3D TURBULENT FLOW AND HEAT TRANSFER IN A VENTILATED COMPRESSOR CAB

by

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ABSTRACT

This report summarises the work concerned the development and application of a PHOENICS-based CFD model for simulating steady, 3d turbulent flow and heat transfer in a ventilated compressor cab. The model allows for heat transfer by conduction, convection and radiation, and the turbulence is represented by an algebraic eddy viscosity model which takes into account viscous effects in low-Reynolds-number regions. Numerical calculations are performed to investigate a modified ventilation system which is designed to reduce the thermal loading on ceiling-mounted heat-sensitive equipment, which shuts down the compressor when the temperature exceeds a critical value. The results of the simulations suggest that the design modification will reduce peak ceiling temperatures by around 15°C, thereby preventing accidental shut-down of the compressor. All the calculations were carried out by using PHOENICS Version 3.1.

CONTENTS

1. INTRODUCTION

The purpose of this report is to describe the work performed by CHAM on behalf of BG plc under CHAM Contract No. 2421/2 and BG Purchase Order No: 450029248. This work concerns the development and application of a CFD model that calculates the flow and heat transfer in a ventilated compressor cab.

The background is that BG wish to use CFD to investigate a proposed modification to the ventilation system of a compressor cab [1]. The cab houses a power unit comprising a compressor, combustor and turbine, and a ventilation system driven by an extractor fan and fed by air-supply grilles. Heat-sensitive detection equipment is located on the ceiling above the power unit which is designed to shut down the installation if the ceiling temperature exceeds a critical value. The current problem with this installation is that in the summer months when the ambient temperature is high, the detection equipment is triggered accidentally because the ceiling temperature exceeds the critical value. The modified ventilation system is designed to rectify the problem, but before authorising engineering work BG would like CFD simulations made in support of the design.

The objectives of the contract are:

- to create a PHOENICS-based CFD model for the calculation of steady, 3d turbulent flow and heat transfer in a ventilated compressor cab;
- to use the model to perform simulations with both the existing and modified ventilation system; and
- to report on the results of the simulations in terms of the computed temperature and velocity fields.

The remainder of this report comprises three further chapters. Chapter 2 summarises the mathematical model, boundary conditions and solution procedure. The results of the computations are presented and discussed in Chapter 3. The report then closes with concluding remarks in Chapter 4. Finally, supplementary material is provided in the references and appendix.

2. MATHEMATICAL MODEL

2.1. Physical Modelling

A three-dimensional model has been developed to simulate the steady flow of air within the compressor cab with convective and radiative heat transfer in the transparent gas medium, and between the power unit and the surrounding external boundaries. The power unit is covered by a couple of steel radiation shields, and the model allows for thermal conduction through these shields. The flow geometry and boundary conditions have been specified by the client.

Conservation equations have been solved for mass, momentum and energy with temperature as dependent variable. The vertical momentum equation allows for buoyancy, as free convection effects are important in low velocity regions with large temperature differences.

The air density is computed from the ideal gas law, while all remaining physical properties have been taken as constant, as follows: air thermal conductivity k_a=* W/mK; air specific heat $C_{p,a}$=* J/kgK; and steel thermal conductivity k_s=*W/mK.

The turbulence effects have been simulated by way of Spalding's algebraic eddy-viscosity model which takes into account viscous effects in low-Reynolds-number regions [2].

Radiative heat transfer has been represented through the IMMERSOL method which involves solution for the radiosity from a Poisson equation [3]. This method provides an economically realisable approximation to the radiative heat transfer process, which is justified for the present engineering application as the modelled geometry is a result of a large number of approximations made by BG plc.

2.2. Geometry and Solution Domain

A Cartesian coordinate system has been employed, and the cab geometry and solution mesh have been created using PHOENICS-VR. The contract calls for two CFD simulations of the compressor cab, one with the existing ventilation system, hereafter cited as Geometry A, and one with a modified ventilation system, hereafter cited as Geometry B.

The cab geometry, as specified by BG [1], is rectangular in plan and in elevation, and L-shaped in side elevation. The power unit is located centrally within the cab, and has been represented by solid rectangular blockages with specified surface temperature distributions [1]. The gas-turbine section of the power unit is enveloped by two separate rectangular radiation shields of 16mm thick mild steel. These shields have been represented as thin plates of zero thickness for the flow calculation, but with due account taken of the conductive and radiative modes of heat transfer. As specified by BG plc, the problem is taken as symmetrical about the gas-tubine axis, so that calculations have been performed over one half of the flow domain only.

The geometry of compressor cab for Geometry A, is shown in Figure 2.1, and in this case the air inflow for the supply grille X is vertically down. Figure 2.2. shows Geometry B with the proposed modification of the ventilation system, i.e: the air inflow for supply grille X is turned through 90° so that the inflow is horizontal and parallel to the axis of the gas turbine.

Figures 2.3 and 2.4 show, respectively the solution meshes employed in the y-z and x-z planes, respectively. The calculations employed 19 cells in the x direction, 40 cells in the y-direction and 40 cells in the z-direction.
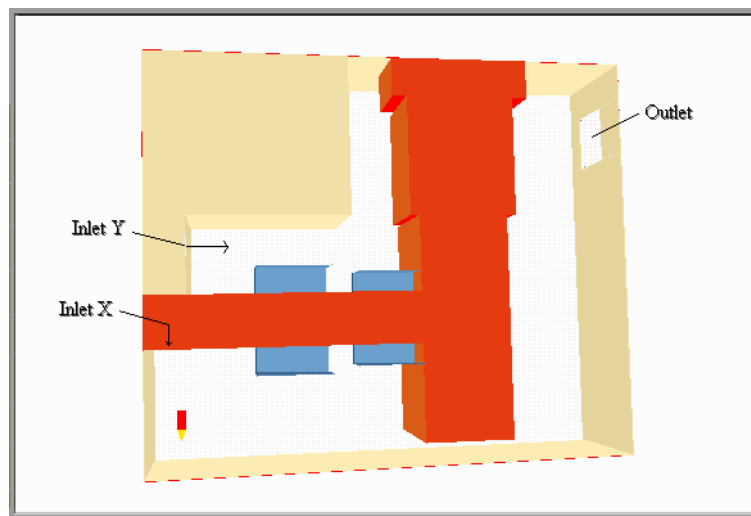
Figure 2.1. Geometry A: Perspective view
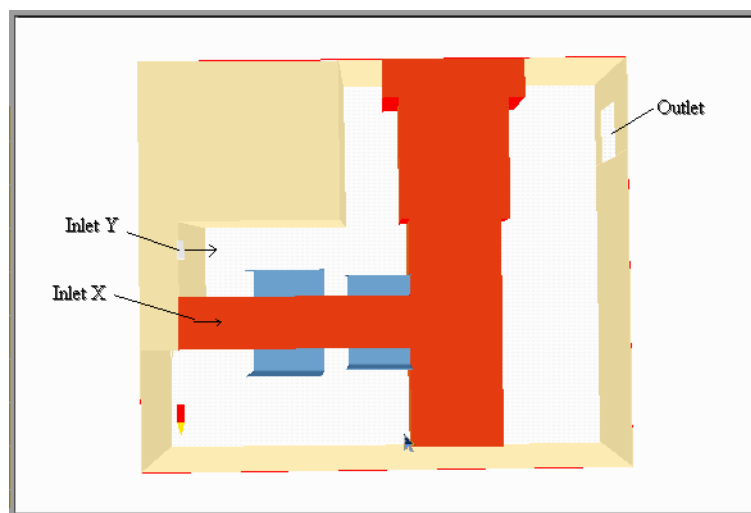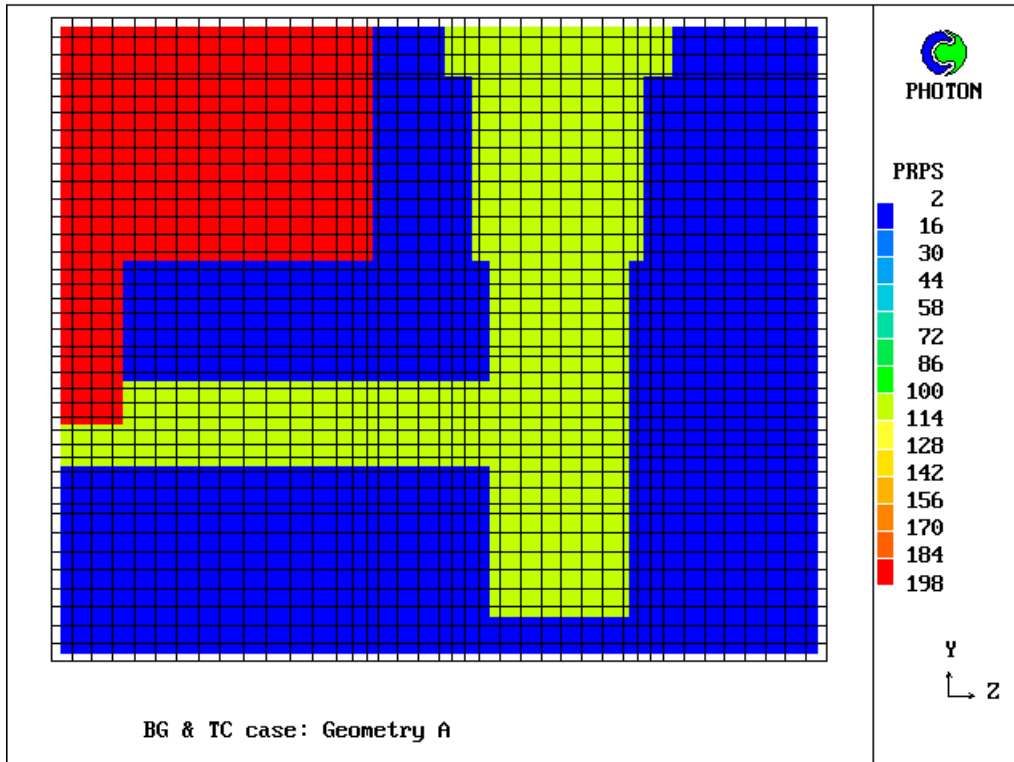

Figure 2.2. Geometry B: Side view

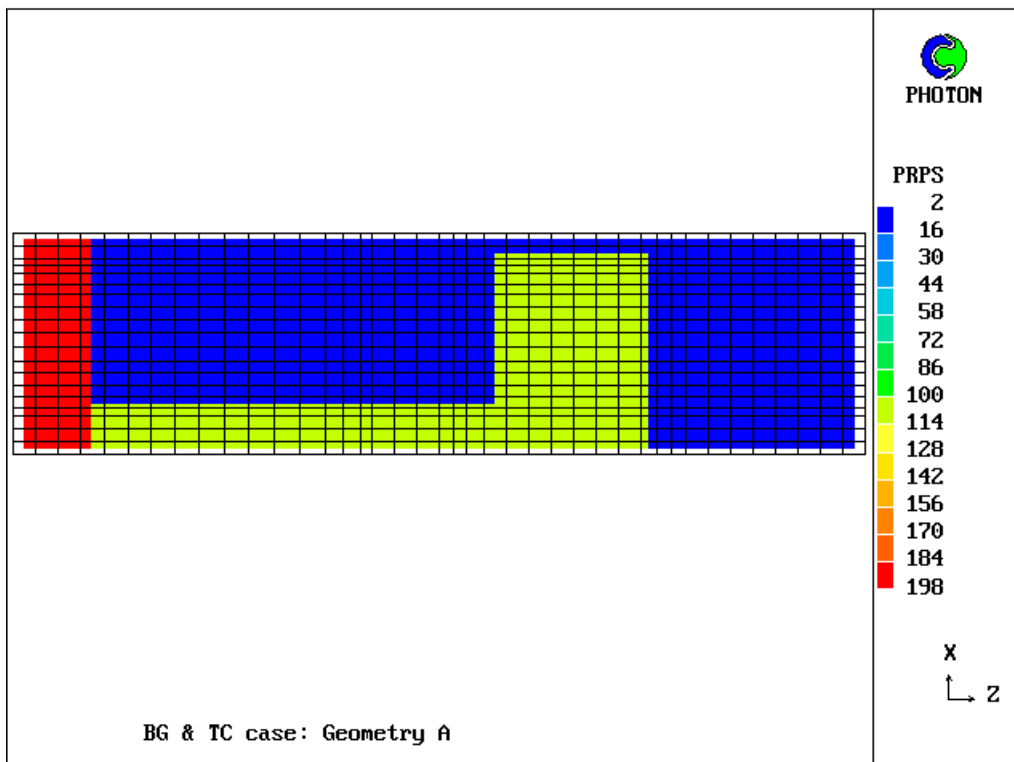**Figure 2.3. Computational mesh in the Y-Z plane**

Figure 2.4. Computational mesh in the X-Z plane

2.3. Boundary Conditions

For one half symmetry, there are two air inlets, X and Y, located on one boundary of the enclosure, and one outlet located on the opposite bounding wall. The mass inflow rate has been specified at inlet X with a uniform velocity of 9.45 m/s. Two types of boundary conditions have been used for inlet Y and outlet areas. At first, a fixed-pressure boundary condition was specified at inlet Y, and a mass outflow rate corresponding to uniform inlet velocity of 13.9 m/s at inlet Y was uniformly distributed over the outlet area. The second type was to specify the mass inflow rates at both inlet X and Y, while a fixed-pressure boundary condition was specified at outlet area.

Preliminary calculations showed that there was no significant differences between the flow fields calculated for the two different types of boundary condition. The second type of boundary condition was employed for the rest of the work.

The incoming air temperatures have been taken as 15°C. The cab enclosure has been presumed perfectly insulated, so that there was no heat transfer through the enclosure boundaries with corresponding radiative boundary conditions being based upon a wall heat balance. The surface temperature around the power unit has been taken as a function of axial distance along the unit increasing linearly from 15°C to 500°C and then reducing linearly to 300°C at the turbine-exhaust boundary, as specified by BG. The surface temperature has been taken as constant around the periphery of the unit at each axial station. The wall emissivity of all surfaces has been taken as 0.85.

2.4. Solution of the Equations

The calculations are performed using PHOENICS V3.1 on a Cartesian mesh using the whole-field solver option for pressure, temperature and radiosity, and the slab-by-slab option for velocities and temperatures.

Two types of relaxation are employed to secure convergence, namely, inertial (or false time step) and linear relaxation.

The computations required about 1000 sweeps using the reported mesh size on a 64MB Pentium Pro 200. The total elapsed computation time for this calculation was about 5 hours.

3. RESULTS AND DISCUSSION

3.1 Presentation of the Results

Results are reported for two simulations, namely, one for the existing ventilation system, Geometry A, and one for the modified ventilation system, Geometry B. The reader is reminded that for the former, the air inflow for supply grille X is vertically down, whereas for the latter the air inflow is horizontal and parallel to the axis of the gas turbine.

For Geometry A, Figures 3.1 to 3.5 display, respectively, the velocity vectors at symmetry plane, at the plane of the X-inlet and on the planes z=0.3m, 2.2m and 3.9m. The temperature contours on the plane of symmetry and at the ceiling are plotted (in ^{o}C) in Figures 3.6 and 3.7.

For Geometry B, Figures 3.8 to 3.12 display, respectively, the velocity vectors at symmetry plane, at the plane of X-inlet and on the planes z=0.3m, 2.2m and 3.9m. The temperature contours on the plane of symmetry and at the ceiling are plotted (in ^{o}C) in Figures 3.13 and 3.14. The biggest number in the legend column of the latter represents the maximum ceiling temperature.

Figure 3.1. Geometry A: Velocity vectors at the symmetry plane
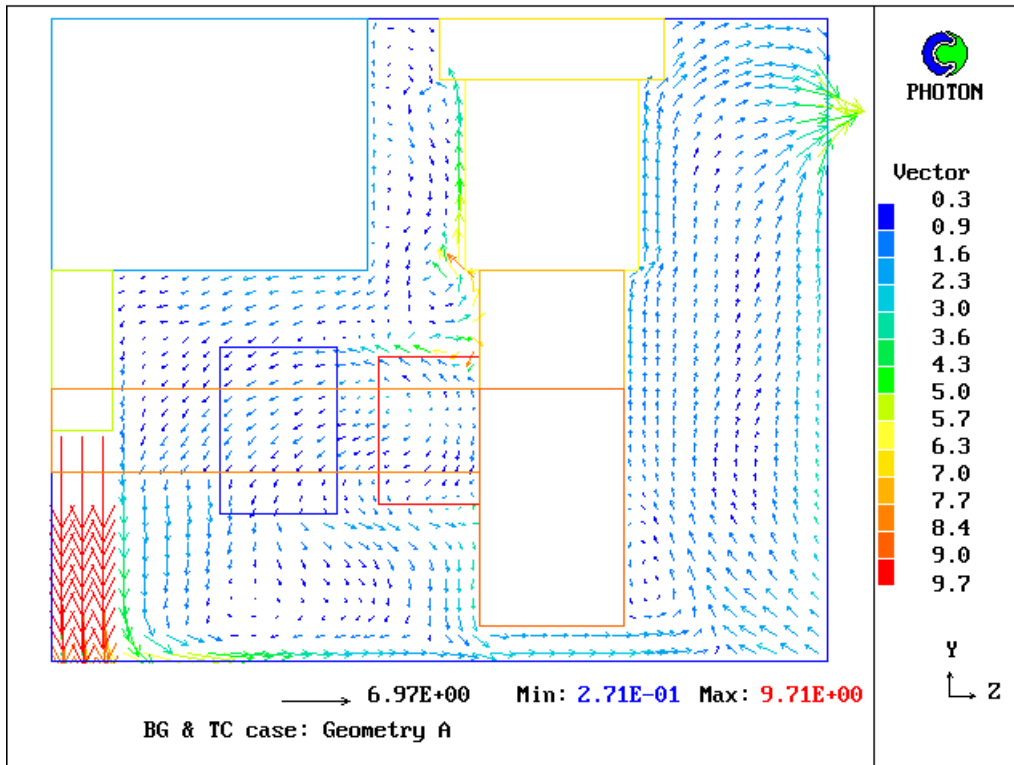
Figure 3.2. Geometry A: Velocity vectors on the plane of X-inlet
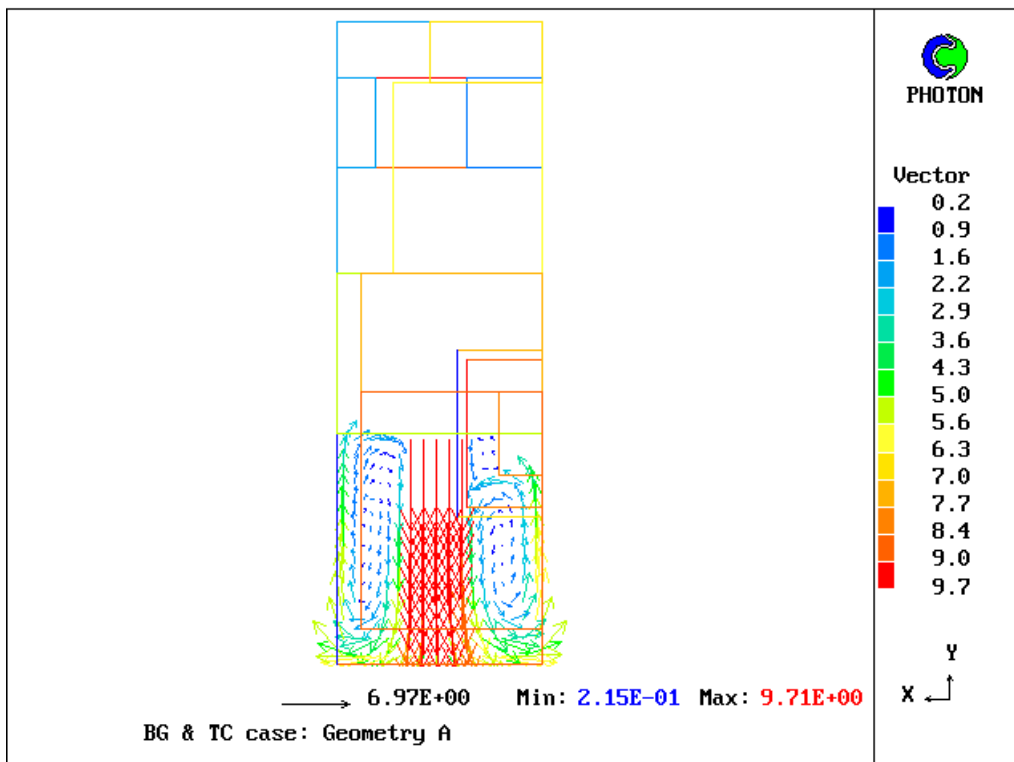
Figure 3.3. Geometry A: Velocity vectors on X-inlet plane: view from Z direction

Figure 3.4. Geometry A: Velocity vectors on the plane Z=2.2 m

Figure 3.5. Geometry A: Velocity vectors on the plane Z=3.9 m

Figure 3.6. Geometry A: Temperature contours on the plane of symmetry

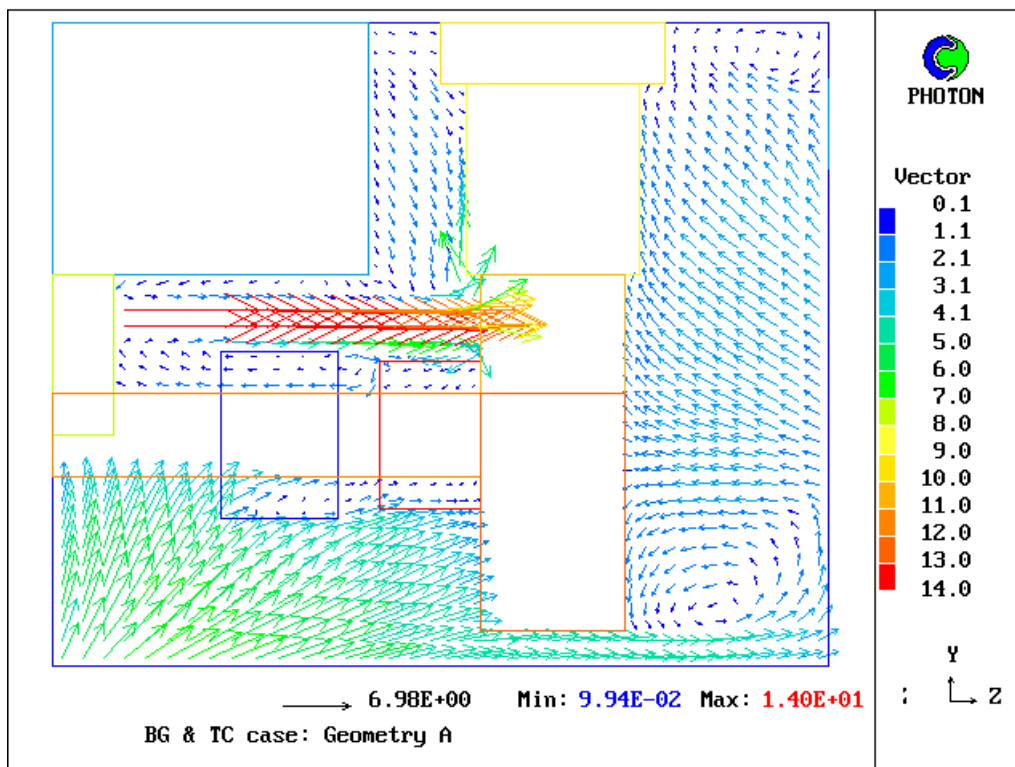**Figure 3.7. Geometry A: Ceiling temperature contours**
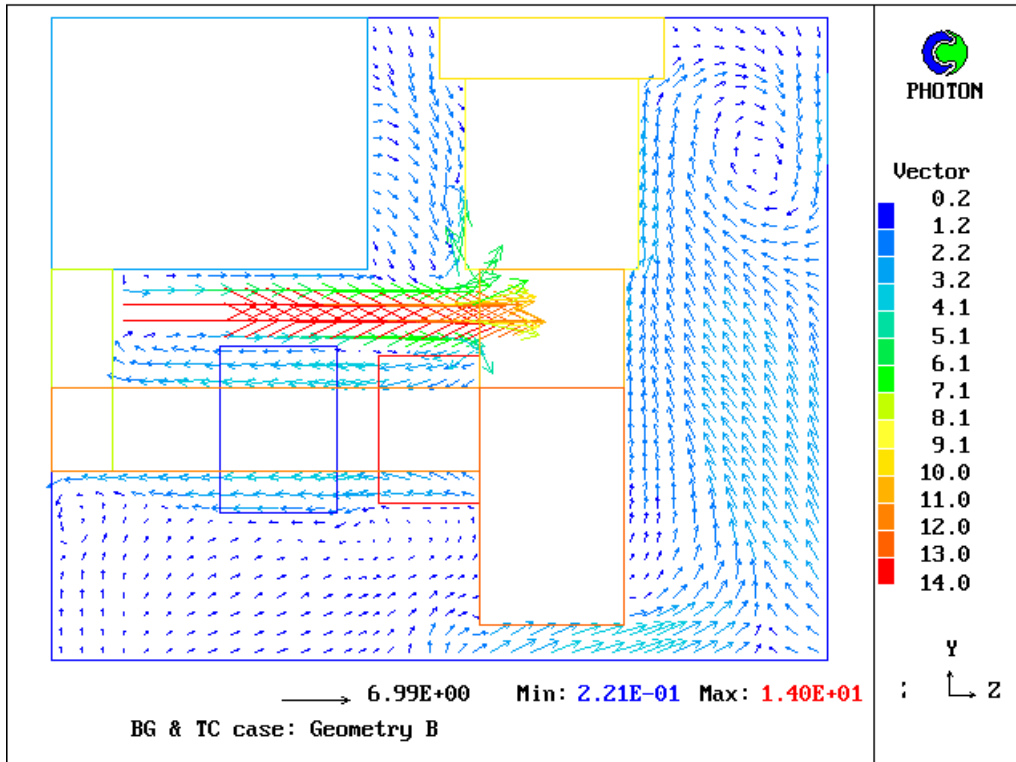
Figure 3.8. Geometry B: Velocity vectors at the symmetry plane
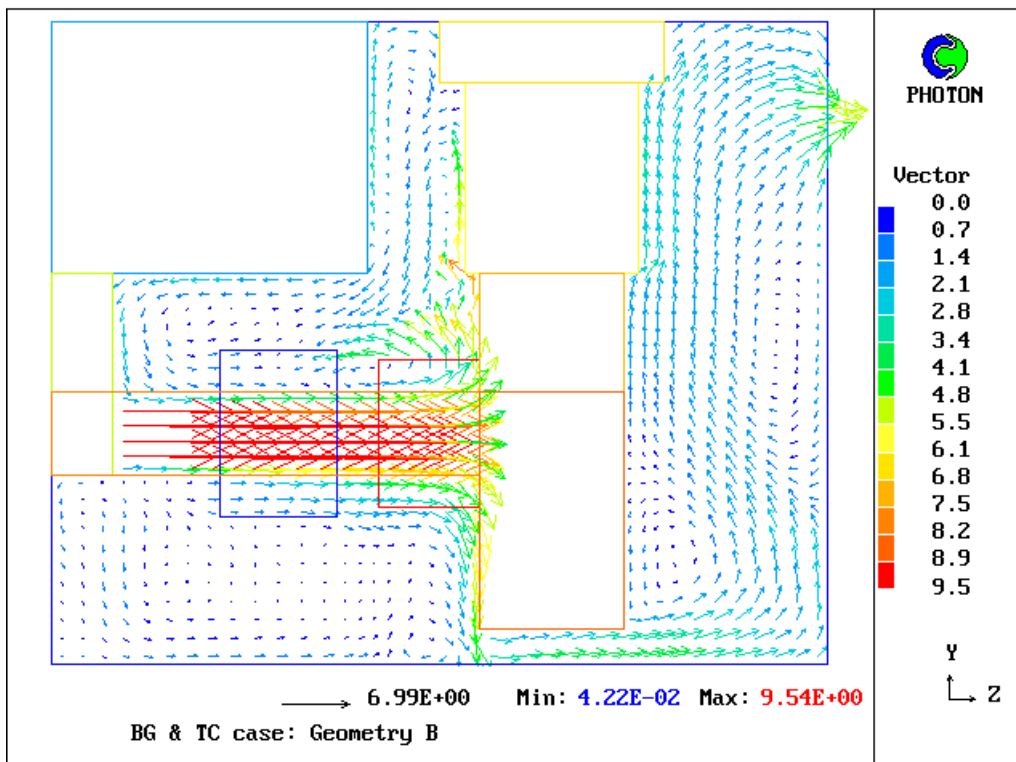
Figure 3.9. Geometry B: Velocity vectors on the plane of X-inlet

3-5
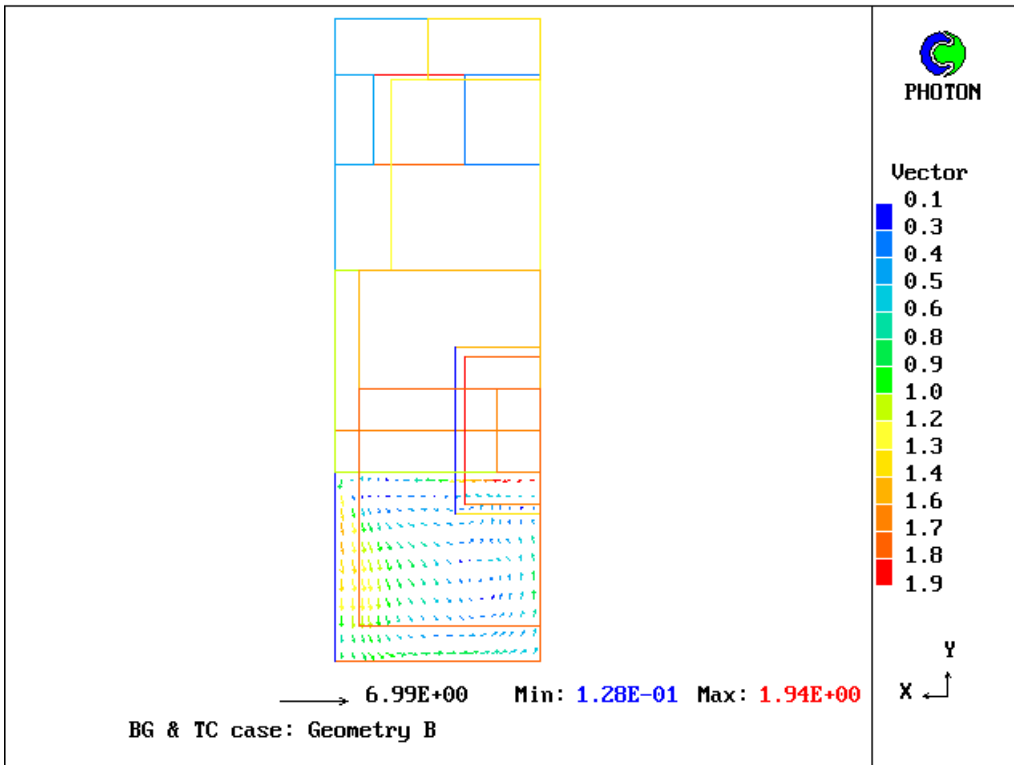
Figure 3.10. Geometry B: Velocity vectors on plane Z=0.3 m
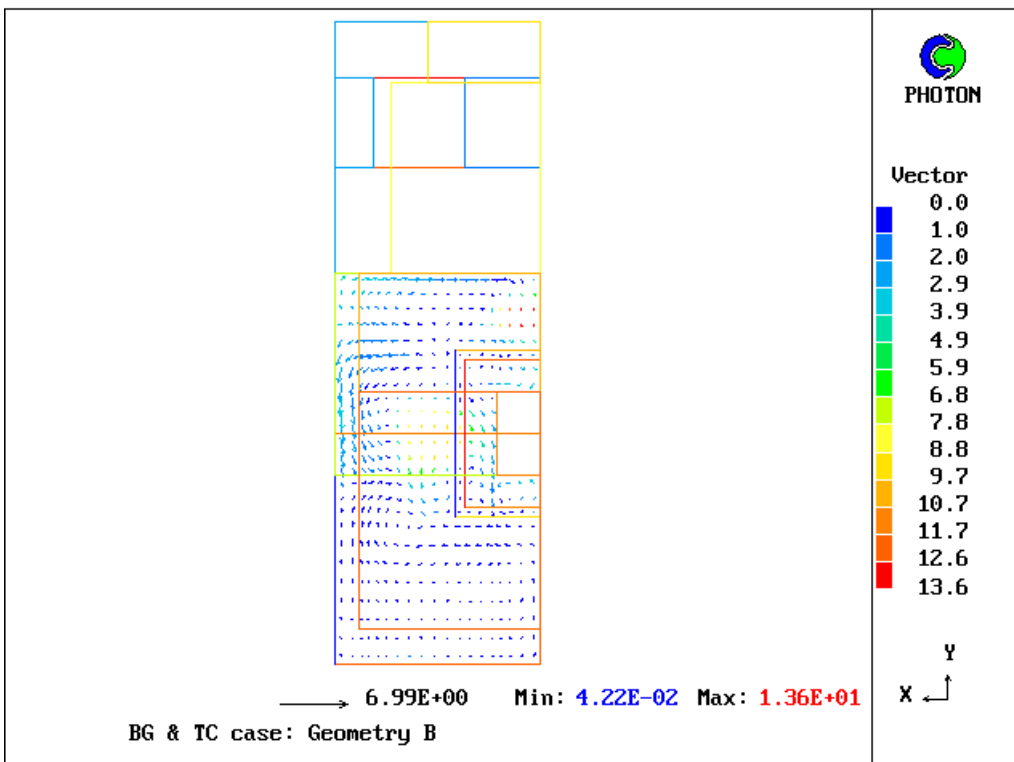
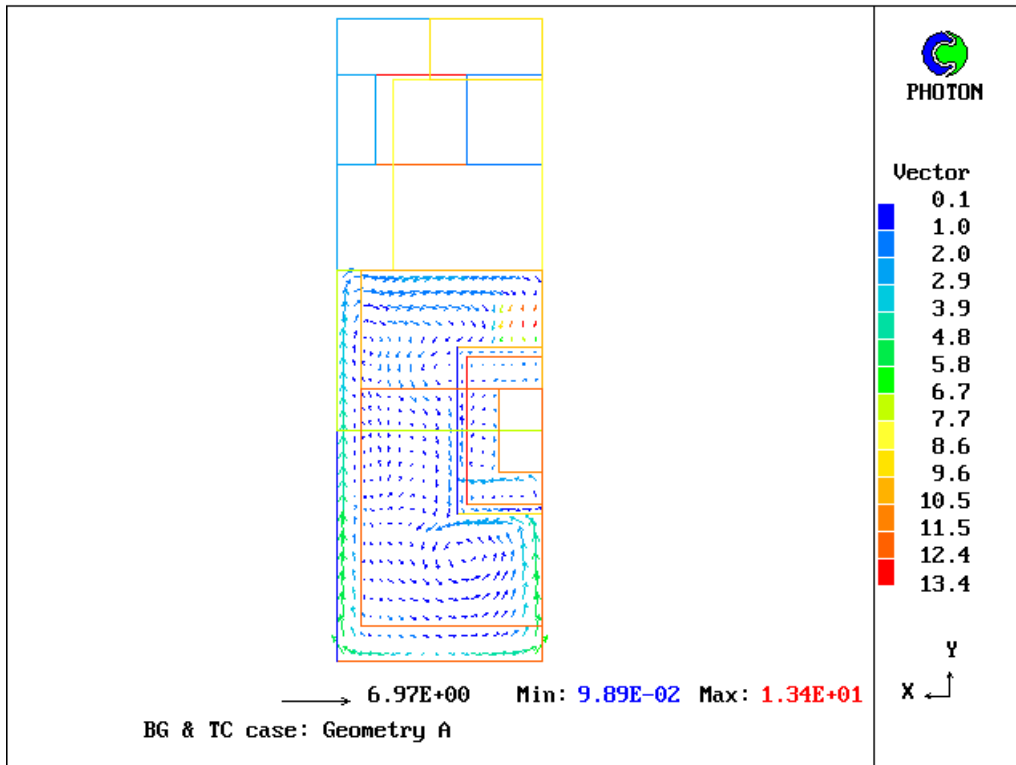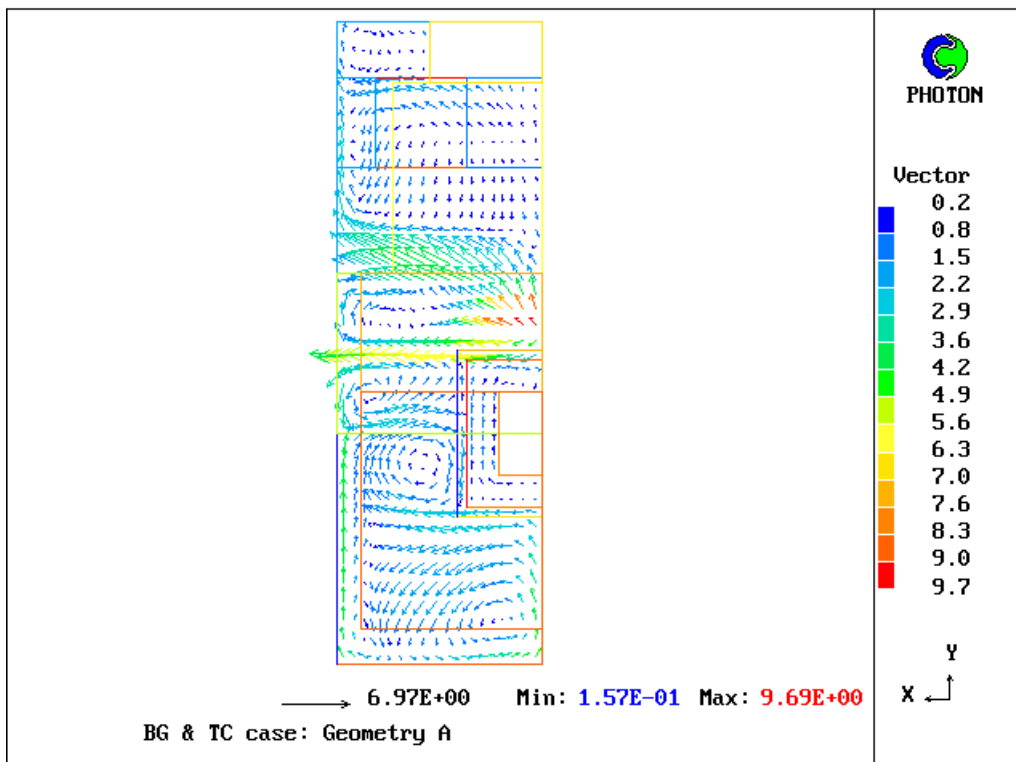**Figure 3.11. Geometry B: Velocity vectors on the plane Z=2.2 m**
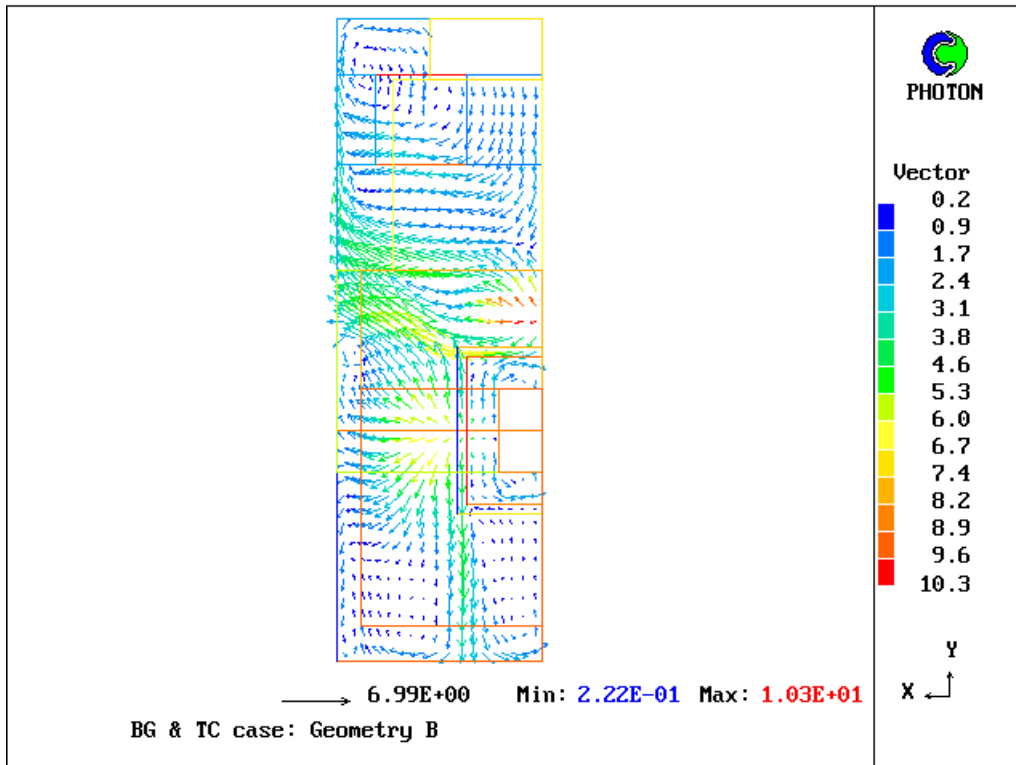
Figure 3.12. Geometry B: Velocity vectors on the plane Z=3.9 m
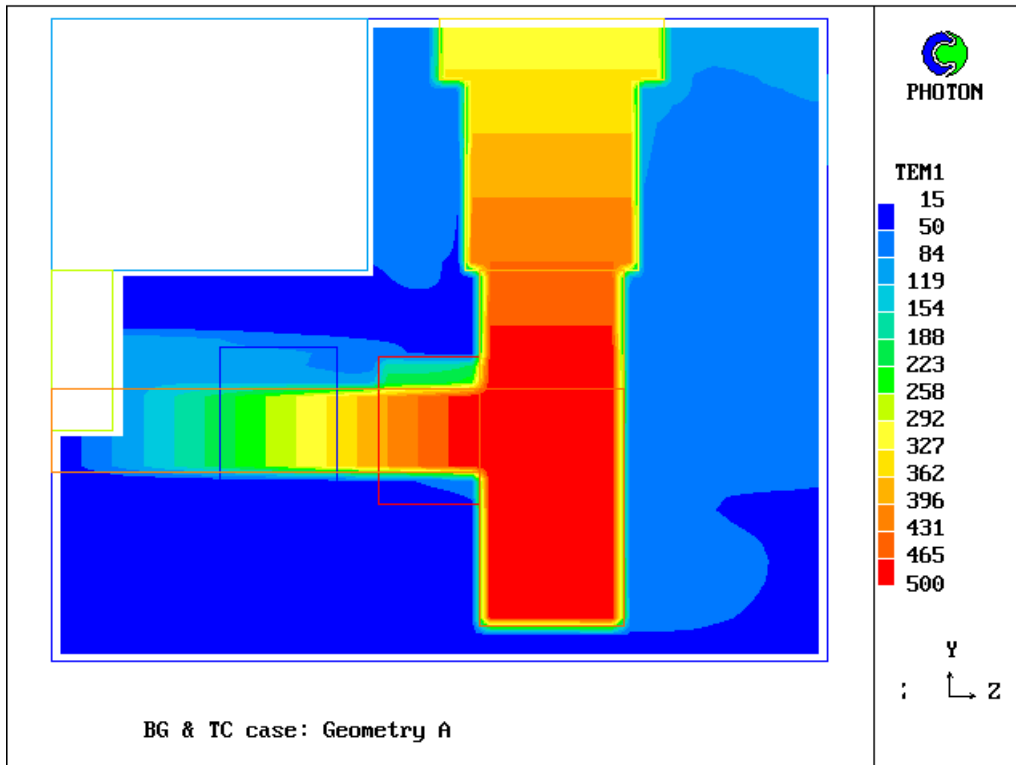

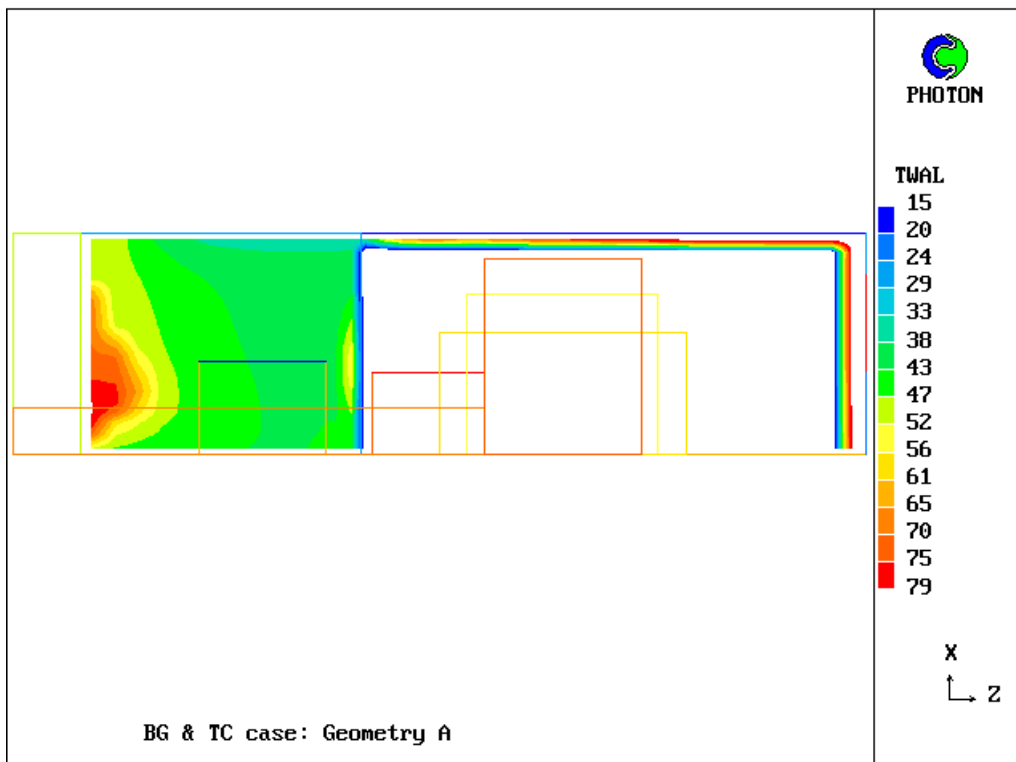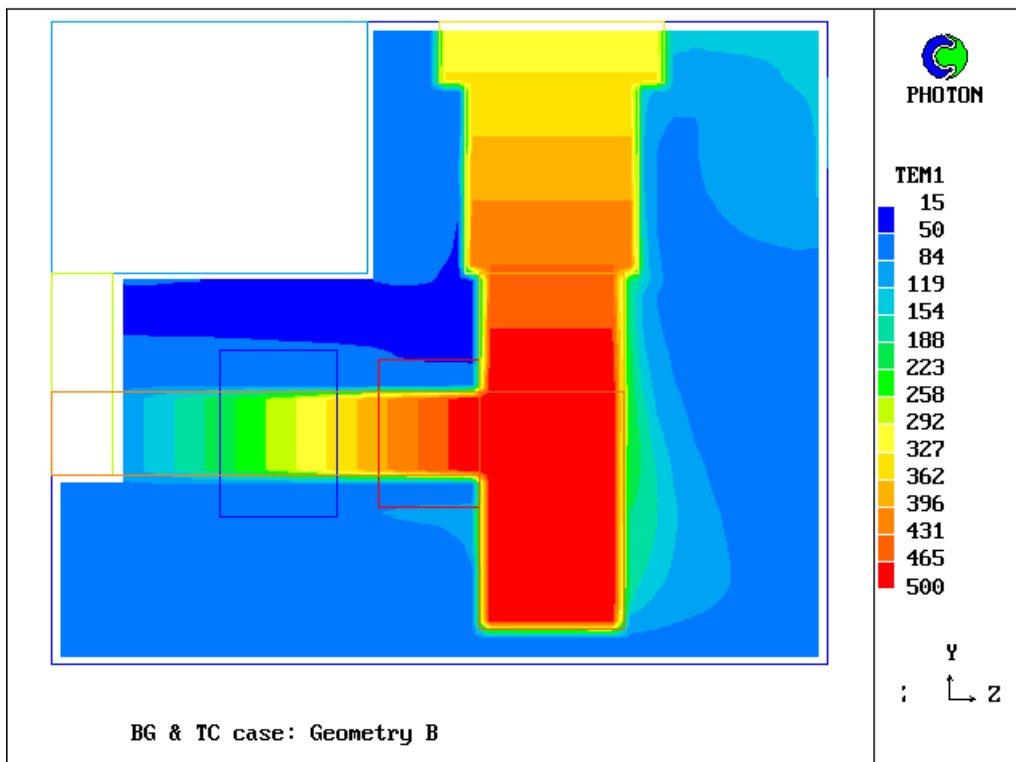**Figure 3.13. Geometry B: Temperature contours on the plane of symmetry**
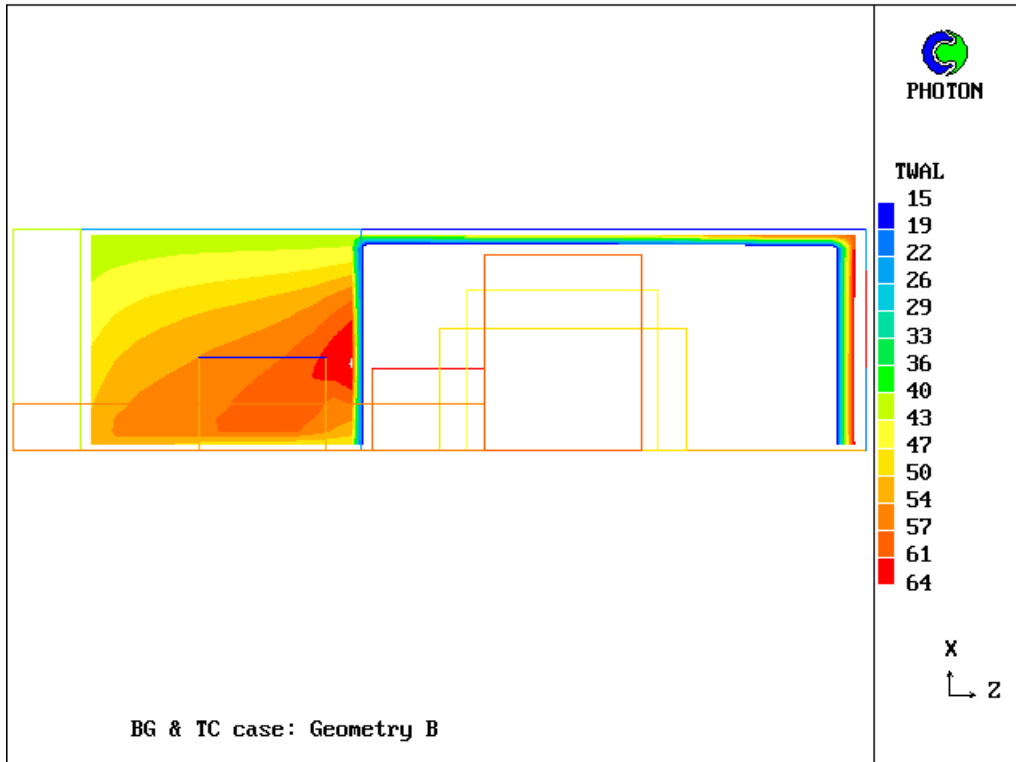
Figure 3.14. Geometry B: Ceiling temperature contours

3.2 Discussion of the Results

The velocity vectors display the expected circulation pattern within the compressor cab. The velocities are relatively low in the outlet compartment, as compared to those in the inlet ducting.

The calculations have shown that the modified ventilation system performed better than existing one, both in terms of decreasing the maximum ceiling temperature by 15°C and in providing a more uniform temperature distribution on the ceiling.

For the existing ventilation system, the ceiling temperature given in Figure 3.7 ranges from 35C to 80C with the highest temperature apparent close to low cab boundary. The figure shows that in this region ceiling temperature is typically about 80°C.

The temperature distribution over ceiling for the modified ventilation system, illustrated in Figure 3.14, shows that the temperature is distributed over ceiling more uniformly as compared with the original design .

The cool air supplied by the horizontal X-inlet in modified ventilation system create the flow pattern which does provide some additional cooling. This results in reducing ceiling temperatures so that they lie in the range of 40 to 65°C.

4. CONCLUDING REMARKS

A three-dimensional model has been developed to simulate the steady flow of air within the compressor cab with convective and radiative heat transfer in transparent gas medium, within partcipating and at non-paticipating solid objects and boundaries.

The created CFD model has been then used to assess the performance of proposed modification to the ventilation system of compressor cab. It was found that the CFD simulations confirmed the expected trends for the modified design of ventilation system.

For the original ventilation system, the computed ceiling temperatures are roughly in the range of 40 to 80°C. The solutions indicate that the new design will reduce the ceiling temperatures so that they lie in the range 40 to 65°C.

5. REFERENCES

1.

2. 'Turbulence Models in PHOENICS; The LVEL Turbulence Model', POLIS Documentation PHOENICS V3.1, (1997)

3. 'Radiative Heat Transfer in PHOENICS; The IMMERSOL model of Radiative Heat Transfer', POLIS Documentation PHOENICS V3.1, (1997)

APPENDIX A: Q1 INPUT FILE

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CPVNAM=VDI;SPPNAM=CORE30
*************************************************************
IRUNN  =     1 ;LIBREF =    14
*************************************************************
 Group 1. Run Title
TEXT(BG & TC case: Geometry B             )
*************************************************************
 Group 2. Transience
STEADY  =   T
*************************************************************
 Groups 3, 4, 5  Grid Information
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RSET(M,19,40,40)
  * Set overall domain extent:
  *      xulast yvlast zwlast   name
XSI= 2.000E+00;YSI= 6.400E+00;ZSI= 7.600E+00;RSET(D,CHAM   )
  * Set objects: x0    y0    z0
  *         dx    dy   dz   name
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XSI= 2.000E+00;YSI= 2.500E+00;ZSI= 3.100E+00;RSET(B,CEILING1)
XPO= 0.000E+00;YPO= 6.400E+00;ZPO= 3.100E+00
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XSI= 4.120E-01;YSI= 8.250E-01;ZSI= 3.600E+00;RSET(B,GAS-TURB)
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XSI= 8.330E-01;YSI= 0.000E+00;ZSI= 1.140E+00;RSET(B,SHIELD2 )
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SOLVE(P1 ,TEM1)
  * Stored variables list
STORE(PRPS)
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SOLUTN(P1 ,Y,Y,Y,N,N,Y)
SOLUTN(TEM1,Y,Y,Y,N,N,Y)
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TEMP0 = 2.730E+02
CP1   = 1.005E+03
ENUL   = 1.000E-05 ;ENUT   = 0.000E+00
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  No PATCHes used for this Group
INIADD =   F
****
 Group 13. Boundary & Special Sources
  No PATCHes used for this Group

BUOYA = 0.000E+00 ; BUOYB =-9.810E+00 ; BUOYC = 0.000E+00
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 Group 15. Terminate Sweeps
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SELREF = T
RESFAC = 1.000E-03
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 Group 17. Relaxation
RELAX(P1 ,LINRLX, 1.000000E+00)
RELAX(TEM1,LINRLX, 1.000000E+00)
****
 Group 19. EARTH Calls To GROUND Station
ASAP = T
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 Group 20. Preliminary Printout
ECHO = T
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 Group 21. Print-out of Variables
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OUTPUT(TEM1,Y,N,Y,N,N,N)
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IXMON =   5 ;IYMON =   3 ;IZMON =   3
NPRMNT =   1
****
 Group 23.Field Print-Out & Plot Control
  No PATCHes used for this Group
****
 Group 24. Dumps For Restarts
NOWIPE =   T

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> OBJ6,   POSITION,   0.000000E+00, 3.550000E-01, 4.200000E+00
> OBJ6,   SIZE,      1.773000E+00, 3.545000E+00, 1.400000E+00
> OBJ6,   CLIPART,    cube4
```

\> OBJ6, ROTATION, 1
\> OBJ6, TYPE, BLOCKAGE
\> OBJ6, MATERIAL, 111
\> OBJ6, HEAT, 0.000000E+00

\> OBJ7, NAME, TURB-EXH
\> OBJ7, POSITION, 0.000000E+00, 3.900000E+00, 4.050000E+00
\> OBJ7, SIZE, 1.450000E+00, 1.900000E+00, 1.700000E+00
\> OBJ7, CLIPART, cube4
\> OBJ7, ROTATION, 1
\> OBJ7, TYPE, BLOCKAGE
\> OBJ7, MATERIAL, 111
\> OBJ7, HEAT, 0.000000E+00

\> OBJ8, NAME, E-WALL1
\> OBJ8, POSITION, 0.000000E+00, 0.000000E+00, 7.600000E+00
\> OBJ8, SIZE, 2.000000E+00, 4.950000E+00, 0.000000E+00
\> OBJ8, CLIPART, cube
\> OBJ8, ROTATION, 1
\> OBJ8, TYPE, PLATE
\> OBJ8, POROSITY, 0.000000E+00
\> OBJ8, HEAT, 0.000000E+00

\> OBJ9, NAME, E-WALL2
\> OBJ9, POSITION, 0.000000E+00, 5.850000E+00, 7.600000E+00
\> OBJ9, SIZE, 2.000000E+00, 5.500002E-01, 0.000000E+00
\> OBJ9, CLIPART, cube
\> OBJ9, ROTATION, 1
\> OBJ9, TYPE, PLATE
\> OBJ9, POROSITY, 0.000000E+00
\> OBJ9, HEAT, 0.000000E+00

\> OBJ10, NAME, OUTLET
\> OBJ10, POSITION, 7.330000E-01, 4.950000E+00, 7.600000E+00
\> OBJ10, SIZE, 9.000000E-01, 9.000000E-01, 0.000000E+00
\> OBJ10, CLIPART, cubet
\> OBJ10, ROTATION, 1
\> OBJ10, TYPE, OUTLET
\> OBJ10, TEMPERATURE, 0.000000E+00
\> OBJ10, PRESSURE, 0.000000E+00
\> OBJ10, COEFFICIENT, 1.000000E+00

\> OBJ11, NAME, SHIELD1
\> OBJ11, POSITION, 0.000000E+00, 1.467000E+00, 1.650000E+00
\> OBJ11, SIZE, 8.330000E-01, 0.000000E+00, 1.140000E+00
\> OBJ11, CLIPART, cube6
\> OBJ11, ROTATION, 1
\> OBJ11, TYPE, NULL

```
> OBJ12, NAME,      SHIELD2
> OBJ12, POSITION,   0.000000E+00, 3.132000E+00, 1.650000E+00
> OBJ12, SIZE,       8.330000E-01, 0.000000E+00, 1.140000E+00
> OBJ12, CLIPART,   cube6
> OBJ12, ROTATION,      1
> OBJ12, TYPE,       NULL

> OBJ13, NAME,      SHIELD3
> OBJ13, POSITION,   0.000000E+00, 1.567000E+00, 3.200000E+00
> OBJ13, SIZE,       7.330000E-01, 0.000000E+00, 9.999998E-01
> OBJ13, CLIPART,   cube6
> OBJ13, ROTATION,      1
> OBJ13, TYPE,       NULL

> OBJ14, NAME,      SHIELD4
> OBJ14, POSITION,   0.000000E+00, 3.032000E+00, 3.200000E+00
> OBJ14, SIZE,       7.330000E-01, 0.000000E+00, 9.999998E-01
> OBJ14, CLIPART,   cube6
> OBJ14, ROTATION,      1
> OBJ14, TYPE,       NULL

> OBJ15, NAME,      TURB-EX2
> OBJ15, POSITION,   0.000000E+00, 5.800000E+00, 3.800000E+00
> OBJ15, SIZE,       1.100000E+00, 6.000000E-01, 2.200000E+00
> OBJ15, CLIPART,   cube4
> OBJ15, ROTATION,      1
> OBJ15, TYPE,       BLOCKAGE
> OBJ15, MATERIAL,   111
> OBJ15, HEAT,        0.000000E+00

> OBJ16, NAME,      SHIELD6
> OBJ16, POSITION,   8.330000E-01, 1.467000E+00, 1.650000E+00
> OBJ16, SIZE,       0.000000E+00, 1.665000E+00, 1.140000E+00
> OBJ16, CLIPART,   cube6
> OBJ16, ROTATION,      1
> OBJ16, TYPE,       NULL

> OBJ17, NAME,      SHIELD5
> OBJ17, POSITION,   7.330000E-01, 1.567000E+00, 3.200000E+00
> OBJ17, SIZE,       0.000000E+00, 1.465000E+00, 9.999998E-01
> OBJ17, CLIPART,   cube6
> OBJ17, ROTATION,      1
> OBJ17, TYPE,       NULL

> OBJ18, NAME,      BK-WALL
> OBJ18, POSITION,   2.000000E+00, 0.000000E+00, 0.000000E+00
> OBJ18, SIZE,       0.000000E+00, 6.400000E+00, 7.600000E+00
> OBJ18, CLIPART,   cubet
> OBJ18, ROTATION,      1
```

> OBJ18, TYPE,   PLATE
> OBJ18, POROSITY,   0.000000E+00
> OBJ18, HEAT,   0.000000E+00

> OBJ19, NAME,   E-WALL3
> OBJ19, POSITION,   0.000000E+00, 4.950000E+00, 7.600000E+00
> OBJ19, SIZE,   7.330000E-01, 9.000001E-01, 0.000000E+00
> OBJ19, CLIPART,   cube
> OBJ19, ROTATION,   1
> OBJ19, TYPE,   PLATE
> OBJ19, POROSITY,   0.000000E+00
> OBJ19, HEAT,   0.000000E+00

> OBJ20, NAME,   E-WALL4
> OBJ20, POSITION,   1.633000E+00, 4.950000E+00, 7.600000E+00
> OBJ20, SIZE,   3.670000E-01, 9.000001E-01, 0.000000E+00
> OBJ20, CLIPART,   cube
> OBJ20, ROTATION,   1
> OBJ20, TYPE,   PLATE
> OBJ20, POROSITY,   0.000000E+00
> OBJ20, HEAT,   0.000000E+00

> OBJ21, NAME,   BLOCK3
> OBJ21, POSITION,   0.000000E+00, 1.888000E+00, 0.000000E+00
> OBJ21, SIZE,   2.000000E+00, 2.012000E+00, 6.000000E-01
> OBJ21, CLIPART,   cube
> OBJ21, ROTATION,   1
> OBJ21, TYPE,   BLOCKAGE
> OBJ21, MATERIAL,   198

> OBJ22, NAME,   INLETX
> OBJ22, POSITION,   7.330000E-01, 2.000000E+00, 6.000000E-01
> OBJ22, SIZE,   6.000000E-01, 5.999999E-01, 0.000000E+00
> OBJ22, CLIPART,   cube2
> OBJ22, ROTATION,   1
> OBJ22, TYPE,   NULL

> OBJ23, NAME,   INLETY
> OBJ23, POSITION,   0.000000E+00, 3.316000E+00, 6.000000E-01
> OBJ23, SIZE,   3.500000E-01, 3.000000E-01, 0.000000E+00
> OBJ23, CLIPART,   cube2
> OBJ23, ROTATION,   1
> OBJ23, TYPE,   NULL

M
STOP

PATCH(INLET-X, LOW , 8 , 12 , 13 , 16 , 4 , 4 , 1 , 1)
COVAL(INLET-X, P1 , FIXFLU , 1.227*9.45)

```
COVAL(INLET-X, W1 , 0.0 , 9.45)
COVAL(INLET-X, TEM1 , 0.0 , 15.)

PATCH(INLET-Y, LOW , 1 , 3 , 22 , 23 , 4 , 4 , 1 , 1 )
COVAL(INLET-Y, P1 , FIXFLU ,1.227*13.9 )
COVAL(INLET-Y,W1,0.0,13.9)
COVAL(INLET-Y, TEM1 ,0.0, 15.)

PRESRELF=SKIP

RELAX(P1  ,LINRLX, 5.0E-1)
RELAX(TEM1,falsdt, 0.5)
RELAX(U1,FALSDT.0.01)
RELAX(V1,FALSDT.0.01)
RELAX(W1,FALSDT.0.01)

STORE(ENUT)
STORE(TWAL)
FIINIT(TEM1)=15.
FIINIT(V1)=1;
FIINIT(W1)=1.
FIINIT(U1)=1.
IXMON=11;IYMON=25;IZMON=15
LSWEEP=2000

    * IMMERSOL settings
  ** declarations needed for many immersol examples **
REAL(QRAD,WSL1,WSL2,WGAP,THOT,TCLD,EPSH,EPSC)
REAL(OPTHI,KROSS,TGHT,TGCL,KGAS,NN1,NN2,AA1,AA2)
REAL(HHOT,HCLD,CP111,CP112)
REAL(SIZX,SIZZ,SIZY,UIN)
REAL(QCNV,AEPSH,AEPSC,NNH,NNC,TGH,TGC)
REAL(LENG1,LENG2,GAP,WPLT)
REAL(EPSM1,EPSM2,EPSW1,EPSW2,REYNO)
REAL(SPH0,TAIR,TFUEL,TWALL,HAIRIN,CPAIR,CPPR,DTF)
REAL(CPFU,WAIR,WFU,WPR,GRHO,STOIC,FSTOI,HFU,TKEI1,EPSI1,FINF,HI
NF)

REAL(SIGMA,SCAT,ABSORB); SIGMA = 5.6697E-8; SCAT=0.0; ABSORB = 0.0
SOLVE(T3); STORE(WGAP)
DISWAL
TERMS(T3,N,N,Y,N,Y,N)
ABSORB= 1.0;   SCAT= 0.0;  EPSH= 0.85;    EPSC= 0.85

STORE(QRX)
STORE(QRY)
STORE(QRZ)

SOLUTN(T3,Y,Y,Y,P,P,P)
```

PRNDTL(T3)=condfile

RADIA= ABSORB; RADIB= SCAT; RSG41=1.E4

  ** Floor: South boundary
PATCH(IMSWSB,SWALL,1,NX,1,1,1,NZ,1,1)
COVAL(IMSWSB,T3,GRND4,GRND5)
COVAL(IMSWSB,TEM1,GRND2,GRND5)

  ** North boundary
PATCH(IMSWNB,NWALL,1,NX,NY,NY,1,NZ,1,1)
COVAL(IMSWNB,T3,GRND4,GRND5)
COVAL(IMSWNB,TEM1,GRND2,GRND5)

  ** East boundary
PATCH(IMSWEB,EWALL,NX,NX,1,NY,1,NZ,1,1)
COVAL(IMSWEB,T3,GRND4,GRND5)
COVAL(IMSWEB,TEM1,GRND2,GRND5)

  ** Low boundary
PATCH(IMSWLB,LWALL,1,NX,1,NY,1,1,1,1)
COVAL(IMSWLB,T3,GRND4,GRND5)
COVAL(IMSWLB,TEM1,GRND2,GRND5)
  ** High boundary
PATCH(IMSWH1,HWALL , 1, NX, 1, 31, 40, 40, 1, 1)
COVAL(IMSWH1,T3 , GRND4 , GRND5)
COVAL(IMSWH1,TEM1, GRND2 , GRND5)

PATCH(IMSWH2,HWALL , 1, NX, 38, 40, 40, 40, 1, 1)
COVAL(IMSWH2,T3 , GRND4 , GRND5)
COVAL(IMSWH2,TEM1, GRND2 , GRND5)

PATCH(IMSWH3,HWALL , 1, 7, 32, 37, 40, 40, 1, 1)
COVAL(IMSWH3,T3 , GRND4 , GRND5)
COVAL(IMSWH3,TEM1, GRND2 , GRND5)

PATCH(IMSWH4,HWALL , 16, NX, 32, 37, 40, 40, 1, 1)
COVAL(IMSWH4,T3 , GRND4 , GRND5)
COVAL(IMSWH4,TEM1, GRND2 , GRND5)

   ** Ceiling low wall
PATCH(IMSWLC ,LWALL , 1, NX, 26, NY, 16, 16, 1, 1)
COVAL(IMSWLC,T3 , GRND4 , GRND5)
COVAL(IMSWLC,TEM1, GRND2 , GRND5)

   ** Ceiling north wall
PATCH(IMSWNC,NWALL, 1, NX, 25, 25, 1, 15, 1, 1)

COVAL(IMSWNC,T3 , GRND4   , GRND5   )
COVAL(IMSWNC,TEM1, GRND2   , GRND5   )

    ** Block3 north wall
PATCH(IMSWB3,NWALL, 1, NX, 11, 11, 1, 3, 1, 1)
COVAL(IMSWB3,T3 , GRND4   , GRND5   )
COVAL(IMSWB3,TEM1, GRND2   , GRND5   )

    ** Inlets plans
PATCH(IMSWI1,LWALL, 1, 3, 24, 25, 4, 4, 1, 1)
COVAL(IMSWI1,T3 , GRND4   , GRND5   )
COVAL(IMSWI1,TEM1, GRND2   , GRND5   )

PATCH(IMSWI2,LWALL, 1, 3, 12, 21, 4, 4, 1, 1)
COVAL(IMSWI2,T3 , GRND4   , GRND5   )
COVAL(IMSWI2,TEM1, GRND2   , GRND5   )

PATCH(IMSWI3,LWALL, 4, 7, 12, 25, 4, 4, 1, 1)
COVAL(IMSWI3,T3 , GRND4   , GRND5   )
COVAL(IMSWI3,TEM1, GRND2   , GRND5   )

PATCH(IMSWI4,LWALL, 8, 12, 17, 25, 4, 4, 1, 1)
COVAL(IMSWI4,T3 , GRND4   , GRND5   )
COVAL(IMSWI4,TEM1, GRND2   , GRND5   )

PATCH(IMSWI5,LWALL, 8, 12, 12, 12, 4, 4, 1, 1)
COVAL(IMSWI5,T3 , GRND4   , GRND5   )
COVAL(IMSWI5,TEM1, GRND2   , GRND5   )

PATCH(IMSWI6,LWALL, 13, NX, 12, 25, 4, 4, 1, 1)
COVAL(IMSWI6,T3 , GRND4   , GRND5   )
COVAL(IMSWI6,TEM1, GRND2   , GRND5   )

SPEDAT(SET,EMISSIVITY,OF PLT*1,R,0.85)
SPEDAT(SET,EMISSIVITY,OF PLT*2,R,0.85)
SPEDAT(SET,EMISSIVITY,OF PLT*3,R,0.85)
SPEDAT(SET,EMISSIVITY,OF PLT*4,R,0.85)
SPEDAT(SET,EMISSIVITY,OF PLT*5,R,0.85)
SPEDAT(SET,EMISSIVITY,OF PLT*6,R,0.85)

SPEDAT(SET,EMISSIVITY,OF IMSWSB,R,0.85)
SPEDAT(SET,EMISSIVITY,OF IMSWNB,R,0.85)
SPEDAT(SET,EMISSIVITY,OF IMSWEB,R,0.85)
SPEDAT(SET,EMISSIVITY,OF IMSWLB,R,0.85)
SPEDAT(SET,EMISSIVITY,OF IMSWH1,R,0.85)
SPEDAT(SET,EMISSIVITY,OF IMSWH2,R,0.85)
SPEDAT(SET,EMISSIVITY,OF IMSWH3,R,0.85)
SPEDAT(SET,EMISSIVITY,OF IMSWH4,R,0.85)
SPEDAT(SET,EMISSIVITY,OF IMSWLC,R,0.85)

```
SPEDAT(SET,EMISSIVITY,OF IMSWNC,R,0.85)
SPEDAT(SET,EMISSIVITY,OF IMSWB3,R,0.85)
SPEDAT(SET,EMISSIVITY,OF IMSWI1,R,0.85)
SPEDAT(SET,EMISSIVITY,OF IMSWI2,R,0.85)
SPEDAT(SET,EMISSIVITY,OF IMSWI3,R,0.85)
SPEDAT(SET,EMISSIVITY,OF IMSWI4,R,0.85)
SPEDAT(SET,EMISSIVITY,OF IMSWI5,R,0.85)
SPEDAT(SET,EMISSIVITY,OF IMSWI6,R,0.85)

  inifld=t
    ** Thin plates

PATCH(PLT*1,NWALL,1,8,8,8,9,13,1,1)
COVAL(PLT*1,PRPS,111,0.016)

PATCH(PLT*2,NWALL,1,8,20,20,9,13,1,1)
COVAL(PLT*2,PRPS,111,0.016)

PATCH(PLT*3,NWALL,1,7,9,9,17,22,1,1)
COVAL(PLT*3,PRPS,111,0.016)

PATCH(PLT*4,NWALL,1,7,19,19,17,22,1,1)
COVAL(PLT*4,PRPS,111,0.016)

PATCH(PLT*5,EWALL,7,7,10,19,17,22,1,1)
COVAL(PLT*5,PRPS,111,0.016)

PATCH(PLT*6,EWALL,8,8,9,20,9,13,1,1)
COVAL(PLT*6,PRPS,111,0.016)

      * PLANT settings

PATCH(HOT1,CELL,1,13,26,36,22,30,1,1)
  <SORC01>VAL=500-200/3.6875*(YG2D-2.7125)
COVAL(HOT1,TEM1,FIXVAL,GRND)

PATCH(HOT2,CELL,1,10,37,40,20,32,1,1)
  <SORC02>VAL=500-200/3.6875*(YG2D-2.7125)
COVAL(HOT2,TEM1,FIXVAL,GRND)

PATCH(HOT3,CELL,1,17,18,25,23,29,1,1)
  <SORC03>VAL=500-200/3.6875*(YG2D-2.7125)
COVAL(HOT3,TEM1,FIXVAL,GRND)

PATCH(HOT4,CELL,1,4,12,17,1,22,1,1)
  <SORC04>VAL=15+485/4.2*ZGNZ
COVAL(HOT4,TEM1,FIXVAL,GRND)

PATCH(HOT5,CELL,1,17,3,17,23,29,1,1)
```

COVAL(HOT5,TEM1,FIXVAL,500.)

STORE(TCEL,TCIL)
  <SC0601> TCEL= 0.8*TWAL
  <SC0602> TCIL= 0.6*TWAL
NXPRIN=1;NYPRIN=1;NZPRIN=1

NAMSAT=MOSG
 restrt(all)

APPENDIX B: GROUND FILE

```
C.... FILE NAME GROUND.FTN------------------------------230597
      SUBROUTINE GROUND
      INCLUDE '/phoenics/d_includ/satear'
      INCLUDE '/phoenics/d_includ/grdloc'
      INCLUDE '/phoenics/d_includ/grdear'
      INCLUDE '/phoenics/d_includ/grdbfc'
      COMMON/GENI/NXNY,IGFIL1(8),NFM,IGF(21),IPRL,IBTAU,ILTLS,
     1          IGFIL(15), ITEM1,ITEM2,ISPH1,ISPH2,ICON1,ICON2,
     1          IPRPS,IRADX,IRADY,IRADZ,IVFOL
      COMMON/DRHODP/ITEMP,IDEN/DVMOD/IDVCGR
      COMMON /LRNTM3/L0UTAU,NMWALL,L0WALL,L0DSKN,IVPRST
      COMMON /NPAT/NAMPAT(1)
      CHARACTER*8 NAMPAT
CXXXXXXXXXXXXXXXXXXXXX USER SECTION STARTS:
C 1   Set dimensions of data-for-GROUND arrays here. WARNING: the
C     corresponding arrays in the MAIN program of the satellite
C     and EARTH must have the same dimensions.
      PARAMETER (NLG=100, NIG=200, NRG=200, NCG=100)
C
      COMMON/LGRND/LG(NLG)/IGRND/IG(NIG)/RGRND/RG(NRG)/
     1               CGRND/CG(NCG)
      LOGICAL LG
      CHARACTER*4 CG
C**************************************************************
C--- GROUP 1. Run title and other preliminaries
    1 GO TO (1001,1002,1003),ISC
 1001 CONTINUE
      CALL MAKE(YG2D)
C   * -----------GROUP 1  SECTION  3 --------------------------
      IF(.NOT.NULLPR.AND.IDVCGR.EQ.0)
     1 CALL WRYT40('GROUND file is GROUND.F   of:   230597 ')
      RETURN
C**************************************************************
C--- GROUP 13. Boundary conditions and special sources
C                   Index for Coefficient - CO
C                   Index for Value      - VAL
 1311 CONTINUE
C------------------ SECTION 12 ------------------ value = GRND
C    Source name: SORC01
      IF(INDVAR.EQ.INAME('TEM1 ').AND.NPATCH.EQ.'HOT1   ') THEN
       LFVAL =L0F(VAL)
       LFYG2D=L0F(YG2D  )
       DO 13801 IX=IXF,IXL
        IADD=NY*(IX-1)
       DO 13801 IY=IYF,IYL
        I=IY+IADD
        L0YG2D=LFYG2D+I
```

```
13801 F(LFVAL+I)=500-200/3.6875*(F(L0YG2D)-2.7125)
      ENDIF
C     Source name: SORC02
      IF(INDVAR.EQ.INAME('TEM1  ').AND.NPATCH.EQ.'HOT2   ') THEN
       LFVAL =L0F(VAL)
       LFYG2D=L0F(YG2D  )
       DO 13802 IX=IXF,IXL
        IADD=NY*(IX-1)
       DO 13802 IY=IYF,IYL
        I=IY+IADD
       L0YG2D=LFYG2D+I
13802 F(LFVAL+I)=500-200/3.6875*(F(L0YG2D)-2.7125)
      ENDIF
C     Source name: SORC03
      IF(INDVAR.EQ.INAME('TEM1  ').AND.NPATCH.EQ.'HOT3   ') THEN
       LFVAL =L0F(VAL)
       LFYG2D=L0F(YG2D  )
       DO 13803 IX=IXF,IXL
        IADD=NY*(IX-1)
       DO 13803 IY=IYF,IYL
        I=IY+IADD
       L0YG2D=LFYG2D+I
13803 F(LFVAL+I)=500-200/3.6875*(F(L0YG2D)-2.7125)
      ENDIF
C     Source name: SORC04
      IF(INDVAR.EQ.INAME('TEM1  ').AND.NPATCH.EQ.'HOT4   ') THEN
       LFVAL =L0F(VAL)
       L0ZGNZ=L0F(ZGNZ  )+IZ
       DO 13804 IX=IXF,IXL
        IADD=NY*(IX-1)
       DO 13804 IY=IYF,IYL
        I=IY+IADD
13804 F(LFVAL+I)=15+485/4.2*F(L0ZGNZ)
      ENDIF
      RETURN
C*******************************************************************
C--- GROUP 19. Special calls to GROUND from EARTH
C
  196 CONTINUE
C   * ------------------ SECTION 6 ---- Finish of iz slab.

      IF(ISWEEP.GT.FSWEEP.OR.ITHYD.GT.1) THEN
         JTWAL = LBNAME('TWAL')
         L0TWAL= L0F(JTWAL)
         DO 1965 IWL= 1,NMWALL
          IPAT= NINT(ABS(F(L0WALL+IWL)))
          IF(NAMPAT(IPAT)(1:4).EQ.'IMSW') THEN
           L0PTW = L0PVAR(PVTEMP,IPAT,0)
           CALL GETPAT(IPAT,IDUM,TYP,IX1,IX2,IY1,IY2,IZ1,IZ2,IT1,IT2)
```

```fortran
       IF(L0PTW.NE.0.AND.IZSTEP.GE.IZ1.AND.IZSTEP.LE.IZ2) THEN
         CALL SUB2(IPLUS,(IX1-2)*NY, J,0)
         DO 1964 IX= IX1,IX2
           IPLUS= IPLUS+NY
           DO 1964 IY= IY1,IY2
             I= IY+IPLUS
             J= J+1
             F(L0TWAL+I)= F(L0PTW+J)
 1964      CONTINUE
       ENDIF
     ENDIF
 1965 CONTINUE
   ENDIF
   RETURN
C***********************************************************

   END
```