the empirical predictions are in good agreement with the theoretical results only at low rock temperatures, i.e., only within the range of rock temperatures at which most of the measurements on which the empirical analysis is based were taken. (In all of the above examples the rock surrounding the airway is assumed to be a Witwatersrand quartzite with a thermal conductivity of 3·2 Btu/hr ft°F).

Finally, Fig. 5 shows the large effect that a short length of wet footwall has in an otherwise dry airway. These results were obtained by using calculated air temperatures at the end of the dry section of the airway as input conditions for the wet section.



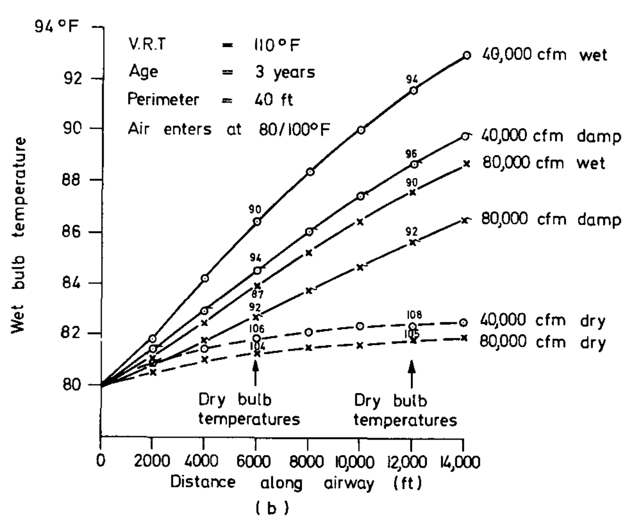


Fig. 2—Air temperatures along an airway 14,000 ft long

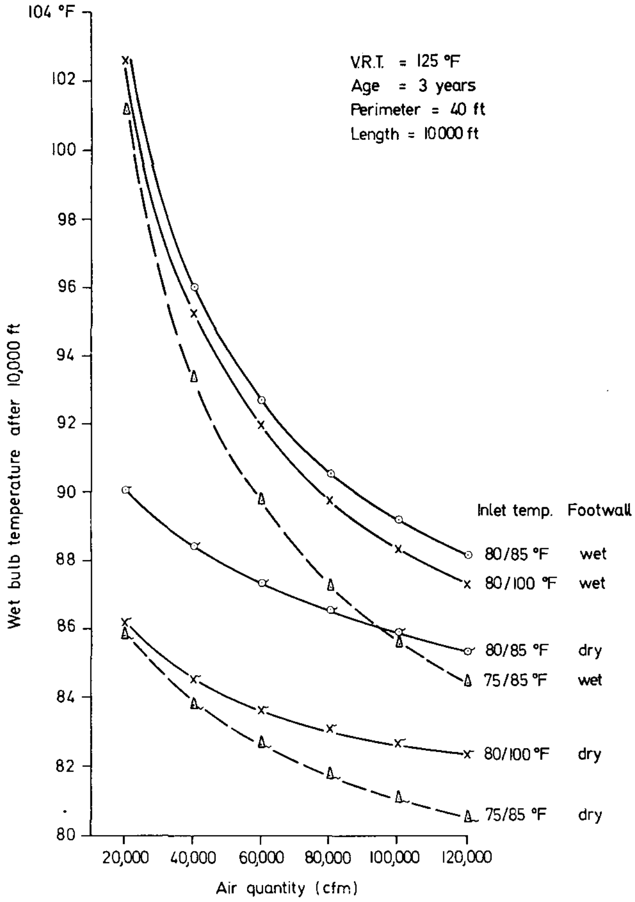


Fig. 3—Wet bulb temperatures at the end of an airway 10,000 ft long for different air quantities

The above calculations are most easily performed at a remote terminal (teletype unit) linked to a central computer*. It is then possible to simply 'call' the rapid programme (which is stored at the central computer), type in the data and watch the results being typed out almost immediately. In fact the availability of both a remote terminal and the programme described in this report would enable an engineer to calculate temperature increases along airways with the same ease with which he usually uses graphs or tables in a hand-book.

ACKNOWLEDGEMENTS

The author would like to thank Miss S. A. Thorpe for her assistance with the computer work.

The work reported in this paper was carried out while the author was employed at the Mining Research Laboratory of the Chamber of Mines of South Africa while on leave of absence from the University of Minnesota.

REFERENCES

1. Starfield, A. M. and Dickson, A. J. 'A study of heat transfer and moisture pick-up in mine airways.' *J. S.Afr. Inst. Min. Metall.*, **68**, (5), 1967.
2. Goch, D. C. and Patterson, H. S. 'The heat flow into tunnels.' *J. Chem. Met. Min. Soc. S.Afr.*, **41**, 1940, 117.
3. Lambrechts, J. de V. 'Prediction of wet bulb temperature gradients in mine airways.' *J. S.Afr. Inst. Min. Metall.*, **67**, 1967, 595-610,
4. Tucker, H. St. G. 'The thermal conductivity of rock.' *J. Mine Vent. Soc. S.Afr.*, **21**, 1968, 179-181.
5. Barenbrug, A. W. T. 'Psychrometry and psychrometric charts.' Tvl. and O.F.S. Chamber of Mines, Johannesburg, 1966.
6. Starfield, A. M., and Dickson, A. J. Authors' reply to discussion: *J. S.Afr. Inst. Min. Metall.*, **69**, (2), 1968, 121.

***This programme is, in fact, available on call under the name MIND 01 at the computation centre of the University of the Witwatersrand. Information on the use of the programme can be obtained either from the Mining Research Laboratory at the Chamber of Mines, or from the Department of Mining at the University.**

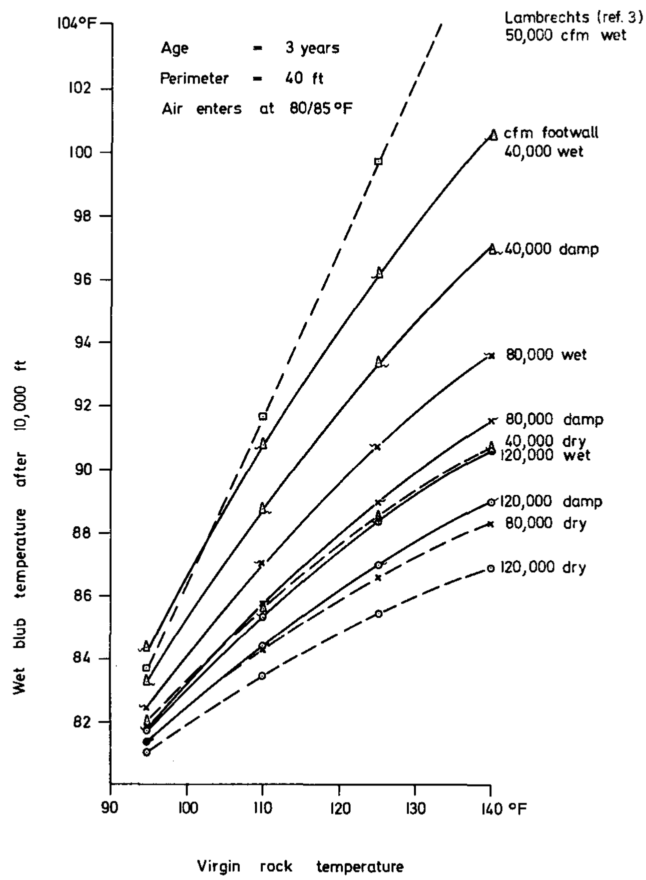


Fig. 4—Wet bulb temperature increases for different virgin rock temperatures

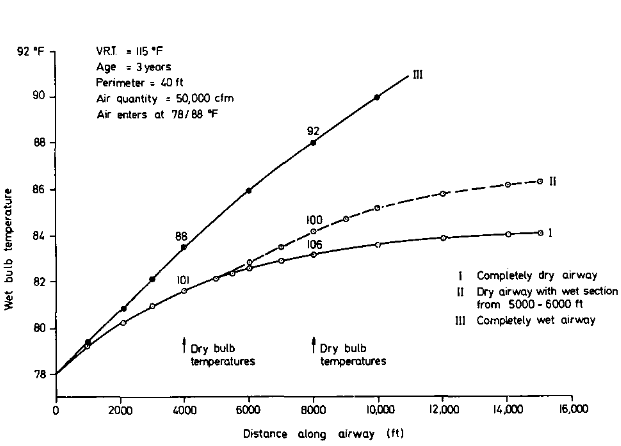


Fig. 5—The influence of a small length of wet footwall on temperature increases along a dry airway

APPENDIX A

ANALYSIS OF RESULTS FROM STARFIELD-DICKSON MODEL

In order to cover the range of conditions likely to be encountered underground, the following values of the various parameters in the Starfield-Dickson model were considered:

1. Footwall wetness	$f=0$ (dry)	$f=0{\cdot}2$ (damp)	$f=1{\cdot}0$ (wet)
2. V.R.T. °F	100	120	140
and associated barometric pressure ″Hg	30	33	36
3. Thermal conductivity of rock[4] Btu/hr ft°F	2·0	3·0	4·0
4. Air quantity, c.f.m.	25,000	50,000	100,000
5. Perimeter, ft	30	40	50
6. Age of airway, years	3		
7. Thermal diffusivity of rock, ft²/hr	0·1		

The influence of each of these variables will now be considered in turn.

Footwall wetness

Fig. 6 shows a typical set of graphs for the three different values of footwall wetness. These graphs show that while the dry bulb gradient at any cross-section is very sensitive to the wetness of the footwall, the wet bulb gradient is insensitive to footwall wetness. This fact is used to simplify the computer description of all three sets of graphs in Fig. 6 as follows:

It will first be assumed that the same set of wet bulb curves (specifically those for $f = 0{\cdot}2$) can be used for all three values of the footwall wetness without significant error. Secondly, since the wet bulb gradient at any point varies very nearly linearly with depression, it will suffice to give the curves for only two values of depression, say 5°F and 20°F. Thirdly, over the range of practically important wet bulb temperatures (65 to 95°F) the wet bulb gradient curves can be approximated by segments of a parabola so that, if θ_W is the wet bulb temperature,

W.B. gradient $= a_1\theta_W^2 + b_1\,\theta_W + c_1$ at a depression of 5°F.

W.B. gradient $= a_2\theta_W^2 + b_2\,\theta_W + c_2$ at a depression of 20°F.

i.e., with interpolation the six constants $a_1, b_1, \ldots c_2$ would reproduce all the wet bulb gradient curves of Fig. 6 to within an accuracy of about 5 to 15 per cent.

The accuracy for the wet case ($f = 1{\cdot}0$) can be improved by multiplying the wet bulb gradients for the damp case ($f = 0{\cdot}2$) by a correction factor C′ which has been obtained as a best fit to a number of curves. This factor is of the form

$$C' = (127 - 0{\cdot}25 \times \text{V.R.T.} + 0{\cdot}000067 \times \text{air quantity} + 0{\cdot}28 \times \text{depression})/100$$

The graphs for the dry bulb gradients are straight lines and again vary nearly linearly with depression. It is thus possible to write

D.B. gradient $= fa_1\theta_W + ga_1$ at a depression of 5°F when $f = 0{\cdot}2$

$= fa_2\theta_W + ga_2$ at a depression of 20°F when $f = 0{\cdot}2$

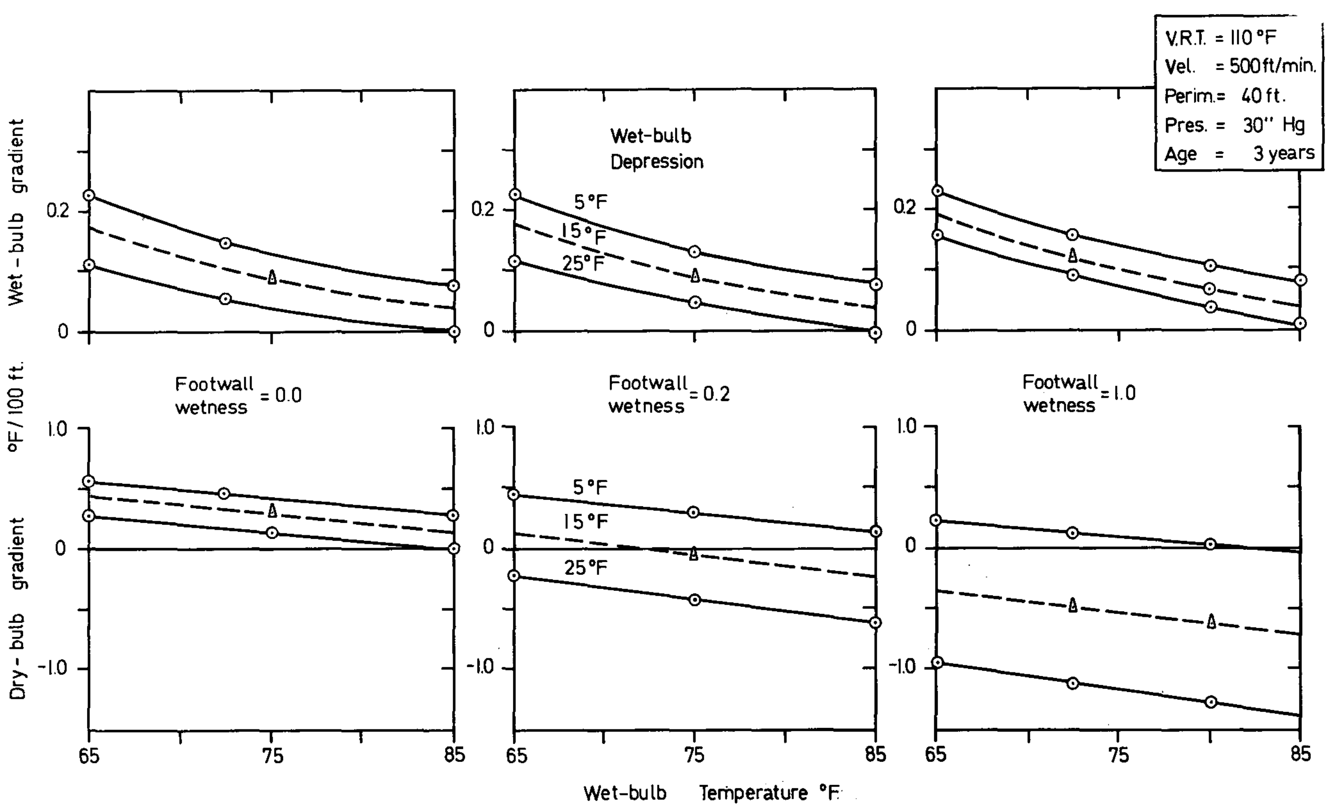


Fig. 6—Dependence of wet and dry bulb gradients on footwall wetness

and

D.B. gradient $= fb_1\theta_W + gb_1$ at a depression of 5°F when $f = 1{\cdot}0$

$= fb_2\theta_W + gb_2$ at a depression of 20°F when $f = 1{\cdot}0$

It is not necessary to specify the dry bulb gradients when $f = 0$ (dry footwall) since, if the wet bulb gradient is known, the dry bulb gradient can be calculated from the psychrometric equations[5], making use of the fact that the absolute humidity of the air must remain constant.

The complete set of graphs in Fig. 6 can thus be synthesized from the 14 constants a_1, b_1 . . . c_2, fa_1, ga_1 . . . gb_2. It is important to note that the observation that the wet bulb gradient at a point is insensitive to the footwall wetness *does not imply* that the wet bulb increase along the airway is insensitive to the wetness of the footwall; temperature increases along an airway depend on both the wet and dry bulb gradients at each cross-section, and the dry bulb gradient *is* sensitive to the wetness of the footwall.

Virgin rock temperature (V.R.T.)

Plots of both wet bulb and dry bulb gradients against V.R.T. for a variety of conditions all showed a markedly linear variation with V.R.T. It was thus sufficient to calculate graphs only for rock temperatures of 100°F and 140°F; the computer then interpolates linearly between these. Fixed values of the barometric pressure have been coupled with the V.R.T. for the calculation of these graphs. It has been shown[1] that the influence of changes in barometric pressure is small.

Again it should be noted that a linear variation of wet and dry bulb gradients with V.R.T. does not imply a linear variation with V.R.T. of temperature increases along a length of airway. The temperature increases will depend on the interaction between wet and dry bulb gradients at each cross-section and these gradients both vary linearly, but not in the same proportion, with V.R.T. This caution applies to all the results of this analysis.

Thermal conductivity of rock

Both wet and dry bulb gradients were linearly dependent on the rock conductivity. A complete set of graphs was thus obtained only for conductivities of 3 and 4 Btu/hr ft°F, and values for other conductivities can be computed by linear interpolation or extrapolation.

Air quantity

Plots of wet and dry bulb gradients versus the reciprocal of the air quantity are nearly, but not quite linear. Graphs for all three values of air quantity were thus calculated, and linear interpolation can be applied depending on the range within which the air quantity falls.

Perimeter

Linear interpolation or extrapolation with the reciprocal of the perimeter is applied to the graphs for perimeters of 40 and 50 ft for a fixed air quantity.

Age of airway and thermal diffusivity of rock

It has been shown[1] that the Goch-Patterson[2] tables for heat flow into a cylindrical cavity provide a satisfactory correction curve for the age of an airway. The Goch-Patterson tables are given in terms of a function T of the dimensionless variable $\alpha t/a^2$, where α is thermal diffusivity, t is time and a the radius of the airway. For square airways it is convenient to use the dimensionless variable $\eta = 16\pi\, \alpha t/P^2$, where P is the perimeter of the airway.

The graphs described above were all calculated for a diffusivity of $0{\cdot}1$ ft²/hr and an age of three years $= 3 \times 365 \times 24$ hours. Suppose that $\eta = \eta_0$ for these conditions. Then for any other values of diffusivity or age, the correction factor C is given by $T(\eta)/T(\eta_0)$. This ratio is calculated using the approximation

$$T(\eta) = 100/[931 + 902{\cdot}5 \log_{10} \eta + 39{\cdot}5 (\log_{10} \eta)^2]$$

which is a good fit to the Goch-Patterson tables for values of η from 10 to 1,000.

The wet bulb gradient is corrected directly by multiplying the computed gradient by C,

e.g., W.B. gradient $= C(a_1\theta_W^2 + b_1\theta_W + c_1)$.

For the dry bulb gradient, it is known that if the dry bulb temperature of the air is exactly equal to the V.R.T., then sensible heat from the air will be converted directly into latent heat for evaporation from the footwall[6]. This process must be independent of time. It follows that the correction to the dry bulb gradient is applied to only part of the expression,

e.g., $fa_1\theta_W + ga_1$ can be written as

$fa_1(\theta_W +$ depression—V.R.T.$) + ga_1 - fa_1 \times$ (depression—V.R.T.)

and only the first term is corrected for age, i.e.,

dry bulb gradient $= C.\, fa_1\, (\theta_W +$ depression—V.R.T.$)$ $+\, ga_1 - fa_1$ (depression—V.R.T.)

APPENDIX B

```
C          RAPID PROGRAM FOR THE CALCULATION OF TEMPERATURE INCREASES
C                             ALONG MINE AIRWAYS
C                             -------------------
      DIMENSION A(4,6,2),B(4,6,2),C(4,6,2),FA(4,6,2),GA(4,6,2),FB(4,6,2)
      DIMENSION GB(4,6,2),DW1(2),DW2(2),DW3(2),DW4(2),DW5(2),DR1(2)
      DIMENSION DR2(2),DR3(2),DR4(2),DR5(2),DB(3),WB(3)
      CRN(X)=1000./(931.+ALOG10(X)*(902.5+39.5*ALOG10(X)))
C     ------------------------------------------------------------------
C     INPUT OF CONSTANTS TO SYNTHESIZE 72 STARFIELD-DICKSON GRAPHS
C     (A LISTING OF THESE CONSTANTS IS GIVEN AT THE END OF THE PROGRAM)
C        K = 1,2      DEPRESSION = 5, 20
C        J = 1,2,3      AIR QUANTITY = 25000, 50000, 100000    VRT=100
C        J = 4,5,6      AIR QUANTITY = 25000, 50000, 100000    VRT=140
C        I = 1,2      CONDUCTIVITY = 3, 4       PERIMETER = 40 FT
C        I = 3,4      CONDUCTIVITY = 3, 4       PERIMETER = 50 FT
C     ------------------------------------------------------------------
      DO2N=1,96
      READ(1,3) IND,I,J,K,AA,BB,CC,DD
      IF(IND)4,2,5
    4 A(I,J,K)=AA
      B(I,J,K)=BB
      C(I,J,K)=CC
      GOTO2
    5 FA(I,J,K)=AA
      GA(I,J,K)=BB
      FB(I,J,K)=CC
      GB(I,J,K)=DD
    2 CONTINUE
      AP=5.0867E-04
      BP=-4.7008E-02
      CONS=3.613E-04
C     ------------------------------------------------------------------
C     INPUT OF PARAMETERS FOR A PARTICULAR EXAMPLE
C     ------------------------------------------------------------------
   10 READ(1,11) WET,DRY,VRT,VEL,COND,DIFF,AGE,PRM,PRES,FLT,DLTH
      NPL=1+DLTH/333.
      DL=DLTH/NPL
      CORN=0.01*(127.-.25*VRT+.000067*VEL)
C     ------------------------------------------------------------------
C     CALCULATION OF AGE CORRECTION
C     ------------------------------------------------------------------
      TYMA=440330.*0.3/(PRM*PRM)
      TYM= 440330.*DIFF*AGE/(PRM*PRM)
      TYM=CRN(TYM)/CRN(TYMA)
      WRITE(3,12) VRT,VEL,COND,DIFF,AGE,PRM,PRES
C     ------------------------------------------------------------------
C     CALCULATION OF INTERPOLATION FACTORS
C     ------------------------------------------------------------------
      DVT=0.025*(140-VRT)
      DCN=4.0-COND
      DPM=(200/PRM-4.0)
      IF(VEL-50000.)13,13,14
   13 NV=0
      DVL=50000./VEL-1.0
      GOTO15
   14 NV=1
      DVL=100000./VEL-1.0
   15 DO17L=1,3
      WB(L)=WET
   17 DB(L)=DRY
C     ------------------------------------------------------------------
C     CALCULATION OF ABSOLUTE HUMIDITY OF THE AIR
C     ------------------------------------------------------------------
      CON=CONS*PRES
      HUM=WET*(AP*WET+BP)+1.5348-CON*(DRY-WET)
      HUM=CON+1.2112*HUM/(1.2112*DRY+556.58)
      X=0
      WRITE(3,19)
   20 WRITE(3,21)X,(WB(L),DB(L),L=1,3)
      X=X+DLTH
      IF(X-FLT)23,23,10
   23 DO24NX=1,NPL
C     ------------------------------------------------------------------
C     CALCULATION OF WET AND DRY BULB TEMPERATURES FOR DRY, DAMP AND
C     WET CONDITIONS, I.E.  L = 1, 2, 3  RESPECTIVELY
C     ------------------------------------------------------------------
      DO24L=1,3
      W=WB(L)
      DEPV=DB(K)-W-VRT
      DDP=(20.0-DB(L)+W)/15.0
      DO25M=1,2
      DO26IA=1,2
      I=IA+2*(M-1)
      DO27KA=1,2
      DO28JA=1,2
      J=3*(KA-1)+JA+NV
      DO29K=1,2
      DW1(K)=W*(A(I,J,K)*W+B(I,J,K))+C(I,J,K)
      DR1(K)=0
      IF(L-2)29,30,31
   30 DR1(K)=GA(I,J,K)+FA(I,J,K)*(TYM*(W+DEPV)-DEPV)
      GOTO29
   31 DR1(K)=GB(I,J,K)+FB(I,J,K)*(TYM*(W+DEPV)-DEPV)
   29 CONTINUE
      DR2(JA)=DDP*DR1(1)+(1-DDP)*DR1(2)
   28 DW2(JA)=DDP*DW1(1)+(1-DDP)*DW1(2)
      DW3(KA)=DVL*DW2(1)+(1-DVL)*DW2(2)
   27 DR3(KA)=DVL*DR2(1)+(1-DVL)*DR2(2)
      DW4(IA)=DVT*DW3(1)+(1-DVT)*DW3(2)
   26 DR4(IA)=DVT*DR3(1)+(1-DVT)*DR3(2)
      DW5(M)=DCN*DW4(1)+(1-DCN)*DW4(2)
   25 DR5(M)=DCN*DR4(1)+(1-DCN)*DR4(2)
      DW=TYM*(DPM*DW5(1)+(1-DPM)*DW5(2))
      IF(L-2)32,33,35
   32 DR=DW*(2*AP*W+BP+CON)/HUM
      GOTO34
   35 DW=(CORN+.0028*(DB(K)-W))*DW
   33 DR=DPM*DR5(1)+(1-DPM)*DR5(2)
   34 WB(L)=W+.01*DL*DW
   24 DB(L)=DB(L)+.01*DR*DL
      GOTO20
    3 FORMAT(4I3,4E12.5)
   11 FORMAT(3F6.2,F8.1,5F5.2,2F7.1)
   12 FORMAT(//2X,4HVRT=,F6.1,5X,8HAIR VEL=,F9.1,4H CFM,5X,10HROCK COND=
     1,F5.2,2X,5HDIFF=,F5.2/5X,4HAGE=,F5.1,4H YRS,5X,6HPERIM=,F5.1,
     2 3H FT,5X,5HPRES=,F5.1)
   19 FORMAT(//2X,12HDISTANCE(FT),13X,3HDRY,20X,4HDAMP,19X,3HWET/13X,
     1  3(11X,2HWB,7X,2HDB))
   21 FORMAT(2X,F9.1,9X,3(F7.2,F9.2,7X))
      END
```

```
----------------------------------------------------------------
 STANDARD SET OF DATA CARDS    THESE GIVE THE CONSTANTS FOR
 THE SYNTHESIS OF THE STARFIELD-DICKSON GRAPHS
----------------------------------------------------------------
-1  1  1  1 0.20255E-03-0.42759E-01 0.22341E 01 0.0
 1  1  1  1-0.26214E-01 0.23331E 01-0.22500E-01 0.17740E 01
-1  1  2  1 0.11018E-03-0.23035E-01 0.11940E 01 0.0
 1  1  2  1-0.14143E-01 0.12134E 01-0.11929E-01 0.86129E 00
-1  1  3  1 0.61483E-04-0.12700E-01 0.65157E 00 0.0
 1  1  3  1-0.78571E-02 0.63857E 00-0.64286E-02 0.39929E 00
-1  2  1  1 0.25500E-03-0.54085E-01 0.28367E 01 0.0
 1  2  1  1-0.33000E-01 0.29780E 01-0.28357E-01 0.23176E 01
-1  2  2  1 0.13905E-03-0.29240E-01 0.15229E 01 0.0
 1  2  2  1-0.17786E-01 0.15589E 01-0.15000E-01 0.11420E 01
-1  2  3  1 0.77033E-04-0.16001E-01 0.82485E 00 0.0
 1  2  3  1-0.97143E-02 0.81314E 00-0.81429E-02 0.55443E 00
-1  1  1  2 0.14369E-03-0.31338E-01 0.15874E 01 0.0
 1  1  1  2-0.30071E-01 0.18497E 01-0.25714E-01 0.68214E 00
-1  1  2  2 0.53646E-04-0.13069E-01 0.70092E 00 0.0
 1  1  2  2-0.17286E-01 0.92086E 00-0.13643E-01 0.43428E-01
-1  1  3  2 0.13228E-04-0.45445E-02 0.27890E 00 0.0
 1  1  3  2-0.10357E-01 0.43957E 00-0.72857E-02-0.24114E 00
-1  2  1  2 0.21160E-03-0.44490E-01 0.22049E 01 0.0
 1  2  1  2-0.36786E-01 0.23909E 01-0.31857E-01 0.11346E 01
-1  2  2  2 0.90395E-04-0.20157E-01 0.10341E 01 0.0
 1  2  2  2-0.20929E-01 0.12103E 01-0.17000E-01 0.27700E 00
-1  2  3  2 0.30342E-04-0.79295E-02 0.44017E 00 0.0
 1  2  3  2-0.12286E-01 0.58986E 00-0.92143E-02-0.11286E 00
-1  1  4  1 0.36357E-03-0.75976E-01 0.41955E 01 0.0
 1  1  4  1-0.27714E-01 0.34211E 01-0.24500E-01 0.27710E 01
-1  2  5  1 0.19064E-03-0.39885E-01 0.22015E 01 0.0
 1  2  5  1-0.14929E-01 0.17823E 01-0.12643E-01 0.13504E 01
-1  2  6  1 0.10049E-03-0.21056E-01 0.11617E 01 0.0
 1  2  6  1-0.82857E-02 0.93986E 00-0.66429E-02 0.64743E 00
-1  2  4  1 0.46368E-03-0.96929E-01 0.53579E 01 0.0
 1  2  4  1-0.34929E-01 0.43673E 01-0.31000E-01 0.35820E 01
-1  1  5  1 0.24615E-03-0.51431E-01 0.28379E 01 0.0
 1  1  5  1-0.18857E-01 0.22936E 01-0.16357E-01 0.18136E 01
-1  1  6  1 0.12985E-03-0.27173E-01 0.14990E 01 0.0
 1  1  6  1-0.10357E-01 0.12086E 01-0.85000E-02 0.87700E 00
-1  1  4  2 0.29017E-03-0.61540E-01 0.33634E 01 0.0
 1  1  4  2-0.31357E-01 0.28886E 01-0.27429E-01 0.16483E 01
-1  1  5  2 0.14972E-03-0.31900E-01 0.17394E 01 0.0
 1  1  5  2-0.17929E-01 0.14563E 01-0.13786E-01 0.45086E 00
-1  1  6  2 0.76455E-04-0.16439E-01 0.89430E 00 0.0
 1  1  6  2-0.10643E-01 0.71443E 00-0.79286E-02 0.24286E-01
-1  2  4  2 0.37291E-03-0.78980E-01 0.43235E 01 0.0
 1  2  4  2-0.38357E-01 0.37146E 01-0.34143E-01 0.23604E 01
-1  2  5  2 0.19485E-03-0.41397E-01 0.22607E 01 0.0
 1  2  5  2-0.21786E-01 0.19029E 01-0.18071E-01 0.92071E 00
-1  2  6  2 0.10004E-03-0.21421E-01 0.11684E 01 0.0
 1  2  6  2-0.12714E-01 0.95014E 00-0.91429E-02 0.14643E 00
-1  3  1  1 0.21418E-03-0.45361E-01 0.23763E 01 0.0
 1  3  1  1-0.27929E-01 0.25173E 01-0.24286E-01 0.19689E 01
-1  3  2  1 0.11548E-03-0.24275E-01 0.12639E 01 0.0
 1  3  2  1-0.14857E-01 0.12996E 01-0.12714E-01 0.95814E 00
-1  3  3  1 0.64249E-04-0.13337E-01 0.68716E 00 0.0
 1  3  3  1-0.81429E-02 0.68043E 00-0.67143E-02 0.44814E 00
-1  4  1  1 0.26863E-03-0.57150E-01 0.30049E 01 0.0
 1  4  1  1-0.35071E-01 0.31977E 01-0.30429E-01 0.25423E 01
-1  4  2  1 0.14522E-03-0.30693E-01 0.16053E 01 0.0
 1  4  2  1-0.18786E-01 0.16719E 01-0.15929E-01 0.12543E 01
-1  4  3  1 0.80165E-04-0.16769E-01 0.86955E 00 0.0
 1  4  3  1-0.10214E-01 0.87614E 00-0.85000E-02 0.61000E 00
-1  3  1  2 0.16402E-03-0.35111E-01 0.17592E 01 0.0
 1  3  1  2-0.31429E-01 0.20333E 01-0.27929E-01 0.96529E 00
-1  3  2  2 0.69373E-04-0.15821E-01 0.82168E 00 0.0
 1  3  2  2-0.17714E-01 0.10171E 01-0.14643E-01 0.21843E 00
-1  3  3  2 0.21530E-04-0.60034E-02 0.34248E 00 0.0
 1  3  3  2-0.10429E-01 0.49829E 00-0.78571E-02-0.10943E 00
-1  4  1  2 0.23358E-03-0.48628E-01 0.23954E 01 0.0
 1  4  1  2-0.38429E-01 0.26003E 01-0.34286E-01 0.14439E 01
-1  4  2  2 0.10745E-03-0.23210E-01 0.11692E 01 0.0
 1  4  2  2-0.21500E-01 0.13200E 01-0.18214E-01 0.47314E 00
-1  4  3  2 0.41229E-04-0.98453E-02 0.52376E 00 0.0
 1  4  3  2-0.12571E-01 0.66771E 00-0.97143E-02 0.13143E-01
-1  3  4  1 0.38759E-03-0.80983E-01 0.44739E 01 0.0
 1  3  4  1-0.29286E-01 0.36639E 01-0.26357E-01 0.30176E 01
-1  3  5  1 0.20291E-03-0.42428E-01 0.23426E 01 0.0
 1  3  5  1-0.15714E-01 0.19081E 01-0.13571E-01 0.14867E 01
-1  3  6  1 0.10739E-03-0.22478E-01 0.12403E 01 0.0
 1  3  6  1-0.86429E-02 0.10064E 01-0.71428E-02 0.72843E 00
-1  4  4  1 0.29625E-03-0.71334E-01 0.44555E 01 0.0
 1  4  4  1-0.36857E-01 0.46616E 01-0.33286E-01 0.38849E 01
-1  4  5  1 0.26044E-03-0.54431E-01 0.30062E 01 0.0
 1  4  5  1-0.19786E-01 0.24419E 01-0.17286E-01 0.19469E 01
-1  4  6  1 0.13834E-03-0.28928E-01 0.15961E 01 0.0
 1  4  6  1-0.10857E-01 0.12926E 01-0.90714E-02 0.96771E 00
-1  3  4  2 0.31068E-03-0.65809E-01 0.35997E 01 0.0
 1  3  4  2-0.32643E-01 0.31394E 01-0.29286E-01 0.19079E 01
-1  3  5  2 0.10914E-03-0.25197E-01 0.14778E 01 0.0
 1  3  5  2-0.18357E-01 0.15886E 01-0.15071E-01 0.67871E 00
-1  3  6  2 0.82967E-04-0.17758E-01 0.96723E 00 0.0
 1  3  6  2-0.10786E-01 0.79886E 00-0.77857E-02 0.10386E 00
-1  4  4  2 0.39866E-03-0.84295E-01 0.46148E 01 0.0
 1  4  4  2-0.39929E-01 0.40073E 01-0.36429E-01 0.26763E 01
-1  4  5  2 0.20777E-03-0.44081E-01 0.24104E 01 0.0
 1  4  5  2-0.22429E-01 0.20623E 01-0.19000E-01 0.10830E 01
-1  4  6  2 0.10810E-03-0.23052E-01 0.12579E 01 0.0
 1  4  6  2-0.12929E-01 0.10453E 01-0.11071E-01 0.42271E 00
```