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RADIANT HEAT TRANSFER IN TENTAGE

by

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DEFENCE RESEARCH ESTABLISHMENT OTTAWA
TECHNICAL NOTE 86-11

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ABSTRACT

Radiant heat transfer was analyzed for tents consisting of single layer fabric walls which are capable of partially transmitting thermal radiation. External radiant temperatures were uniform. Radiant heat loss from the tent surface to the external surroundings was found theoretically to represent approximately 25% of the total heat loss from the tent. Theoretical predictions of the fraction radiated to the floor of the tent, based on experimentally determined surface temperatures, agreed to within an order of magnitude with the measured radiant heat flux to the floor. Signal noise and measurement precision affected these experimental results. An empirical equation for predicting sky temperature was compared with measured sky temperature and was found to underestimate the sky temperature by approximately 10%.

RÉSUMÉ

On a analysé le transfert de chaleur rayonnante de tentes comportant une seule toile capable de transmettre partiellement le rayonnement thermique. Les températures de rayonnement extérieures étaient uniformes. La prévision théorique du transfert de chaleur rayonnante à travers le tapis de sol de la tente, basée sur des températures superficielles mesurées expérimentalement, concorde avec le flux de chaleur rayonnante mesuré sur le tapis de sol. A cause du bruit présent dans le signal et de la précision insuffisante des mesures, on a pu vérifier seulement que les résultats de l'analyse théorique et les mesures expérimentales étaient du même ordre de grandeur. On a établi que la perte de chaleur rayonnante vers l'extérieur, à la surface de la tente, représentait environ 25% de la perte de chaleur totale. Les résultats obtenus à l'aide d'une équation empirique permettant de calculer la température du rayonnement ambiant ont été comparés avec des mesures de cette température. L'équation empirique sous-estime la température du rayonnement ambiant d'environ 10%.

GLOSSARY

a,b	disk radii
A	surface area, m^2
F_{ij}	view factor from surface i to surface j
h	vertical separation between concentric disks
r_{ij}	a vector between points on surface i and surface j
R	radiative heat flux, W/m^2
S	a contour line around a surface
T	absolute temperatue, K
q_s	radiative heat flux of the pyranometer sensor, W/m^2
Q_{NET}	total net radiative heat flux, W/m^2
δ_{ij}	Kronecker delta
ε	surface emissivity
ϕ	angular step size around the vertical axis disk, radians
ρ	surface reflectivity
σ	Stefan-Boltzmann constant = 5.67×10^{-8} W/m^2K^4
τ	surface transmissivity
θ	angle between the surface normal and the vector r_{ij}

Subscripts

A	ambient
dp	dew point
i,j	surface identifiers
I	inside
L	left
O	outside
R	right
s	sensor

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1.0 INTRODUCTION

This study examines the exchange of radiant thermal energy between surfaces of a tent. A general theoretical analysis of radiant heat transfer is outlined with descriptions of techniques required to perform the required analysis. The difference between this problem and most other radiant heat transfer problems is that the fabric surfaces of the tent transmit some portion of the incident thermal radiation to or from the external surroundings whereas typical engineering materials have no transmission of radiant thermal energy. Therefore, the conventional radiant heat transfer analysis [1] has been extended to include the transmission of radiative thermal energy.

To illustrate the technique, a conical tent shape was assumed. The dimensions of the theoretical tent were chosen such that the theoretical tent approximated a Canadian Forces 5-Man Arctic Tent as closely as possible. For experimental verification of the analysis, a 5-Man Arctic Tent was instrumented to measure surface temperatures and radiant heat transfer at the floor.

In this study, it is assumed that the external radiant temperature is uniform. This precludes solar heating as well as cases where sky temperatures vary substantially from the ground temperature. These cases are to be studied in a subsequent investigation.

Appendix A provides interested readers with the computer program used to do the numerical computations involved in determining the radiative heat fluxes in the test. Appendix B gives some examples of the viewfactor algebra required for implementing the computer analysis. Appendix C gives a listing of several standard library routines which are called by the program in Appendix A for interested readers who may not have them on their computer system.

This study is part of a larger investigation, the goals of which are to produce an understanding of the important heat transfer mechanisms in tentage and to provide a means of analysing the heat transfer in tents. This information could be used to aid in the development of tents with superior performance characteristics which are required to meet the ever-expanding requirements of the military and civilian markets.

2.0 THEORY

The equations governing radiant heat transfer between surfaces are well established for opaque surfaces [1,2] but seldom is transmission included in the analysis. For most engineering materials, the transmission is zero, however, surfaces made of textile fabrics can have transmissivities between 0.05 and 0.25 [3]. The analysis outlined below follows conventional approaches but has been extended to include the transmission component of thermal radiation.

2.1 RADIANT HEAT TRANSFER EQUATIONS

The analysis begins by assuming an arbitrary enclosure as shown in Figure 1. Let R_{LIi} be the radiative heat flux leaving surface i and entering the enclosure, R_{RIi} be the radiant heat flux incident on the inner surface of surface i, R_{ROi} be the radiant heat flux leaving surface i to the external surroundings of the tent, and R_{LOi} be the radiant heat flux arriving at exterior of surface i from the surroundings.

The radiant energy arriving at the exterior side of surface i is given by:

$$R_{LOi} = \sigma T_A^4 \tag{1}$$

where it is assumed that the emissivity of the external surroundings of the enclosure is 1.0 and that T_A is the radiant temperature of the external surroundings. The radiant energy leaving the exterior side of surface i is due to emitted, reflected and transmitted radiant energy and is given by:

$$R_{ROi} = \varepsilon_i \sigma T_i^4 + \rho_i R_{LOi} + \tau_i R_{RIi} \tag{2}$$

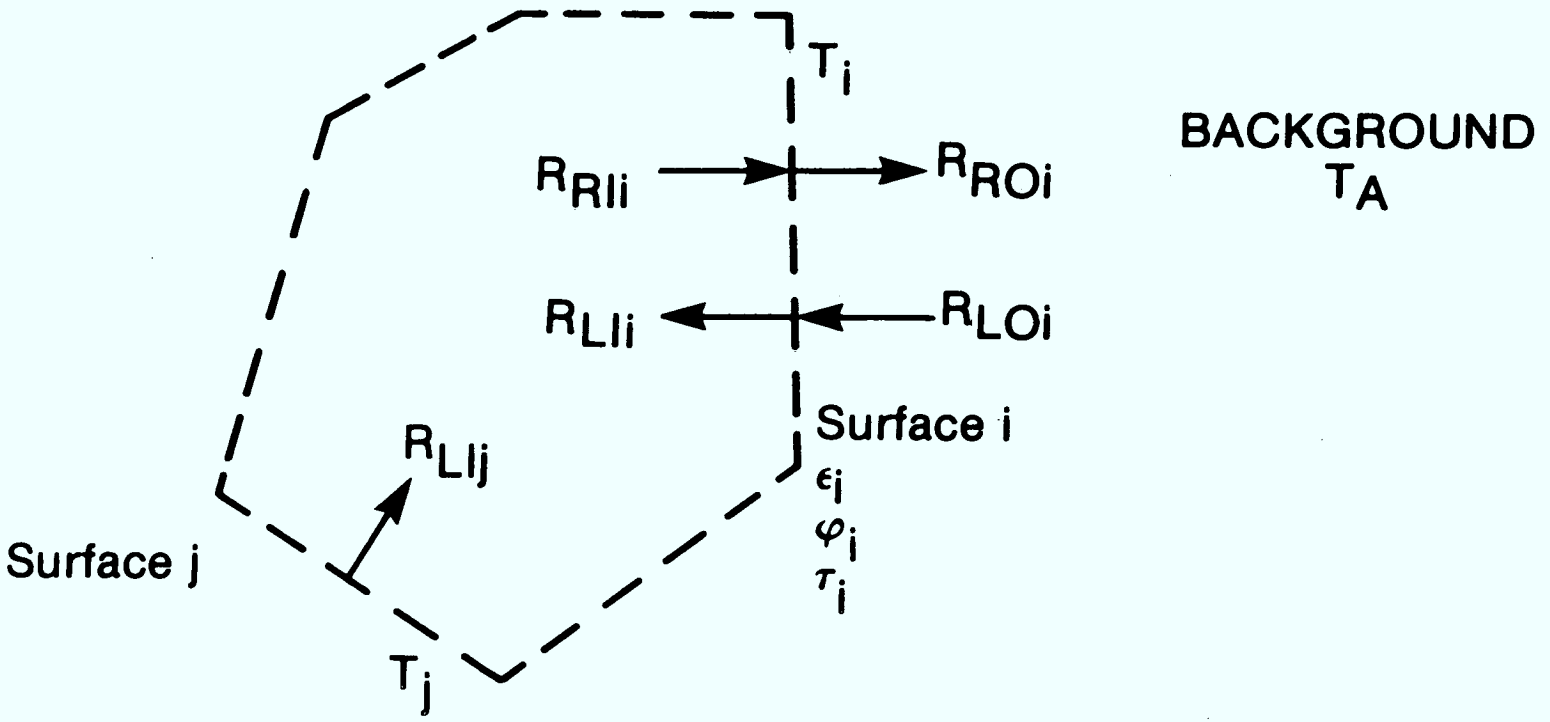

Figure 1. Configuration for the development of the radiant heat transfer equations for an enclosure with transmitting walls.

Similarly, the radiant energy leaving the interior side of surface i is given by:

$$R_{LIi} = \varepsilon_i \sigma T_i^4 + \rho_i R_{RIi} + \tau_i R_{LO} \tag{3}$$

The radiant energy arriving at the interior edge of surface i is the sum of all the radiant fluxes leaving the j internal surfaces of the enclosure which strike surface i directly. Using view factor algebra, it can be shown [1] that this may be expressed as:

$$R_{RIi} = \sum_j F_{ij} R_{LIj} \tag{4}$$

Using equations 1,3 and 4, all but one unknown radiative flux, R_{LIj}, can be eliminated from a system of simultaneous equations leaving:

$$\sum_j (\delta_{ij} - \rho_i F_{ij}) R_{LIj} = \varepsilon_i \sigma T_i^4 + \tau_i \sigma T_A^4 \tag{5}$$

where δ_{ij} is the Kronecker delta which assumes the value 1 when i equals j and zero otherwise.

Solving equation 5 for R_{LIj} allows the remaining radiant fluxes to be evaluated from the above equations. The net heat loss to the exterior surroundings and the net heat loss from each surface are given by:

$$R_{OUTi} = R_{ROi} - R_{LOi} \tag{6}$$

$$Q_{NETi} = (R_{ROi} - R_{LOi}) + (R_{LIi} - R_{RIi}) \tag{7}$$

Equation 5 can be solved by matrix inversion, Gaussian elimination or by iterative routines. Gaussian elimination is the most common technique for small systems of linear equations and was the technique used here. Appendix C gives a listing of the subroutines [8] which were used to solve the system of equations.

Equation 5 requires the surface temperatures as known data. These temperatures may be found through measurements on a model or by a complete analysis which includes all modes of heat transfer.

2.2. VIEW FACTOR EVALUATION

The solution of equation 5 requires the evaluation of the view factors, F_{ij}, between each of the surfaces in the enclosure. Physically, the view factor between surface i and surface j is the fraction of the total radiant energy leaving surface i which strikes surface j directly.

The view factor is a function of the orientation of two surfaces with respect to each other and the distance between them. The view factor between two finite surfaces, as shown in Figure 2, is given by [1]:

$$F_{ij} = \frac{1}{A_i} \iint \frac{\cos\theta_i \cos\theta_j}{\pi r_{ij}^2} \, dA_j dA_i \tag{8}$$

Solution of equation 8, in closed form, is possible for a limited number of surface shapes and orientations [1,2,4,5]. It is often possible to assemble several surfaces with known view factors to form irregular surfaces for which the view factor may be determined by view factor algebra [1].

Equation 8 may be solved by direct numerical integration, but this requires a considerable amount of computer time. Monte Carlo methods [2] have been used successfully to obtain view factors, and these methods have the advantage that equation 8 does not need to be solved directly. Alternatively, considerable savings in computer time may be obtained with direct numerical integration of the view factor equation by first applying Gauss' law to equation 8 [6]. This reduces the integration from a double area integral to a double contour integral. Application of Gauss' law to equation 8 yields:

$$F_{ij} = \frac{1}{2\pi A_i} \oint\oint \ln(r_{ij}) \, dS_j dS_i \tag{9}$$

where r_{ij} is now the vector between points on the contour of each surface.

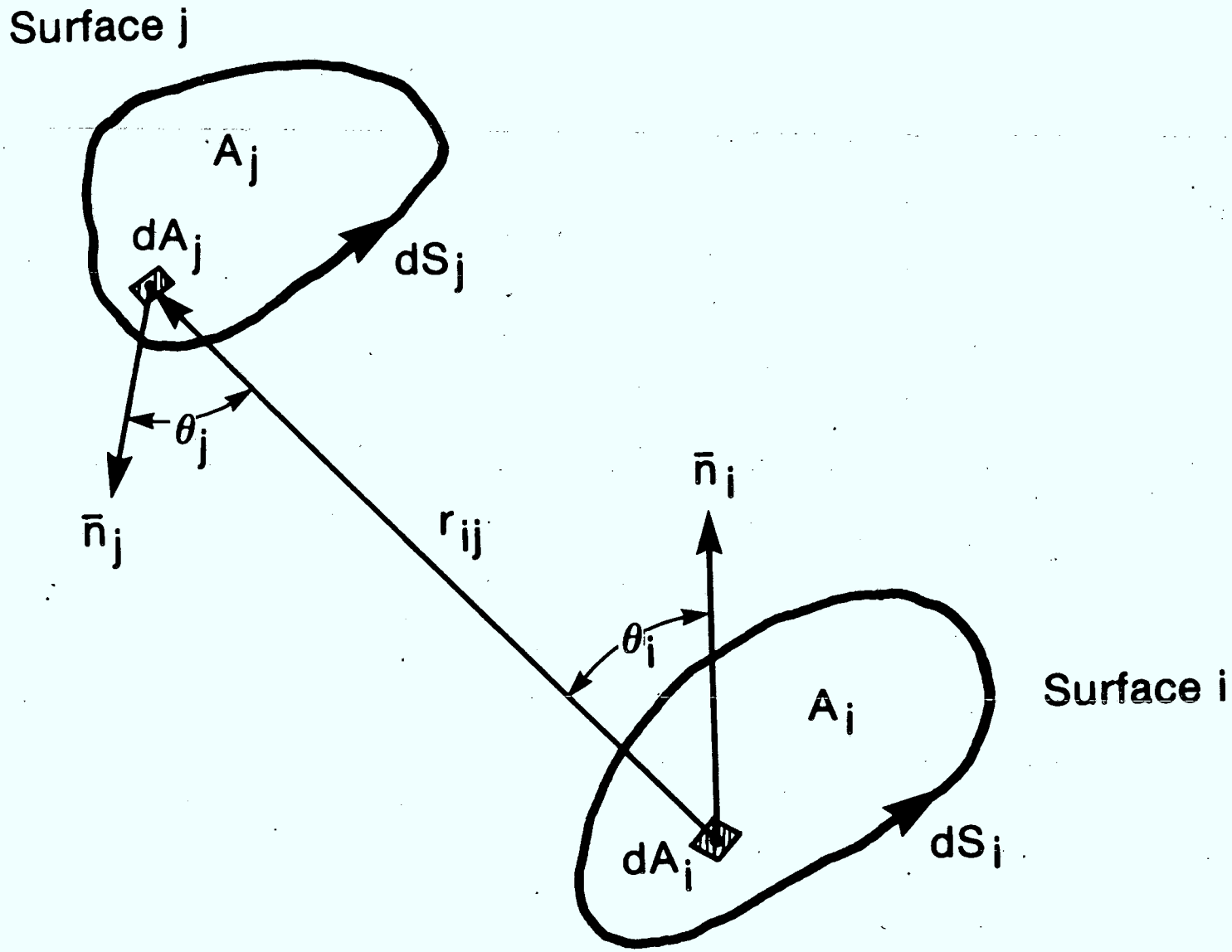

Figure 2. Development of the view factor, F_{ij} , from surface "i" to surface "j". (After [1]).

View factors for the conical tent used in the theoretical portion of this study can be found by knowing the view factors between parallel concentric disks, and applying view factor algebra to obtain the view factors between actual surfaces (Appendix B). These view factors should not vary appreciably for the 5-Man Arctic Tent used in the experimental portions of this study. A closed form solution to equation 8 exists for parallel concentric disks [5] and, using the notation of Figure 3, is found to be:

$$F_{ij} = \tfrac{1}{2}(z - \sqrt{z^2 - 4x^2y^2}) \qquad (10)$$

where

$$x = a/h$$
$$y = h/b$$
$$z = 1 + (1 + x^2)y^2$$

Evaluation of equation 9 by numerical integration was performed using the program listed in Appendix A. Although the program uses a simple integration technique, the results obtained were in close agreement with those obtained using the exact solution. Table 1 lists the results obtained for different step sizes and different disk dimensions along with the exact solution in each case. The error incurred by using a relatively coarse step size of 0.1 radians was less than 7% in all cases, the greatest error occuring in the analysis between the two smallest disks. This was as expected since, as the disks become smaller, or closer together, a fixed step size of angle around the disk produced an arc length which was closer to the characteristic dimension of the problem. Decreasing the step size from 0.1 radians to 0.01 radians produced only marginal improvements while significantly increasing computation time. Increasing the step size to 0.5 radians caused a substantial increase in the error.

Table 1. Comparison of results of view factor evaluation between numerical evaluation of equation 10 and the exact solution: (a) with various step sizes; (b) with various disk dimensions. Angles are expressed in radians; lengths are expressed in metres.

(a) a=0.254, b=0.465, h=0.27, F_{ij}=0.212 (exact)

Step Size $\Delta\phi$	F_{ij}	Error %
0.01	0.226	+6
0.10	0.227	+7
0.50	0.243	+14

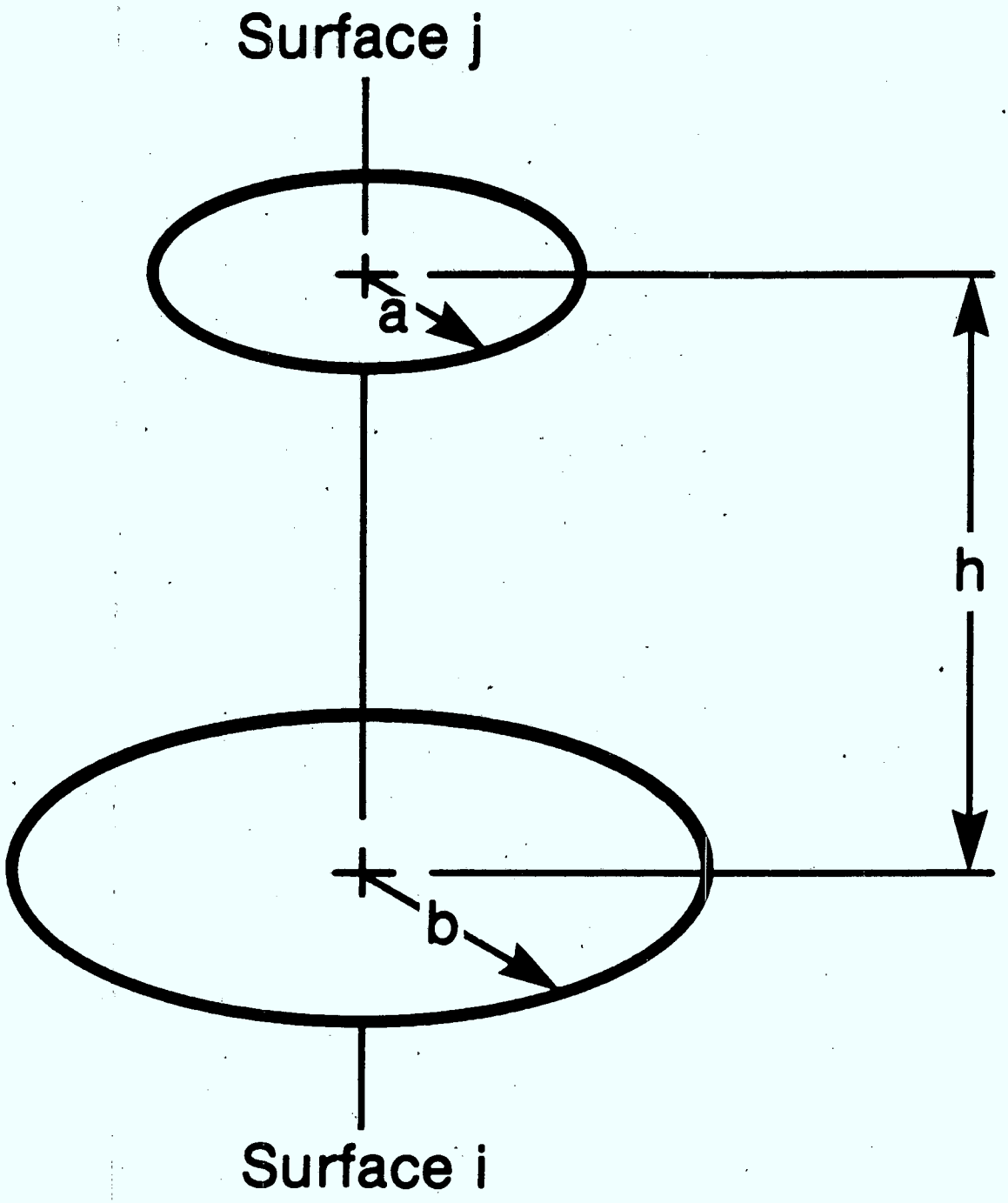

Figure 3. Configuration of the concentric disks for which the view-factor is described by equation 10.

(b) Step Size, $\Delta\phi = 0.10$

Disk Dimensions a	b	h	F_{ij} (comp)	F_{ij} (exact)	Error %
0.47	0.93	0.33	0.217	0.216	0.5
0.93	1.17	0.40	0.513	0.511	0.4
1.17	1.91	0.45	0.348	0.348	0.0
1.91	1.91	0.50	0.774	0.774	0.0

2.3 FABRIC PROPERTIES

The thermal radiative properties of fabrics have been found to vary considerably between different materials and types of fabric construction [3]. The thermal radiative properties of several fabrics which are commonly used in tentage are listed in Table 2.

Table 2. Thermal Radiative Properties Of Selected Tent Fabrics. (Quoted values indicate ranges and [3] should be consulted for actual values of specific fabrics.)

Material	Mass/Area (kg/m^2)	Emissivity	Reflectivity	Transmissivity
Nylon	0.05 - 0.11	0.49 - 0.51	0.33 - 0.41	0.06 - 0.18
Cotton	0.11 - 0.24	0.60 - 0.82	0.12 - 0.31	0.07 - 0.12
Cotton/Nylon	0.19 - 0.30	0.51 - 0.59	0.33 - 0.41	0.07 - 0.08
Polyester	0.07 - 0.27	0.54 - 0.85	0.11 - 0.38	0.08 - 0.14
Polypropylene	0.07 - 0.15	0.40 - 0.51	0.40 - 0.50	0.07 - 0.18

2.4 EXTERNAL BACKGROUND TEMPERATURE

The external background temperature influences the internal thermal radiant exchange through the transmissivity of the tent surfaces.

As the transmissivity of most tent fabrics is small, and since multiple layers of fabric are often used, the external background temperature is usually of secondary importance in determining the internal radiant heat fluxes. It is, however, a significant factor in the overall radiant heat transfer from the tent. For typical, single layer fabrics, a temperature difference of 10 C between the background and a surface inside the tent corresponds to an additional heat transfer of approximately 2 W/m^2 of radiant energy from that surface to the external background, assuming a transmissivity of 0.15 for the tent walls. For the same temperature difference between the tent fabric and the external background, the radiant energy transfer by emission from the fabric will be approximately 7 to 13 W/m^2.

In general, the background temperature will be some combination of the temperatures of the sky and ground, as well as their respective radiative properties in the infrared region of the spectrum and the view factors from the external tent surfaces to the sky and ground. For the purposes of this study, it will be assumed that the sky dominates the external radiant heat flux and that the ground has the same temperature as the sky. This would correspond to a worst case analysis for the experiments of this study as the sky was found to be slightly colder than the ground. This approximation significantly simplifies the analysis as external view factors for the tent surfaces to the surroundings become 1. The errors incurred by using this approximation are small for this study as experimental results were chosen from times when the sky temperature was close to the ambient temperature. This approximation would result in serious errors if solar heating occurs or if the sky temperature varies substantially from the ground temperature. External view factors and solar heating will be studied in a second investigation on radiant heat transfer in tents.

Two methods of predicting the sky temperature from conventional meteorological data have been reported [7]. The simplest of these relationships depends only upon the ambient air temperature and takes the form:

$$T_{sky} = 0.0552\ T_A^{1.5} \tag{11}$$

Another relationship includes the dew point temperature in an attempt to account for moisture in the air:

$$T_{sky} = T_A\left(0.8 + \frac{T_{dp} - 273}{250} \right)^{1/4} \tag{12}$$

In the experimental portion of this study, a pyranometer was used to monitor the sky temperature. This device can be used to calculate the sky temperature by using the following equation:

$$\sigma T_{sky}^{4} = q_s + \sigma T_s^{4} \tag{13}$$

where it has been assumed that the sensor and background emissivities are both 1.

3.0 EXPERIMENT

A Canadian Forces 5-Man Arctic Tent was set up in an open field and instrumented with thermocouples, thermistors and heat flow disks. Due to the geometric symmetry of the tent, only one sector of the tent was instrumented. Heat was supplied by two forced air electric heaters with a nominal heat output of 1300 W each.

Wall temperatures were measured by mounting pairs of thermocouples, connected in parallel, on the surface of the tent wall as shown in Figure 4. It was assumed that the small wire size (30 Gauge) and the pairing of the thermocouples would improve the measurement of the wall temperature. Floor temperatures were measured by differential thermocouples at each of the heat flow disk positions.

Heat flow disks were placed on the floor of the tent in pairs at four positions. The disks were placed so as to give an equal area weighting of the heat flux to the floor. For each pair of heat flow disks, one was covered with a flat-black paint ($\varepsilon = 0.95$) which was used to measure the total heat transfer rate due to radiation and conduction to the floor. The other heat flow disk was covered with a layer of aluminum foil ($\varepsilon = 0.05$), attached with heat sink compound. This heat flow disk was used to measure the conductive component of heat flow to the floor. The radiative component of the heat flow to the floor was calculated from the difference between these two measurements.

Measurements were taken at night to eliminate solar heating, thereby minimizing the effect of external conditions on the internal radiative heat fluxes. Solar heating results in asymmetric radiant heat loss transfer to the tent which further complicates the analysis. The sky temperature was calculated from a measurement with a pyranometer, referenced to the air temperature, using equation 13.

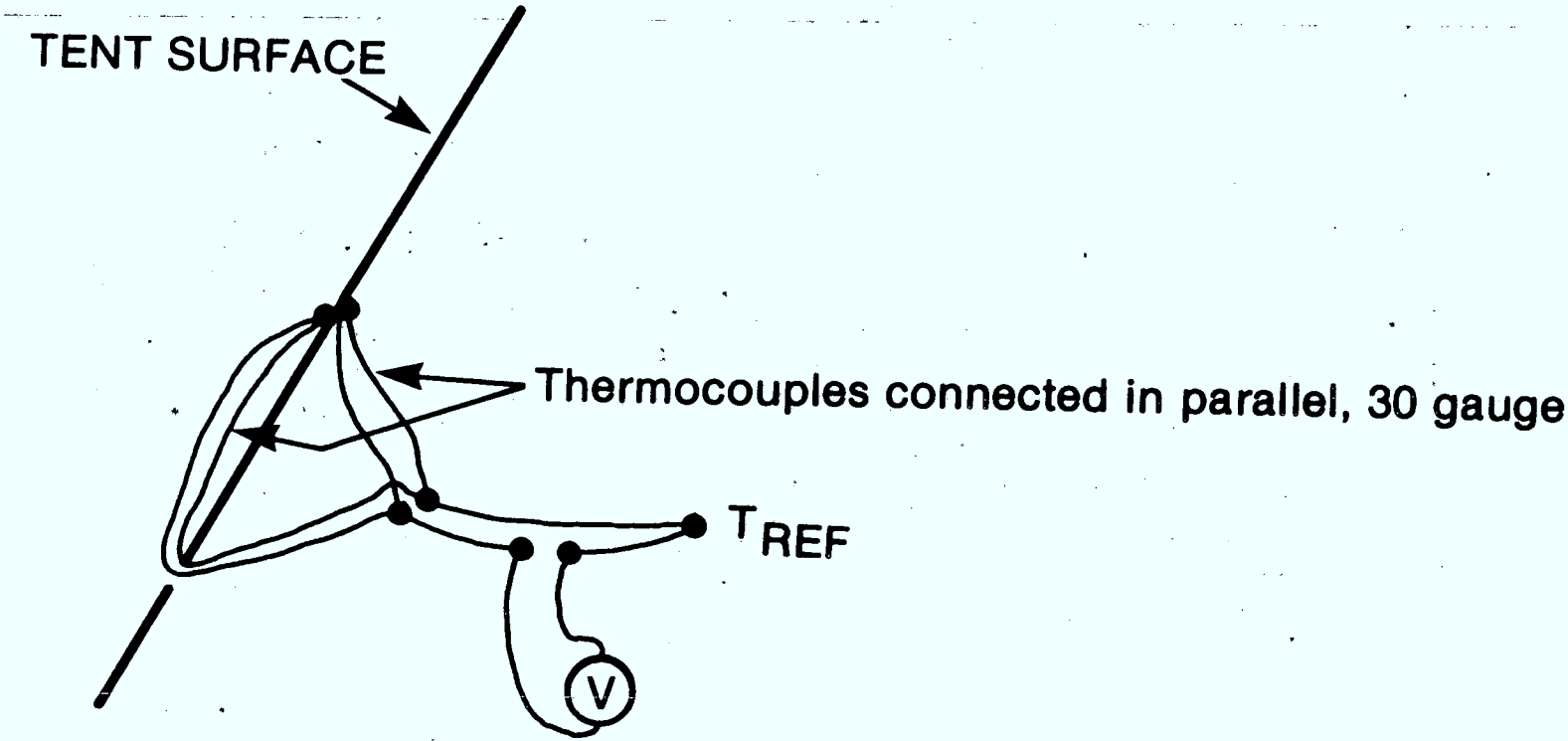

Figure 4. Configuration of the thermocouples used for measuring the tent wall temperatures.

4.0 RESULTS

The output voltage of the thermocouples and the heat flow disks was small, typically 0.1 mV and 15 μV respectively. Signal noise with these devices was found to be approximately ±5 μV. The signal noise was presumably caused by electromagnetic interference picked up by the long lead wires from the tent to the data acquisition system. The use of signal amplifiers would have been advantageous, however, none was available. As a result, the measurements obtained could only be expected to give an order of magnitude confirmation of the theoretical predictions of the radiant heat transfer.

Sky temperatures, as determined using equation 11, were found to underestimate the sky temperature evaluated from equation 13 from between 15 and 20 C, or by 10% of the absolute temperature. This would typically result in errors in the radiant heat transfer calculations of approximately 4 W/m^2 for transmitted radiant energy and 20 W/m^2 for emitted radiant energy by the fabric surface.

The temperature and heat flow measurements were recorded under uncontrollable environmental field conditions. Thus, each experimental set of results was unique. Therefore, the complete set of results, nineteen in all, are not presented here, but rather typical wall and floor temperatures and radiant heat fluxes are given, as shown in Figure 5. Considering the signal noise and the precision of the reference thermistors (±0.2 C), the wall surface temperature readings are thought to be accurate to within ±0.5 C. Scatter in the floor surface temperature measurements indicated a variability of as much as ±1 C over the floor. The precision of the surface temperature measurement corresponds to a precision in the computed radiant heat flow between 15 and 50% as the difference between the wall temperatures and the floor temperature varied between 3 and 10 C over the series of experiments. The measured radiant heat flux from the floor to the tent walls was found to be between 20 and 60 W/m^2 with an arithmetic average of all measurements of approximately 40 W/m^2.

The values of R_{LIj} for each experiment was calculated using the measured values of surface and sky temperatures with equation 5. These values of radiant heat flux were then used with equation 7, and the resulting radiant heat flux from the floor computed. The computed radiant heat flux to the floor was then compared with the measured value of the relevant experiment. In all cases, the computed radiant heat flux from the floor was less than the measured radiant heat flux but it was of the same order of magnitude. Computed radiant heat flows from the floor varied from 16 to 36 W/m^2 with a numerical average of 25 W/m^2. Differences between

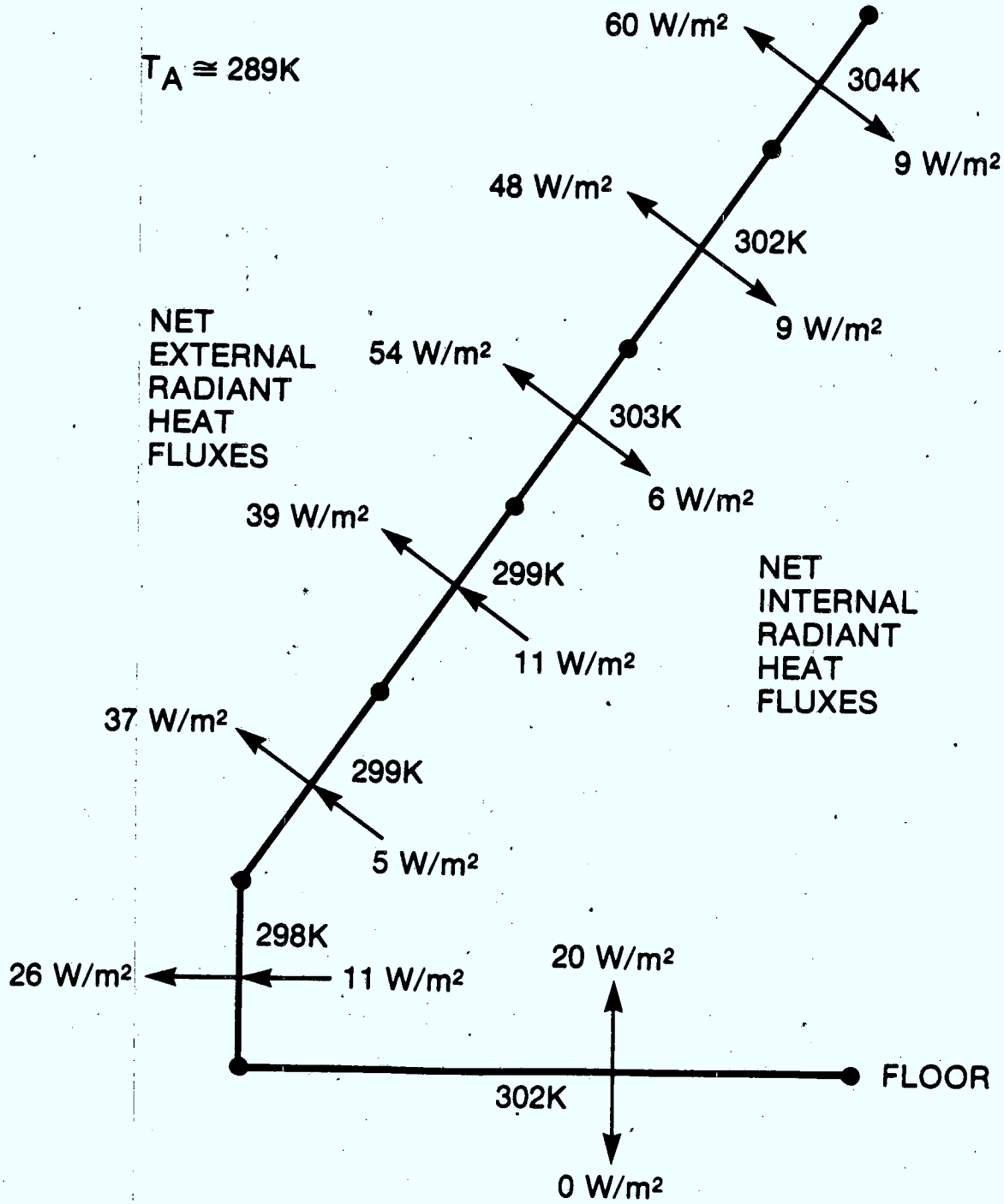

Figure 5. Typical surface temperatures and net radiant heat fluxes for the 5-Man Arctic Tent when heated by a 2000 Watt heat source.

computed and measured values ranged between 5 and 70%. This is consistent with the temperature measurement precision and the observed signal noise.

The temperatures of the surfaces of the tent depend upon the ambient temperature and the rate of heating of the tent. Thus, the radiant heat fluxes found in this study are specific to the conditions at the time of the experiments. The values of temperature and radiant heat flux shown in Figure 5 represent typical values for the study only and the radiant heat transfer analysis should be applied for cases were ambient temperature or rate of heating differ. It should also be noted that these values are specific to the 5-Man Arctic Tent as the view factors for tents of different shapes and sizes will be different.

Due to the small signal of the heat flow disks, the observed signal noise and possible contamination of the sensors by dust, the measured radiant heat flow was considered to be less accurate than that predicted based on temperature measurement.

The total radiant heat loss from the tent to the external surroundings was found to be approximately 600 to 750 W, or 25% of the total heat loss from the tent in this case. These values will depend upon the tent wall construction, the amount of heat supplied to the tent and the tent fabric properties. Total radiant heat loss from the tent walls, internal plus external radiant heat transfer, was found to be approximately 700 to 850 W.

5.0 CONCLUSION

Predictions of radiant heat transfer, using surface temperature measurements in a Canadian Forces 5-Man Arctic Tent with a model tent of comparable dimensions, agreed with measured radiant heat transfer rates to the floor of the 5-Man Arctic Tent to within the expected precision of the experimental method. The floor was found to be a major contributor to the radiant heat transfer in the tent. The magnitude and sense of the radiant heat transfer from the floor will depend upon the ground temperature history and the rate of heat supplied to the floor of the tent.

The radiant heat loss from this single walled tent to the external surroundings was found to be approximately 600 to 750 W when heat was supplied to the tent at a rate of 2600 W or approximately 25% of the total heat loss from the tent. Approximately 100 W (net) of radiant thermal energy was transferred from the internal surfaces to the interior of the tent which was subsequently absorbed by the walls or transmitted to the exterior surroundings. The total net radiant heat transfer from all of

the surfaces, both external and internal, was found to be 700 to 850 W. This quantity of thermal energy must be supplied to the walls by conductive transfer from the heated internal air.

View factor evaluation by numerical integration utilizing Gauss' law was found to be both accurate and fast. Computation of view factors is made easier by using interstitial geometric surfaces which are easily described mathematically in computer code and applying view factor algebra to obtain the view factor between desired surfaces and the interstitial surfaces.

Sky temperature prediction based on ambient temperature alone was found to be accurate to approximately 10% for overcast skies or warm, clear skies. This results in an error in the radiant heat transfer computations of approximately 20 W/m^2 for net emitted radiant energy and 4 W/m^2 for radiant energy transmitted by a single fabric layer.

6.0 REFERENCES

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APPENDIX A

COMPUTER PROGRAM FOR EVALUATION OF VIEW FACTORS BETWEEN CONCENTRIC DISKS

Appendix A. Computer Program For Evaluation Of View Factors Between Concentric Disks.

```
1: C
2:       PROGRAM CVIEW
3: C
4: C
5  C     THIS PROGRAM IS INTENDED FOR DETERMINING THE
6: C     VIEWFACTOR BETWEEN TWO SURFACES FOR USE IN RADIATIVE
7: C     HEAT TRANSFER PROBLEMS. THE PROGRAM MAKES USE OF THE
8: C     CONTOUR INTEGRAL FORMULATION INSTEAD OF THE
9: C     CONVENTIONAL AREA INTEGRAL.
10: C    THE INFORMATION ON THIS TECHNIQUE MAY BE FOUND IN:
11: C      SPARROW;A NEW AND SIMPLER FORMULATION FOR RADIATIVE
12: C           ANGLE FACTORS;J.OF HEAT TRANS.;C85;MAY1963.
13: C    IT USES A TRAPEZIODAL RULE TO DO THE INTEGRATION  THE
14: C    LIMITS OF THE CONTOURS AROUND THE TWO SURFACES, THE
15: C    AREA OF SURFACE "1" AND THE INCREMENTAL STEP SIZES ARE
16: C    READ IN AS DATA. THE DIRECTION OF THE INTEGRATION
17: C    AROUND THE CONTOURS IS SUCH THAT IF AN OBSERVER WERE
18: C    TO WALK AROUND THE CONTOUR IN THE DIRECTION OF THE
19: C    INTEGRATION WITH HIS HEAD POINTING IN THE DIRECTION
20: C    OF THE SURFACE NORMAL AT THE CONTOUR  THEN THE AREA
21: C    BOUNDED BY THAT CONTOUR WOULD ALWAYS LIE TO THE
22: C    LEFT OF THE OBSERVER.
23: C
24* C    THIS UPDATE PROGRAM IS FOR USE WITH CIRCULAR CONTOURS
25* C    LYING IN THE R-THETA PLANE.
26: C    THE CORRECT SOLUTION TO THIS PROBLEM MAY BE FOUND IN:
27: C      OZISIK; BASIC HEAT TRANSFER; MCGRAW-HILL
28: C
29. C    AREA1   = THE AREA OF THE FIRST SURFACE
30: C    LIMIT() = THE LIMITS OF THE CONTOURS AROUND THE
31: C              TWO SURFACES
32* C    R,THETA,Z = THE POLAR COORDINATES OF THE CONTOURS
33: C    F()     = THE VALUE OF THE INTEGRAND AT THE PRESCRIBED
34: C              COORDINATES
35: C    SUM     = THE RUNNING SUM OF THE INTEGRATION
36: C    HTRAP   = THE VALUE OF THE MULTIPLICATION OF THE
37: C              SEP SIZES.
38: C    FTRAP   = THE VALUE OF THE INTEGRAL FOR SPECIFIC
39: C              COORDINATES
40: C    ITRAP   = THE VALUE OF THE INTEGRAL OVER A PORTION
41: C              OF THE CONTOUR.
42: C    F12     = THE VALUE OF THE VIEWFACTOR BETWEEN
43: C              SURFACES ONE AND TWO.
44* C
45*      REAL LIMIT(12),THETASTEP,THETA1STEP,THETA2STEP,PI
46*      REAL R1,R2,Z1,Z2,FTRAP,F(4),HTRAP,ITRAP,SUM,AREA1
47*      REAL THETA1P,THETA2P
48* C
49*      DO 10 I=1,12
50*        LIMIT(I)=0.0
51*  10  CONTINUE
52* C
53*      PI=3.141592654
```

```
54*         SUM = 0.0
55* C
56*         LIMIT(2)=2*PI
57*         LIMIT(3)=2*PI
58* C
59*         READ(105,*) R1,R2,Z1,Z2,THETASTEP
60*         AREA1=PI*R1**2
61* C
62* C
63* C       THIS PORTION OF THE PROGRAM IS SET UP TO DETERMINE
64* C       THE VIEWFACTOR BETWEEN TWO CONCENTRIC HORIZONTAL
65* C       DISKS.
66* C
67*         THETA1STEP=THETASTEP
68*         THETA2STEP=-THETASTEP
69* C
70*         HTRAP=THETA1STEP*THETA2STEP
71* C
72*         DO 40 THETA1=LIMIT(1),LIMIT(2),THETA1STEP
73*            THETA1P=THETA1+THETA1STEP
74* C
75*            DO 30 THETA2=LIMIT(3),LIMIT(4) THETA2STEP
76*               THETA2P=THETA2+THETA2STEP
77* C
78*               F(1)=FUN(R1,THETA1,Z1,R2,THETA2,Z2)
79*               F(2)=FUN(R1,THETA1P,Z1,R2,THETA2,Z2)
80*               F(3)=FUN(R1,THETA1,Z1,R2,THETA2P,Z2)
81*               F(4)=FUN(R1,THETA1P,Z1,R2,THETA2P,Z2)
82*               FTRAP=0.0
83* C
84*               DO 20 I=1,4
85*                  FTRAP=FTRAP+F(I)
86*  20           CONTINUE
87* C
88*               ITRAP=HTRAP*FTRAP/4.0
89*               SUM=SUM+ITRAP
90* C
91*  30        CONTINUE
92*  40    CONTINUE
93:         F12=SUM/(AREA1*3.14159*2)
94: C
95:         WRITE(6,190) F12,AREA1
96:  190    FORMAT( 0 ,'THE VIEWFACTOR FROM SURFACE 1 TO 2 IS: ',
97:        + F10.7,/,' THE AREA OF SURFACE 1 IS: ',F10.3)
98: C
99:         RETURN
100:        END
```

```
1: C
2:       FUNCTION FUN(X1,Y1,Z1,X2,Y2,Z2)
3: C
4: C***** THIS FUNCTION EVALUATES THE INTEGRAND FOR THE
5  C***** CONTOUR INTEGRAL AT THE PRESCRIBED POINTS ON
6: C***** THE CONTOUR.
7: C
8* C
9*       REAL R,X1,X2,Y1,Y2,Z1,Z2
10* C
11* C     NOW, X,Y,Z REFER TO R,THETA,Z RESPECTIVELY
12* C
13*      COSY = COS(Y1-Y2)
14* C
15*      R=SQRT(X1**2+X2**2 2*X1*X2*COSY+(Z2 Z1)**2)
16*      FUN = LOG(R)*X1*X2*COSY
17: C
18:      RETURN
19:      END
```

APPENDIX B

EXAMPLES OF VIEW FACTOR ALGERBRA

It is assumed that the view factors between surfaces 1,2 and 3 of Figure B-1 are known by evaluating the view factor equation for these concentric disks (so chosen for the ease of evaluation of the view factor equation). From conservation of energy, the sum of all view factors from a surface must equal 1. The view factor from surface 3 to surface 5 can then be found from:

$$F_{35} + F_{32} = 1 \tag{B1}$$

Similarly:

$$F_{34} + F_{35} + F_{31} = 1 \tag{B2}$$

Alternatively:

$$F_{34} = F_{32} \times F_{24} \tag{B3}$$

Finding one view factor between two surfaces and knowing the surface areas of the two surfaces provides sufficient information to determine the remaining unknown view factor:

$$A_5 \times F_{53} = A_3 \times F_{35} \tag{B4}$$

as this relationship is required for conservation of radiant thermal energy.

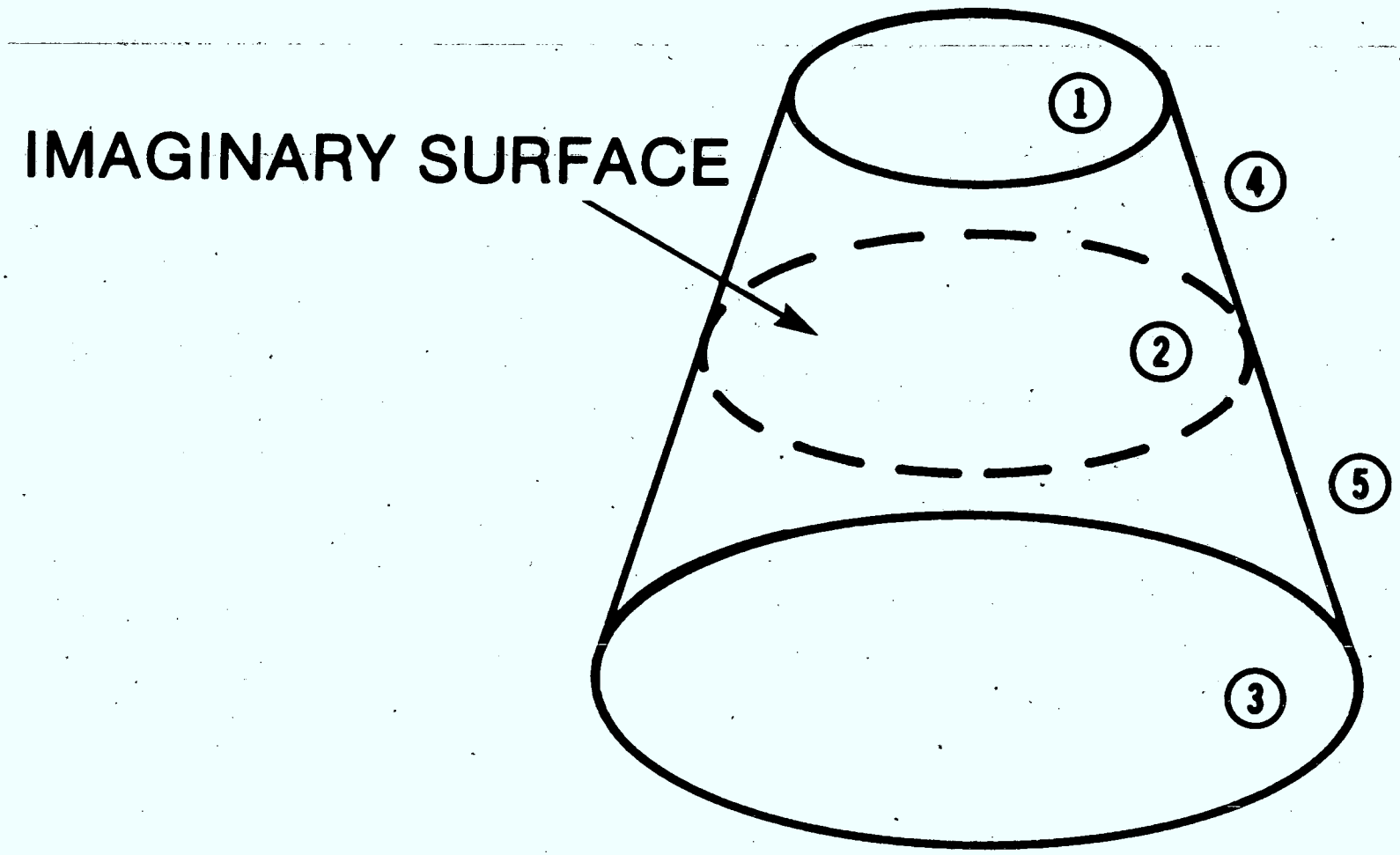

Figure B1. Example configuration for view-factor algebra.

APPENDIX C

COMPUTER PROGRAM FOR SOLUTION OF THE RADIATIVE HEAT TRANSFER IN TENTS

Appendix C. Computer Program For Solution Of The Radiative Heat Transfer In Tents.

```
      C
      PROGRAM RADQ
      C
      C
      C
      C     THIS PROGRAM IS INTENDED TO SOLVE THE SYSTEM OF
      C     EQUATIONS: M.R = T, TO DETERMINE THE RADIOSITIES
      C     FROM THE SURFACES OF AN ENCLOSURE
      C
      REAL M(20,20),RLI(20),T(20),TAMB,RHO(20),EPS(20)
      REAL SIGMA,DQ,D(20),MM(20,20),Z(20),RES(20)
      REAL FIJ(20,20),QMEAS,TSKY,QSKY,DELTA(20,20)
      REAL ROUT(20),RIN(20),RRI(20),TT(20),TOUT(20)
      REAL QNET(20)
      INTEGER NPIV(20),IND,L,N,EXPT,EQ
      C
      C
      READ(105,*) L,N
      READ(105,*) ((FIJ(I,J),J=1,N),I=1,N)
      READ(105,*) ((EPS(I),RHO(I)),I=1,N)
      SIGMA = 5.6696E-8
      C
      C     SET UP THE STIFFNESS MATRIX OF VIEWFACTORS AND RHO'S
      C
      DO 20 I=1,N
      C
         DO 10 J=1,N
      C
            IF(I.EQ.J)THEN
            DELTA(I,J) = 1.0
            ELSE
            DELTA(I,J) = 0.0
            END IF
      C
            M(I,J) = DELTA(I,J) - RHO(I)*FIJ(I,J)
            MM(I,J) = M(I,J)
      C
      10    CONTINUE
      C
      20 CONTINUE
      C
      C     DO THE LU DECOMPOSITION OF THE STIFFNESS MATRIX
      C
      CALL DCOMS(20,N,M,NPIV,D,IND)
      C
      C     READ IN THE TEMPERATURE DATA (REFERENCED TO AMBIENT)
      C
      DO 60 K=1,L
      C
      READ(105,*) QMEAS,EXPT,TAMB,QSKY
      READ(105,*) (T(I),I=1,N)
      TSKY = QSKY + SIGMA*(TAMB+273.16)**4
      C
      C     CONVERT TEMPERATURES TO RADIANT ENERGIES
```

```
1   55 C
1   56       DO 30 I=1,N
1   57 C
1   58          T(I) = SIGMA*(T(I)+TAMB+273.16)**4
1   59 C
1   60 C     EVALUATE THE AMBIENT BACKGROUND RADIANT ENERGIES
1   61 C
1   62          IF (I.EQ.1) THEN
1   63             TOUT(I) = T(I)
1   64          ELSE
1   65             TOUT(I) = TSKY
1   66          END IF
1   67 C
1   68 C     CONSTRUCT THE RIGHT HAND SIDE OF THE SYSTEM OF EQ.
1   69 C
1   70          TT(I) = EPS(I)*T(I) + (1-EPS(I)-RHO(I))*TOUT(I)
1   71 C
1   72  30   CONTINUE
1   73 C
1   74 C     SOLVE FOR RLI, THE INWARD FLUX FROM THE SURFACES
1   75 C
1   76       CALL SOLVE(20,N,M,NPIV,TT,RLI)
1   77       CALL IMPRV(20,N,MM,M,NPIV,TT,RLI,Z,RES)
1   78 C
1   79       PRINT *,' '
1   80       PRINT *,'EXPERIMENT NUMBER : ',EXPT
1   81       PRINT *,' '
1   82       PRINT *,' '
1   83       PRINT *,'SURFACE     NET HEAT       NET HEAT       NET HEAT'
1   84       PRINT *,'          LOSS AMBIENT  LOSS INTERNAL    LOSS TOTAL'
1   85       PRINT *,' '
1   86 C
1   87       DO 50 I=1,N
1   88 C
1   89 C     SUM UP THE INTERNAL,INBOUND ENERGIES TO EACH SURFACE
1   90 C
1   91       RRI(I) = 0.0
1   92 C
1   93          DO 40 J=1,N
1   94 C
1   95             RRI(I) = RRI(I) + FIJ(I,J)*RLI(J)
1   96 C
1   97  40      CONTINUE
1   98 C
1   99 C     COMPUTE THE NET HEAT LOSSES INTERNALLY, EXTERNALLY
1  100 C     AND TOTAL FOR EACH SURFACE
1  101 C
1  102          ROUT(I) = EPS(I)*T(I) - (1.-RHO(I))*TOUT(I) +
1  103      +             (1.-EPS(I)-RHO(I))*RRI(I)
1  104 C
1  105          RIN(I)  = RLI(I) - RRI(I)
1  106 C
1  107          QNET(I) = ROUT(I) + RIN(I)
1  108 C
```

```
1  109 C     PRINT OUT THE RESULTS
1  110 C
1  111 C
1  112       WRITE(106,100) I,ROUT(I),RIN(I),QNET(I)
1  113  100  FORMAT(' ',3X,I2,3(F15.2))
1  114 C
1  115  50   CONTINUE
1  116 C
1  117 C     PRINT OUT COMPARISON BETWEEN COMPUTED AND MEASURED
1  118 C     RADIANT HEAT TRANSFER AT THE FLOOR
1  119 C
1  120       PRINT *,' '
1  121       PRINT *,'COMPUTED RADIATIVE FLOOR HEAT LOSS = ',QNET(1)
1  122       PRINT *,'MEASURED RADIATIVE FLOOR HEAT LOSS = ',QMEAS
1  123       PRINT *,'                                      -------'
1  124       DQ = QNET(1) - QMEAS
1  125       PRINT *,'                          DIFFERENCE = ',DQ
1  126       EQ = ( DQ/QMEAS )*100
1  127       PRINT *,'                               ERROR = ',EQ,'%'
1  128       PRINT *,' '
1  129       PRINT *,' '
1  130       PRINT *,' '
1  131       PRINT *,' '
1  132 C
1  133 C
1  134  60   CONTINUE
1  135       STOP
1  136       END
2    1 C
2    2 C
2    3       SUBROUTINE DCOMS(NDIM,N,A,NPIV,D,IND)
2    4 C
2    5 C
2    6 C   THIS SUBROUTINE, DECOMPOSITION WITH SCALED PARTIAL PIVOTING,
2    7 C DOES GAUSSIAN ELIMINATION OR, EQUIVALENTLY, A TRIANGULAR (LU)
2    8 C FACTORIZATION OF THE N*N MATRIX STORED IN THE ARRAY "A".  AT
2    9 C COMPLETETION, THE "A" WILL CONTAIN THE LOWER TRIANGULAR MATRIX
2   10 C OF MULTIPLIERS USED IN THE ELIMINATION AS WELL AS THE UPPER
2   11 C TRIANGULAR MATRIX "U", THE RESULT OF THE ELIMINATION.
2   12 C
2   13 C   THE MATRIX IS ASSUMED TO BE SINGULAR IF EITHER SOME ROW IS
2   14 C ZERO INITIALLY, OR, SOME "SCALED" PIVOT DURING THE ELIMINATION
2   15 C IS SMALLER THAN UNIT ROUND-OFF.  IF THE FORMER HOLDS, THE
2   16 C DECOMPOSITION DOES NOT COMMENCE.  IN THE LATTER CASE, DCOMS
2   17 C WILL COMPLETE THE DECOMPOSITION BUT THE RESULTING UPPER
2   18 C TRIANGULAR MATRIX WILL BE SINGULAR.
2   19 C
2   20 C   THIS ROUTINE CAN BE USED IN CONJUNTION WITH THE ROUTINE
2   21 C SOLVE TO FIND THE SOLUTION TO A SYSTEM OF LINEAR EQUATIONS.
2   22 C     THE CURRENT MAXIMUM SIZE OF THE SYSTEM IS 50*50
2   23 C
2   24 C   TAKEN FROM: STUNT MANUAL; DEPT OF COMPUTER SCIENCE;U OF T
2   25 C
2   26 C
```

```
2   27 C   CALLING SEQUENCE:   CALL DCOMS(NDIM,N,A,NPIV,D,IND)
2   28 C
2   29 C   PARAMETERS:
2   30 C
2   31 C     NDIM       - AN INTEGER INDICATIONG THE NUMBER OF ROWS
2   32 C                  IN THE ARRAY "A" AS DECLARED IN THE
2   33 C                  CALLING PROGRAM.
2   34 C
2   35 C     N          - AN INTEGER CONSTANT INDICATING THE SIZE OF
2   36 C                  THE SYSTEM TO BE SOLVED
2   37 C
2   38 C     A          - A REAL 2-DIMENSIONAL ARRAY, OF SIZE NDIM*N
2   39 C                  HOLDING THE MATRIX TO BE DECOMPOSED.  ON
2   40 C                  RETURN, THE CONTENTS OF "A" ARE REPLACED
2   41 C                  BY THE LU FACTORIZATION.
2   42 C
2   43 C     NPIV       - AN INTEGER VECTOR, OF SIZE N, WHICH IS
2   44 C                  UNINITIALIZED AT THE TIME OF CALLING.  THIS
2   45 C                  ARRAY WILL RECORD THE REARRANGING OF THE
2   46 C
2   47 C     D          - A REAL VECTOR, OF SIZE N, THAT IS USED AS
2   48 C                  A WORKSPACE FOR THE SCALING OPERATION.  THIS
2   49 C                  ARRAY IS DECLARED BUT NOT INITIALIZED IN
2   50 C                  THE CALLING PROGRAM.
2   51 C
2   52 C     IND        - AN INTEGER INDICATING IF "A" IS SINGULAR OR NOT.
2   53 C                     IND = -1 ;  "SCALED" PIVOT < UNIT ROUND-OFF
2   54 C                         = 0 ;  "A" IS NONSINGULAR
2   55 C                  THIS PARAMETER IS NOT INITIALIZED AT THE TIME
2   56 C                  OF CALLING.
2   57 C
2   58 C
2   59         DIMENSION A(NDIM,NDIM),D(NDIM),NPIV(NDIM)
2   60         IND = 0
2   61 C
2   62 C   CHECH FOR A SYSTEM OF ONLY ONE UNKNOWN
2   63 C
2   64         IF (N.EQ.1) RETURN
2   65 C
2   66 C   INITIALIZE PIVOT AND D VECTORS
2   67 C
2   68         DO 20 I=1,N
2   69            NPIV(I) = I
2   70            D(I)=0.E0
2   71 C
2   72 C   THE LARGEST ABSOLUTE VALUES IN EACH ROW ARE RECORDED IN "D"
2   73 C
2   74            DO 10 J=1,N
2   75               D(I) = AMAX1(D(I),ABS(A(I,J)))
2   76   10       CONTINUE
2   77 C
2   78            IF (D(I).EQ.0.E0) D(I) = 1.E0
2   79   20    CONTINUE
2   80 C
```

```
2   81 C   MAIN LOOP FOR GAUSS ELIMINATION
2   82 C
2   83       NM1 = N-1
2   84 C
2   85       DO 80 I=1,NM1
2   86 C
2   87 C   DETERMINE THE LARGEST "SCALED PIVOT, IE,
2   88 C        MAX |A(J,I)/D(J)|, I<=J<=N
2   89 C
2   90          COLMAX = 0.0
2   91 C
2   92          DO 30 J=I,N
2   93             IP = NPIV(J)
2   94             HOLD = ABS(A(IP,I))/D(IP)
2   95             IF (HOLD.LE.COLMAX) GOTO 30
2   96             COLMAX = HOLD
2   97             NROW = J
2   98  30      CONTINUE
2   99 C
2  100 C  TEST FOR SINGULARITY.  THE MATRIX IS ASSUMED TO BE SINGULAR
2  101 C  IF COLMAX (THE ABS. VALUE OF THE SCALED PIVOT) IS EQUIVALENT
2  102 C  TO ZERO, IE, 1.0 + COLMAX = 1.0
2  103 C
2  104 C  IF THIS IS TRUE THEN THE ROUTINE PROCEEDS ON TO THE (I+1)TH
2  105 C  STAGE OF THE ELIMINATION
2  106 C
2  107         IF ((1.0+COLMAX) .NE. 1.0) GOTO 40
2  108          IND = -1
2  109          GOTO 80
2  110 C
2  111 C  IF AN INTERCHANGE IS NECESSARY, ALTER THE PIVOT VECTOR "NPIV"
2  112 C
2  113  40      IPIVOT = NPIV(NROW)
2  114          IF (NROW .EQ. I) GOTO 50
2  115          NPIV(NROW) = NPIV(I)
2  116          NPIV(I) = IPIVOT
2  117 C
2  118 C  THE MULTIPLIERS FOR THE COMPUTATION OF THE REMAINING ROWS ARE
2  119 C  DETERMINED AND ELINIMATION IS PERFORMED.  THE VALUE OF EACH
2  120 C  MULTIPLIER IS STORED IN THE POSITION OF THE ELIMINATED
2  121 C  ELEMENT.
2  122 C
2  123  50      IP1 = I+1
2  124          DO 70 J=IP1,N
2  125             JPIVOT = NPIV(J)
2  126             AMULT = A(JPIVOT,I)/A(IPIVOT,I)
2  127             A(JPIVOT,I) = AMULT
2  128 C
2  129             DO 60 K=IP1,N
2  130                A(JPIVOT,K)=A(JPIVOT,K)-AMULT*A(IPIVOT,K)
2  131  60         CONTINUE
2  132  70      CONTINUE
2  133  80   CONTINUE
2  134 C
```

```
2  135        TEST = 1. + ABS(A(NPIV(N),N))
2  136        IF (TEST .EQ. 1.) THEN
2  137        IND = -1
2  138        END IF
2  139 C
2  140        RETURN
2  141        END
```

```
3    1 C
3    2        SUBROUTINE SOLVE(NDIM,N,LU,NPIV,B,X)
3    3 C
3    4 C
3    5 C   THIS SUBROUTINE PERFORMS THE FORWARD AND BACKWARD SUBSTITUTIONS
3    6 C STEPS IN THE SOLUTION OF A SYSTEM OF LINEAR EQUATIONS AX=B.
3    7 C IT ASSUMES THAT THE TRIANGULAR (OR LU) FACTORIZATION OF A HAS
3    8 C ALREADY BEEN COMPUTED BY, SAY, THE ROUTINE DCOMP OR DCOMS.  IF
3    9 C EITHER ROUTINE INDICATES THAT "A" IS SINGULAR, THEN THE USE OF
3   10 C SOLVE MAY PRODUCE AN OVERFLOW INDICATION.
3   11 C
3   12 C
3   13 C   REPRODUCED FROM: STUNT MANUAL, DEPT OF COMPUTER SCIENCE, U OF T
3   14 C
3   15 C
3   16 C     CALLING SEQUENCE:   CALL SOLVE(NDIM,N,LU,NPIV,B,X)
3   17 C
3   18 C     PARAMETERS:
3   19 C
3   20 C        NDIM  -  AN INTEGER INDICATING THE NUMBER OF ROWS IN THE
3   21 C                 ARRAY "A" AS DECLARED IN THE CALLING PROGRAM
3   22 C
3   23 C        N     -  AN INTEGER CONSTANT INDICATING THE SIZE OF THE
3   24 C                 SYSTEM TO BE SOLVED.
3   25 C
3   26 C        LU    -  A REAL 2-D ARRAY OF SIZE NDIM*N CONTAINING THE
3   27 C                 LU DECOMPOSITON OF A.  THIS ARRAY IS NOT ALTERED
3   28 C                 BY SOLVE.
3   29 C
3   30 C        NPIV  -  AN INTEGER VECTOR, OF DIMENSION N, HOLDING THE
3   31 C                 PIVOT INFORMATION FOR THE ELIMINATION STEP.
3   32 C
3   33 C        X     -  A REAL VECTOR, OF SIZE N, THAT IS DECLARED BUT
3   34 C                 NOT INITIALIZED BY THE CALLING PROGRAM. ON
3   35 C                 RETURN, THIS ARRAY CONTAINS THE COMPUTED
3   36 C                 SOLUTION OF THE SYSTEM.
3   37 C
3   38 C        B     -  A REAL VECTOR, OF SIZE N, HOLDING THE RIGHT HAND
3   39 C                 SIDE OF THE ORIGINAL SYSTEM TO BE SOLVED.  THE
3   40 C                 CONTENTS OF THIS VECTOR ARE UNALTERED BY SOLVE.
3   41 C
3   42 C
```

```
3   43       DIMENSION B(NDIM),X(NDIM),NPIV(NDIM)
3   44       REAL LU(NDIM,NDIM)
3   45 C
3   46 C  CHECK FOR SYSTEM OF ONLY ONE UNKNOWN
3   47 C
3   48       IF (N.GT.1) GOTO 10
3   49       X(1) = B(1)/LU(1,1)
3   50       RETURN
3   51 C
3   52 C  FORWARD ELIMINATION ON "B".  THE RESULT IS PLACED IN X
3   53 C
3   54  10   KPIVOT = NPIV(1)
3   55       X(1)=B(KPIVOT)
3   56       DO 30 K=2,N
3   57          KPIVOT = NPIV(K)
3   58          KM1 = K-1
3   59          SUM = B(KPIVOT)
3   60          DO 20 J=1,KM1
3   61             SUM = SUM - LU(KPIVOT,J)*X(J)
3   62  20      CONTINUE
3   63          X(K) = SUM
3   64  30   CONTINUE
3   65 C
3   66 C  BACK SUBSTITUTION BEGINS
3   67 C
3   68       X(N) = X(N)/LU(KPIVOT,N)
3   69       K = N
3   70       DO 50 I=2,N
3   71          KP1 = K
3   72          K = K-1
3   73          KPIVOT = NPIV(K)
3   74          SUM = X(K)
3   75          DO 40 J = KP1,N
3   76             SUM = SUM - LU(KPIVOT,J)*X(J)
3   77  40      CONTINUE
3   78          X(K) = SUM/LU(KPIVOT,K)
3   79  50   CONTINUE
3   80 C
3   81       RETURN
3   82       END
```

```
4    1 C
4    2 C
4    3       SUBROUTINE IMPRV(NDIM,N,A,LU,NPIV,B,X,Z,R)
4    4 C
4    5 C
4    6 C GIVEN AN APPROXIMATE SOLUTION FOR A LINEAR SYSTEM OF EQUATIONS
4    7 C THIS SUBROUTINE CARRIES OUT ONE ITERATION OF THE ITERATIVE
4    8 C IMPROVEMENT PROCESS FOR COMPUTING A BETTER APPROXIMATE SOLUTION.
4    9 C IT IS ASSUMED THAT BOTH THE ORIGINAL MATRIX AND ITS LU
```

```
C DECOMPOSITION ARE AVAILABLE.  THIS SUBROUTINE CAN BE USED
C IN CONJUNCTION WITH THE SUBROUTINES DCOMP, DCOMS AND SOLVE
C TO FIND THE SOLUTION OF A LINEAR SYSTEM OF EQUATIONS.
C
C     TAKEN FROM: STUNT MANUAL, DEPT OF COMPUTER SCIENCE, U OF T
C
C     CALLING SEQUENCE:    CALL IMPRV(NDIM,N,A,LU,NPIV,B,X,Z,R)
C
C     PARAMETERS:
C
C        NDIM      -  AN INTEGER CONSTANT INDICATING THE NUMBER OF
C                     ROWS IN THE ARRAYS, "A" AND "LU" AS DECLARED
C                     IN THE CALLING PROGRAM
C
C        N         -  AN INTEGER CONSTANT INDICATING THE NUMBER OF
C                     UNKNOWNS IN THE SYSTEM
C
C        A         -  A REAL 2-D ARRAY OF SIZE NDIM*N HOLDING THE
C                     ORIGINAL MATRIX.  THIS ARRAY IS NOT ALTERED BY
C                     IMPRV.
C
C        LU        -  A REAL 2-D ARRAY OF SIZE NDIM*N HOLDING THE
C                     LU DECOMPOSITON OF THE ORIGINAL MATRIX.  THIS
C                     ARRAY IS NOT ALTERED BY IMPRV
C
C        NPIV      -  A INTEGER VECTOR OF SIZE N HOLDING THE PIVOT
C                     INFORMATION FROM THE ELIMINATION STEP.
C
C        B         -  A REAL VECTOR OF SIZE N HOLDING RIGHT HAND
C                     SIDE OF THE ROIGINAL SYSTEM TO BE SOLVED. THIS
C                     ARRAY IS NOT ALTERED BY IMPRV.
C
C        X         -  A REAL VECTOR OF SIZE N HOLDING THE INITAL
C                     APPROXIMATE SOLUTION. ON RETURN THIS VECTOR
C                     WILL CONTAIN THE IMPROVED APPROXIMATION
C
C        Z         -  A REAL VECTOR OF SIZE N WHICH IS DECLARED BUT
C                     NOT INITIALIZED BY THE CALLING PROGRAM.  ON
C                     RETURN Z WILL CONTAIN THE CORRECTIONS TO THE
C                     GIVEN APPROXIMATE SOLUTION
C
C        R         -  A REAL VECTOR OF SIZE N WHICH IS DECLARED BUT
C                     NOT INITIALIZED BY THE CALLING PROGRAM.  ON
C                     RETURN "R" WILL CONTAIN THE RESIDUAL R=B-AX
C                     WHERE X IS THE INITIAL APPROXIMATE SOLUTION.
C                     DOUBLE PRECISION ARITHMETIC IS USED IN
C                     COMPUTING "R"
C
C
      REAL*8 AA,XX,SUM
      DIMENSION A(NDIM,NDIM),Z(NDIM),R(NDIM),NPIV(NDIM)
      DIMENSION B(NDIM),X(NDIM),LU(NDIM,NDIM)
C
C CALCULATE THE RESIDUALS
```

```
4   64 C
4   65       DO 20 I=1,N
4   66          SUM = B(I)
4   67          DO 10 J=1,N
4   68             AA=A(I,J)
4   69             XX=X(J)
4   70             SUM=SUM-AA*XX
4   71   10     CONTINUE
4   72          R(I) = SUM
4   73   20  CONTINUE
4   74 C
4   75 C THE RESIDUAL SYSTEM IS SOLVED
4   76 C
4   77       CALL SOLVE(NDIM,N,LU,NPIV,R,Z)
4   78 C
4   79 C THE IMPROVED APPROXIMATION IS COMPUTED
4   80 C
4   81       DO 30 I=1,N
4   82          X(I)=X(I)+Z(I)
4   83   30  CONTINUE
4   84 C
4   85       RETURN
4   86       END
```

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13. ABSTRACT

Radiant heat transfer was analyzed for tents consisting of single layer fabric walls which are capable of partially transmitting thermal radiation. External radiant temperatures were uniform. Radiant heat loss from the tent surface to the external surroundings was found theoretically to represent approximately 25% of the total heat loss from the tent. Theoretical predictions of the fraction radiated to the floor of the tent, based on experimentally determined surface temperatures, agreed to within an order of magnitude with the measured radiant heat flux to the floor. Signal noise and measurement precision affected these experimental results. An empirical equation for predicting sky temperature was compared with measured sky temperature and was found to underestimate the sky temperature by approximately 10%.

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