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THERMOD, an Enhanced Thermal Model for Determining Aircraft Operational Temperatures

December 2004

Final Report

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16. Abstract

An enhanced version of a thermal analysis computer program called THERMOD was developed for determining the maximum operating limit (MOL) temperatures of general aviation aircraft. The project was undertaken under a Federal Aviation Administration-AGATE sponsorship. This report is the second of two reports prepared in conjunction with this project. Enhancements included program debugging and corrections as well as development of an alternate implicit finite difference method, which is used in transient analysis. Numerical validation of THERMOD was undertaken with respect to the finite element methods. Good correlation was found. The validated THERMOD can be used to determine the MOL temperatures of a typical aircraft that has a low wing configuration.

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LIST OF ACRONYMS

EFFDM	Explicit forward finite difference method
FAA	Federal Aviation Administration
FEM	Finite element method
IBFDM	Implicit backward finite difference method
MOL	Maximum operating limit
SPC	

EXECUTIVE SUMMARY

Composite aircraft structural elements are unfavorably affected by an increase in temperature due to exposure to the thermal environment. For design purposes, the synergistic effects of extreme ambient temperatures and the accompanying solar radiation should be taken into consideration in determining the maximum operating limit (MOL) temperatures experienced by the structural elements. Allowable design properties of composite materials may then be generated based on these MOL temperatures. THERMOD is a computer model that was developed for determining the MOL temperatures for aircraft under various paint schemes. The selected low-wing geometry is best suited to general aviation aircraft.

In determining the MOL temperatures, THERMOD considers the effects of radiation, convection, and conduction. Radiation includes direct solar radiation, infrared sky radiation, and their reflections from the tarmac. Infrared emission from the surrounding structures, including the tarmac, wings and the fuselage and its interaction among these structures, are also considered. Convection due to the wind, as well as turbulent convection within the cabin, is also simulated, as are one-dimensional conduction through element thickness. The model incorporates the effect of fillets at the wing-fuselage junction. Due consideration is also given to the greenhouse effect within the cabin, which allows for a realistic modeling of the thermal environment within the cabin. The effect of shade underneath the wing is also modeled.

The soaked temperatures of an aircraft are predicted based on steady-state assumptions, giving conservative steady-state temperatures. Because limit loads generally occur in flight conditions, a transient (unsteady-state) thermal analysis is used to simulate the thermal conditions while the aircraft executes the following maneuvers: taxi, takeoff, climb, and cruise. These maneuvers are cooling effects that in addition to intentional cooling of the cabin through opening the door simulate a more realistic thermal environment for predicting the MOL temperature.

THERMOD formulates a total of 67 independent equations within a nonlinear system of equations. The nonlinearity is introduced through radiation effects and through convective properties with the cabin, which are modeled as temperature-dependent. This system of equations is solved using the Newton-Raphson iteration technique.

This report is the third of four reports prepared in conjunction with this project. The fourth report is entitled “THERMOD User’s Manual,” and it will serve as an instructive guide for users who wish to use THERMOD for determining aircraft MOL temperatures. The first two reports validated THERMOD analyses with test data and studied the sensitivity to input variables.

The enhanced version of THERMOD was developed for simulating the MOL temperatures of general aviation aircraft. Enhancements included program debugging and corrections as well as development of an alternate implicit finite difference method. This method for solving the transient problem is unconditionally stable over all time and spatial domain as opposed to the existing explicit forward finite difference method. Numerical validation of THERMOD was undertaken with respect to the finite element methods. Good correlation was found.

1. INTRODUCTION.

An enhanced version of an original thermal analysis computer program called THERMOD [1] has been developed for simulating maximum operating limit (MOL) temperatures for general aviation aircrafts. This project was undertaken under a Federal Aviation Administration (FAA)-AGATE sponsorship.

This report is the third of four reports prepared in conjunction with this project. The fourth report, "THERMOD User's Manual," serves as a guide for users who wish to use THERMOD for determining aircraft MOL temperatures [2]. The first two reports validated THERMOD analyses with test data and studied the sensitivity to input variables [3 and 4].

To help the reader get acquainted with THERMOD, background information on pertinent thermal aspects of the program and input data requirements are presented. This is followed by a statement of the project objectives. A more complete description of THERMOD and the development of model equations can be found in the original THERMOD document [1].

1.1 BACKGROUND.

Structural components strength and sharpness of composite airframe are unfavorably affected by an increase in their temperatures due to exposure to the thermal environment. For design purposes, the combined effects of extreme ambient temperature and the accompanying solar radiation should be taken into consideration in determining the MOL temperatures experienced by the structural elements. Design properties of composite materials may then be generated based on these MOL temperatures. THERMOD was developed for determining the MOL temperatures of low-wing aircraft under various paint schemes.

In determining the MOL temperatures, THERMOD considers the effects of radiation, convection, and conduction. Radiation includes direct solar radiation, infrared sky radiation, and their reflections from the tarmac. Infrared emission from the surrounding elements, including the tarmac, wings, fuselage, and its interaction among these elements, are also considered. Convection due to the wind as well as turbulent convection within the cabin is also simulated, as are one-dimensional conduction through element thickness. The model incorporates the effect of fillets at the wing-fuselage junction. Due consideration is also given to the greenhouse effect within the cabin that allows for a realistic modeling of the thermal environment within the cabin. The effect of shade underneath the wing is also modeled.

In addition to the above factors, the following assumptions are made in THERMOD: (1) nonparticipating medium (air); (2) discretized space and time domains; (3) discretized elements being isothermal, opaque, diffuse, gray and characterized by uniform radiosity, irradiation, and material properties; (4) nonopaque materials such as windows and windshields are considered transparent with associated transmissivity values; and (5) constant material properties with respect to time (and, hence, temperature). These assumptions are necessary in simplifying the complexities involved in a three-dimensional thermal problem being addressed.

The soaked temperatures of an aircraft are predicted based on steady-state assumptions, giving conservative steady-state temperatures. Because limit loads generally occur in flight conditions,

a transient (unsteady-state) thermal analysis is used to simulate the thermal conditions while the aircraft executes the following maneuvers: taxi, takeoff, climb, and cruise. These maneuvers are cooling effects that in addition to intentional cooling of the cabin through opening the door simulate realistic thermal environment for predicting the MOL temperature.

THERMOD formulates a total of 67 independent equations within a nonlinear system of equations. The nonlinearity is introduced through radiation effects and through convective properties with the cabin, which are modeled as temperature-dependent. This system of equations is solved using the Newton-Raphson iteration technique [5].

As previously noted, THERMOD considers all three heat transfer mechanisms (convection, conduction, and radiation) normally associated with an aircraft parked in the open. Figure 1-1 is a schematic representation of a thermal environment showing short wavelength solar radiation, long wavelength sky (infrared) radiation, convective heat transfer due to the wind, and one-dimensional conduction (through the thickness). THERMOD also considers reflected solar energy between the fuselage and wing, diffused solar energy reflected from the tarmac, and infrared reflections. The fillets and greenhouse effects are considered as well. Because THERMOD simulates a total of 67 independent equations, 67 unknowns are needed. These unknowns are 53 temperatures and 14 radiosites. The 53 temperatures (T1 through T53) and their locations are noted in figure 1-1.

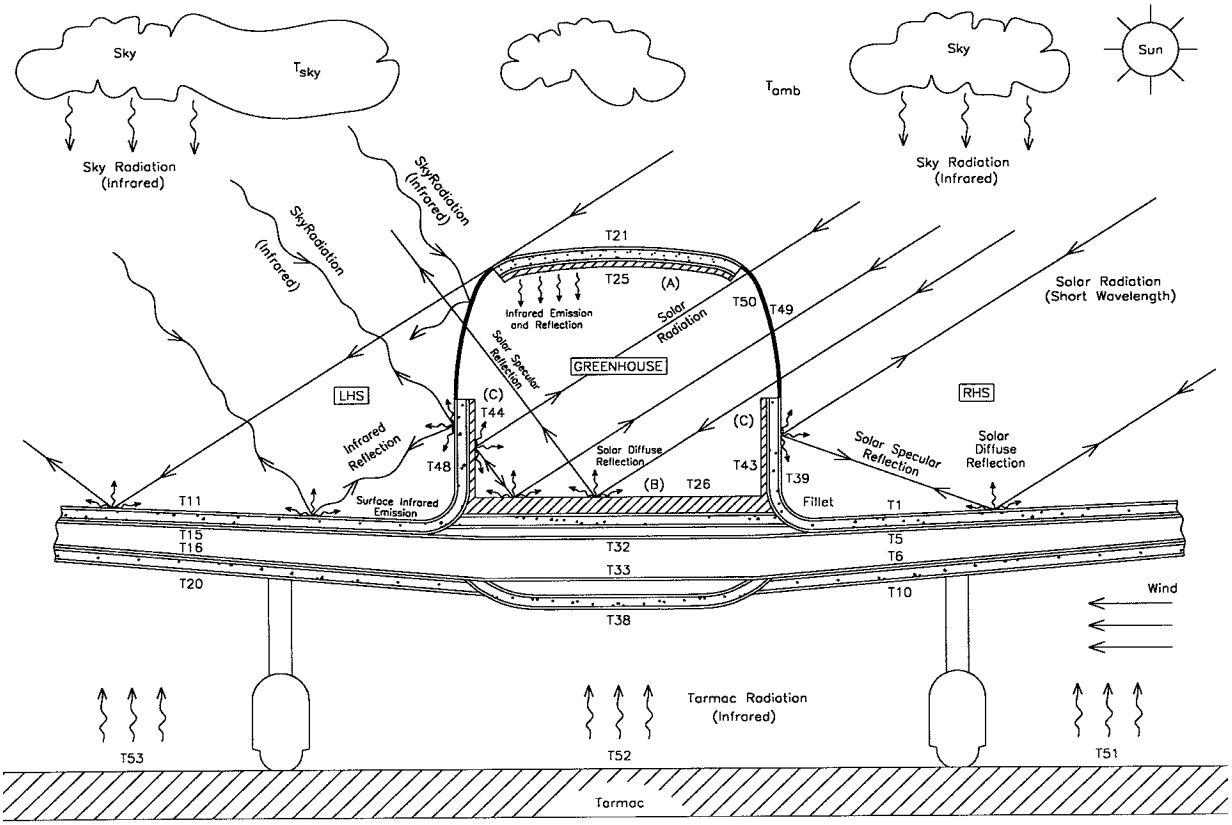


FIGURE 1-1. A SCHEMATIC PRESENTATION OF THERMOD

Note that not all the unknown temperatures are shown. T2, for example, is located immediately below T1 at the skin-core interface (see figure 1-2 for further clarity). Similarly, T27 is located immediately below T26 at the insulatory material B-composite floor interface.

The geometry of the aircraft shown is low wing with sandwich construction for skins. The sandwich can be either foam or honeycomb. Nonsandwich skins are also admissible if the thickness of the core is assumed to be very small.

A typical THERMOD analysis begins at the steady-state phase and continues on to the transient phase; a phase in which cooling is introduced due to aircraft maneuvers. At the point of application of limit or gust load, the temperatures at all 53 locations are noted. Of these 53 temperatures, 9 temperatures are considered nonstructural. These nonstructural temperatures are the three tarmac temperatures (T51, T52, and T53); four insulatory material temperatures (T25, T26, T43, and T44); and two transparent material temperatures (T49 and T50), leaving 44 temperatures to be considered structural.

THERMOD repeats its analysis over different time periods, as requested. The maximum temperature over these time periods is then reported as the MOL temperature. This MOL temperature may be located at the surface (depending on how dark the paint is), inside the cabin, within the floor space, or located anywhere else in the aircraft.

1.2 THERMOD GEOMETRY AND INPUT DATA.

Figure 1-1 showed a typical cross section of a small general aviation aircraft. A simplified rendering of the model is shown in figure 1-2. THERMOD is built on this simplified model. Figure 1-2 also shows typical sections at critical locations. In addition to the overall geometry as indicated in figure 1-2, a set of input data characterizing each layer, as shown in figure 1-3, is also needed. The layer properties include thickness, density, thermal conductivity, and specific heat capacity. To consider surface effects, all exposed aircraft surfaces are assigned their respective absorptivity and emissivity values. These values are dependent on paint color and surface texture. The tarmac is also considered a surface, whose surface and other thermal properties are required as well. THERMOD models the greenhouse and fillet effects. Transmissivity and fillet color information is needed to consider these two effects. The degree of greenhouse effect is also dependent on the percentage of transparent material. This information is input in the form of transparent surface area in relation to the overall cabin surface area. To simulate convective coefficients, the kinematic viscosity and Prandtl number are needed. Because the aircraft is left out in the open, it is subjected to the environment. The climatic data of the environment, for each time period, includes ambient temperature, sky temperature, solar radiation, and wind speed.

The final piece of information concerns the cooling that takes place when the aircraft executes the following maneuvers: taxi, takeoff, climb, and cruise. This data was furnished through a flight profile that is unique to a particular aircraft and is part of the input. The flight profile provides information on typical aircraft maneuvering speed with respect to time, from which, the time-varying convective coefficient is determined. This coefficient is then used in the subsequent transient cooling process. An example flight profile is shown in figure 1-4.

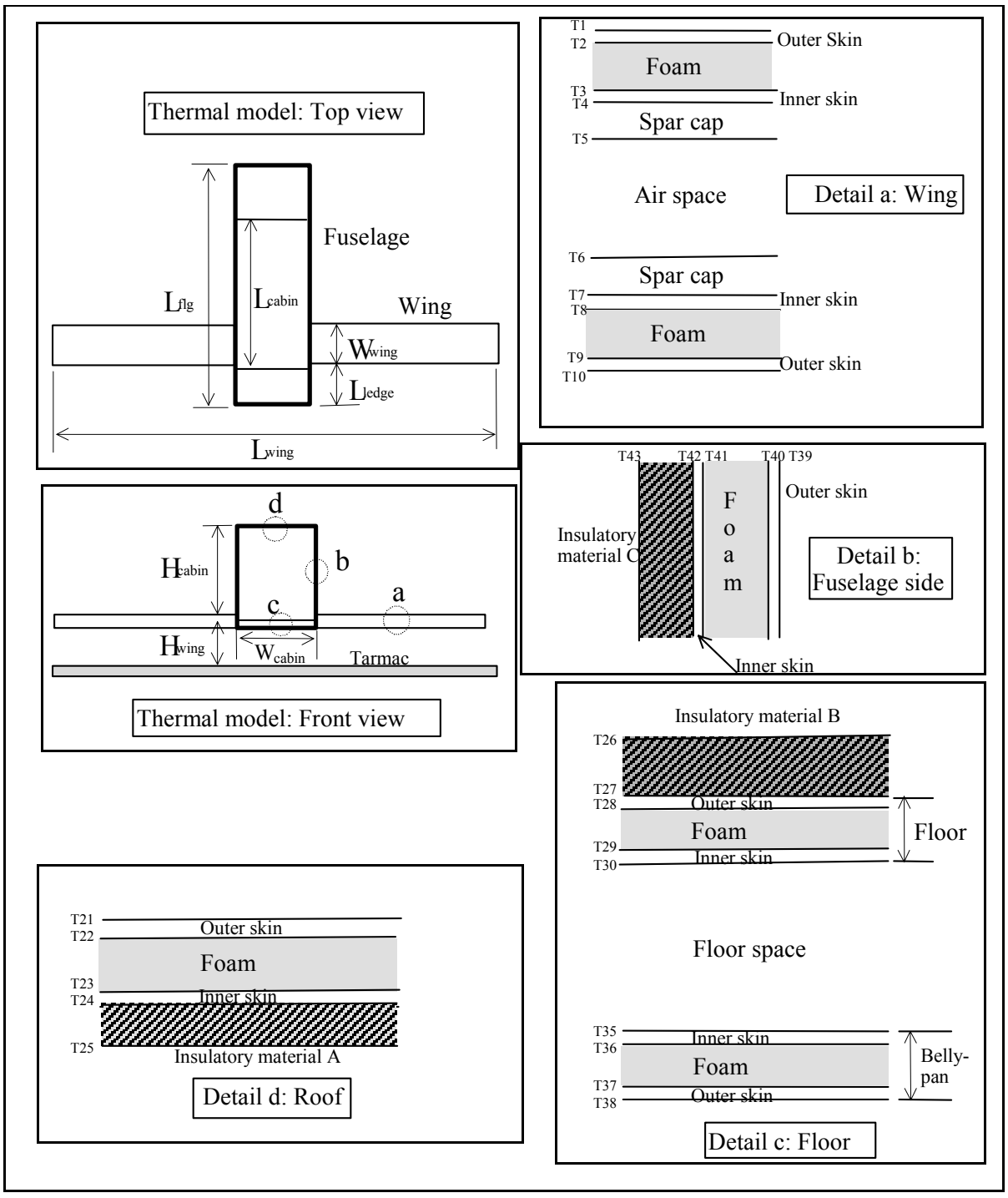


FIGURE 1-2. OVERALL MODEL GEOMETRY AND TYPICAL TEMPERATURE PROFILES AT CRITICAL LOCATIONS

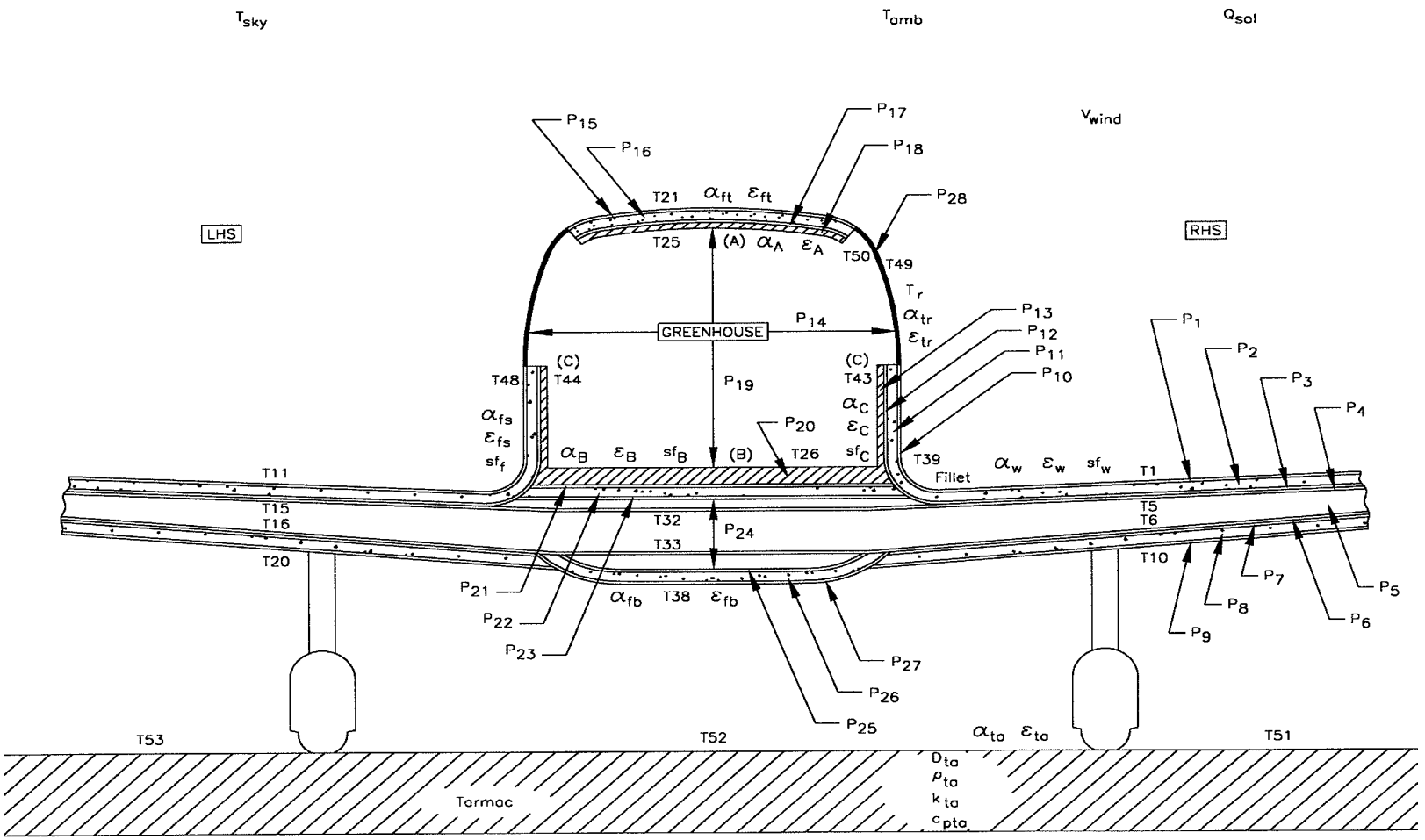


FIGURE 1-3. INPUT THERMAL PROPERTIES FOR THE THERMOD MODEL

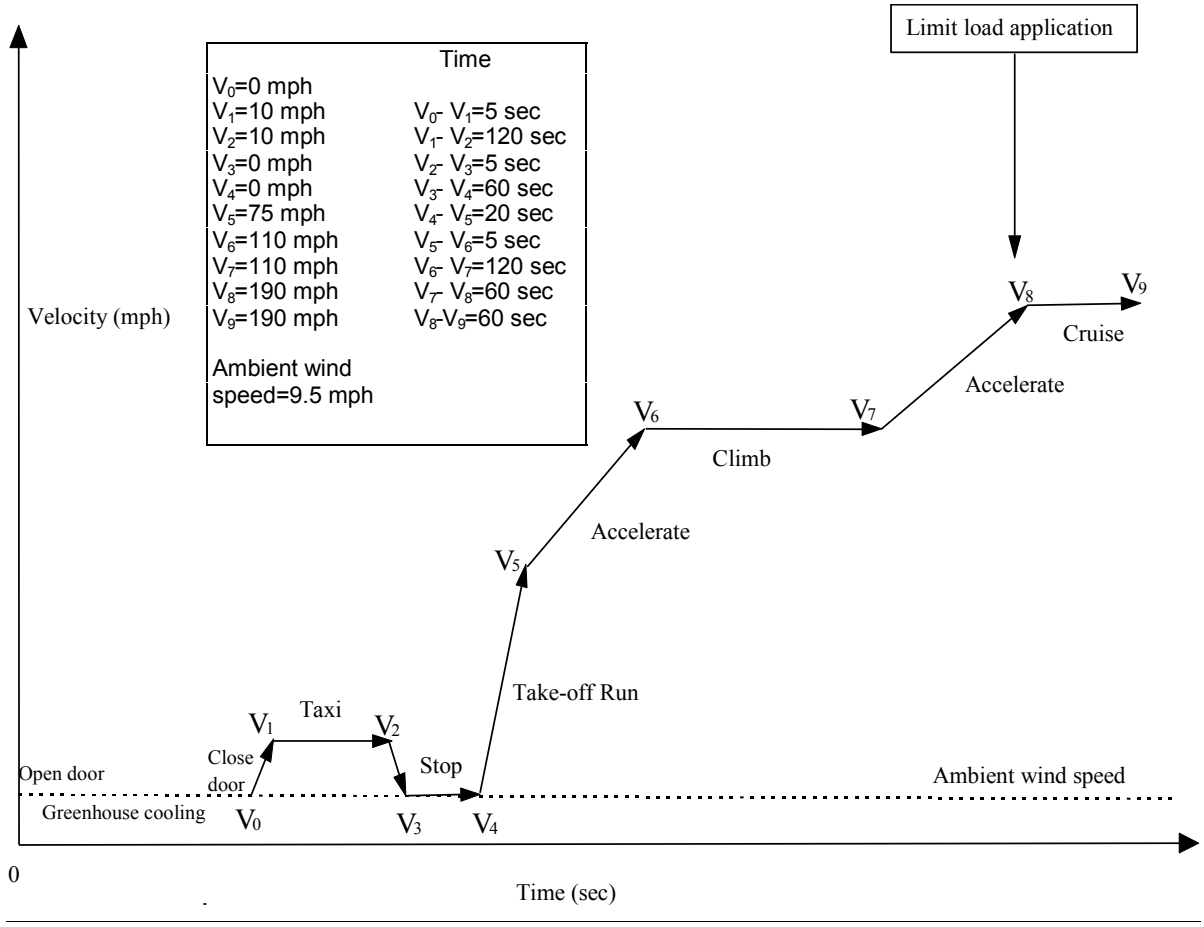


FIGURE 1-4. A TYPICAL FLIGHT PROFILE DURING TRANSIENT COOLING

Fuselage is modeled as a box and treated as an enclosure in modeling the greenhouse effect. The fuselage roof is treated as a surface with an equivalent transmissivity, allowing solar radiation to enter the cabin. The insulatory materials (A), (B), and (C) are simplified representations of cabin roof interior, cabin floor, and cabin side interiors.

A total of 28 distinct layers are considered. Each layer, labeled P_1 to P_{28} in figure 1-3, is assigned four properties, i.e., thickness, density, thermal conductivity, and specific heat capacity. The tarmac is regarded as a special layer and also characterized by these four properties, as indicated in figure 1-3. The eight exposed surfaces are assigned absorptivity (α)or emissivity (ε) properties, depending on their surface texture and color. The wing, fuselage, and the interior (B) and (C) surfaces are assigned scatter factors (*sf*). The aircraft is subjected to climatic factors that include solar radiation (Q_{sol}), wind (V_{wind}), ambient temperature (T_{amb}), and sky temperature (T_{sky}).

Cooling is assumed to occur as soon as the door is opened. The greenhouse cooling duration is a function of the soaked steady-state ambient temperature of the cabin and of the tolerable ambient temperature desired before closing the door. This tolerable temperature, arbitrarily selected, is

input into THERMOD as *ambcabt*. The MOL temperature is determined at the point when limit load is applied. This moment in time is located at 395 seconds from point V_0 , as shown in figure 1-4. The ambient wind speed is added to the flight speed to give the total relative wind speed. THERMOD uses this relative wind speed at selected times to determine convective coefficient, which is a required input in the cooling process.

1.3 PROJECT OBJECTIVES.

The objectives of the project were to

- Debug, identify, and correct the existing errors in THERMOD.

- develop and validate an alternate transient solution process based on the implicit backward finite difference method (IBFDM). The existing transient model in THERMOD is based on the explicit forward finite difference method (EFFDM), which is not unconditionally stable. The solution to some problems may not converge. An IBFDM, however, guarantees convergence by virtue of it being unconditionally stable across all time and spatial domain.

- undertake numerical validation of THERMOD, with respect to the finite element methods (FEM). The three modes of heat transfer, i.e., conduction, convection, and radiation, were investigated. In addition, both the steady-state analysis and the transient analysis were considered.

- solve a sample aircraft problem. The problem entailed developing input data sets and determining the MOL temperature of a typical small aircraft.

2. DEBUGGING AND PROGRAM CORRECTIONS.

Several bugs were detected in the older THERMOD program [1]. This section discusses these bugs and presents remedial actions that were taken to correct them.

2.1 BUG 1.

BUG 1 caused occasional program nonconvergence. The problem was traced to subroutine updradio. This subroutine updates radiosity at each time step of the transient analysis.

Radiosity is defined as the total energy leaving a surface, which includes both infrared reflection and emission. There are a total of 14 radiosity functions in THERMOD. Two of these radiosity functions were found to be in error. The infrared emission terms in these functions were inadvertently left out. The subroutine is called from either subroutine trnsien1 or trnsien2, depending on whether the EFFDM or IBFDM is selected. Subroutine updradio in turn calls subroutines ludcmp and lubksb.

The two radiosities affected were J_{12} and J_{14}. In both functions, the infrared emission effect of the tarmac were inadvertently left out, which are shown below:

- function J_{12} : sig*t(51)**4/((1-emista)/emista)
- function J_{14} : sig*t(53)**4/((1-emista)/emista)

These errors have been fixed by including the terms in the appropriate locations. Simulation runs of sample problems were found to converge.

2.2 BUG 2.

BUG 2 occasionally produced negative temperatures in some of the 53 temperatures that defined THERMOD, which is not necessarily an error. In the solution process, the nonlinear solution routine determines the temperature values that satisfy user input tolerances for temperatures or thermal functions. As long as one of the tolerances are satisfied, the solution is said to have converged, regardless of whether there are any negative temperatures found as part of the solution. Mathematically, the solution is correct.

The variable-based convergence criterion must satisfy the following condition:

$$\frac{\sum_{j=1}^{67} abs\left(X_{j_{i+1}} - X_{j_i}\right)}{\sum_{j=1}^{67} X_{j_{i+1}}} \leq tolx \qquad (2\text{-}1)$$

where:

$X_{j_{i+1}}$ = The current value of the unknown variable X_j
X_{j_i} = The previous value of the unknown variable X_j

The function-based convergence criterion must satisfy the following condition:

$$\frac{\sum_{j=1}^{67} abs\left(fn_{j_{i+1}} - fn_{j_i}\right)}{\sum_{j=1}^{67} fn_{j_{i+1}}} \leq tolf \qquad (2\text{-}2)$$

where:

$fn_{j_{i+1}}$ = The current value of the function fn_j
fn_{j_i} = The previous value of the function fn_j

In the older version of THERMOD, when either of these two criteria were satisfied, the solution was completed. Because of this approach, both the tolerances were not satisfied at the same time. In the current version of THERMOD, both criteria must be satisfied simultaneously before the program exits. This is enforced through the statement

"if(errf.le.tolf.and.errx.le.tolx) goto 20"

This dual enforcement removed the problem of negative temperatures for sample problems considered.

2.3 BUG 3.

BUG 3 prevented solution convergence for certain laminate thickness or when too small a time step was used. This problem occurs only in the transient phase of THERMOD. This problem was caused by the EFFDM. This method is not unconditionally stable and is the only method found in the original THERMOD program. An alternate finite difference method IBFDM, was developed to solve this problem. Simulation studies demonstrated that IBFDM has effectively eliminated this problem.

The IBFDM is unconditionally stable over all spatial and time domain [6]. This stability is attributed to the fact that, unlike EFFDM, IBFDM considers the transient problem as a system of equations to be solved in a simultaneous manner. This imparts stability to the solution process and allows the use of less refined spatial discretization and larger time steps. The advantages of IBFDM over EFFDM come, however, at the expense of more complex programming and bookkeeping procedures. In THERMOD, for example, the development of the IBFDM necessitated the rearrangement of the transient equations, their assembly into a set of simultaneous equations, their nonlinear solution using the Newton-Raphson iteration technique [5], and the retrieval of the solved transient temperatures. These solution steps require a substantial increase in computing time. However, this increase in computing time may be offset by the use of less refined spatial discretization and larger time steps, exploiting the inherent stability of IBFDM.

The following section discusses the development of the algorithm for IBFDM followed by an example problem substantiating IBFDM with respect to the existing EFFDM. In addition, an example problem will be presented that will illustrate the inherent stability of IBFDM over EFFDM.

2.4 ALGORITHM DEVELOPMENT FOR IBFDM.

IBFDM in THERMOD can be conceptually viewed as a procedure that recognizes the fact that the temperature of a point in space at a certain instance in time is dependent on the temperatures of all other points that are directly associated with that point. The temperature of each of these other points in turn has its own dependence on temperatures and other points associated with it, and so on. One then notices a chain-like link being formed among all transient temperatures of a system. A unique solution for this link exists for every time step, and only a system of simultaneous equations will provide this solution. THERMOD sets up these equations, assembles them, solves them, and retrieves the transient temperatures for each time step requested.

The governing equation of the transient heat transfer process is based on the formula

$$\dot{E}_{in} \quad - \quad \dot{E}_{out} \quad = \quad \Delta\dot{E} \tag{2-3}$$

Where $\dot{E}_{in}$ = rate of incoming energy; $\dot{E}_{out}$ = rate of outgoing energy; and $\Delta\dot{E}$ = rate of energy gain or energy lost. A positive $\Delta\dot{E}$ indicates energy is gained, while a negative $\Delta\dot{E}$ indicates energy is lost. A zero $\Delta\dot{E}$ implies a steady-state system where there is no gain or lost of energy in the system. Note that equation 2-3 does not include the effect of energy generation, which is certainly absent in the case of an aircraft parked in the open.

The implementation of the IBFDM transient programming rests on setting up equation 2-3 for each one of the control volumes defined in the system and solving the resulting set of simultaneous equations.

The procedure can be demonstrated by developing the equation for control volume 3 shown in figure 2-1. This control volume may be viewed to be within the wing of an aircraft where the surface effects are absent. The only mode of heat transfer in this region is conduction. Only through thickness, one-dimensional conduction is assumed. Along-wing span and along-wing width conduction were neglected in THERMOD to produce conservative temperatures.

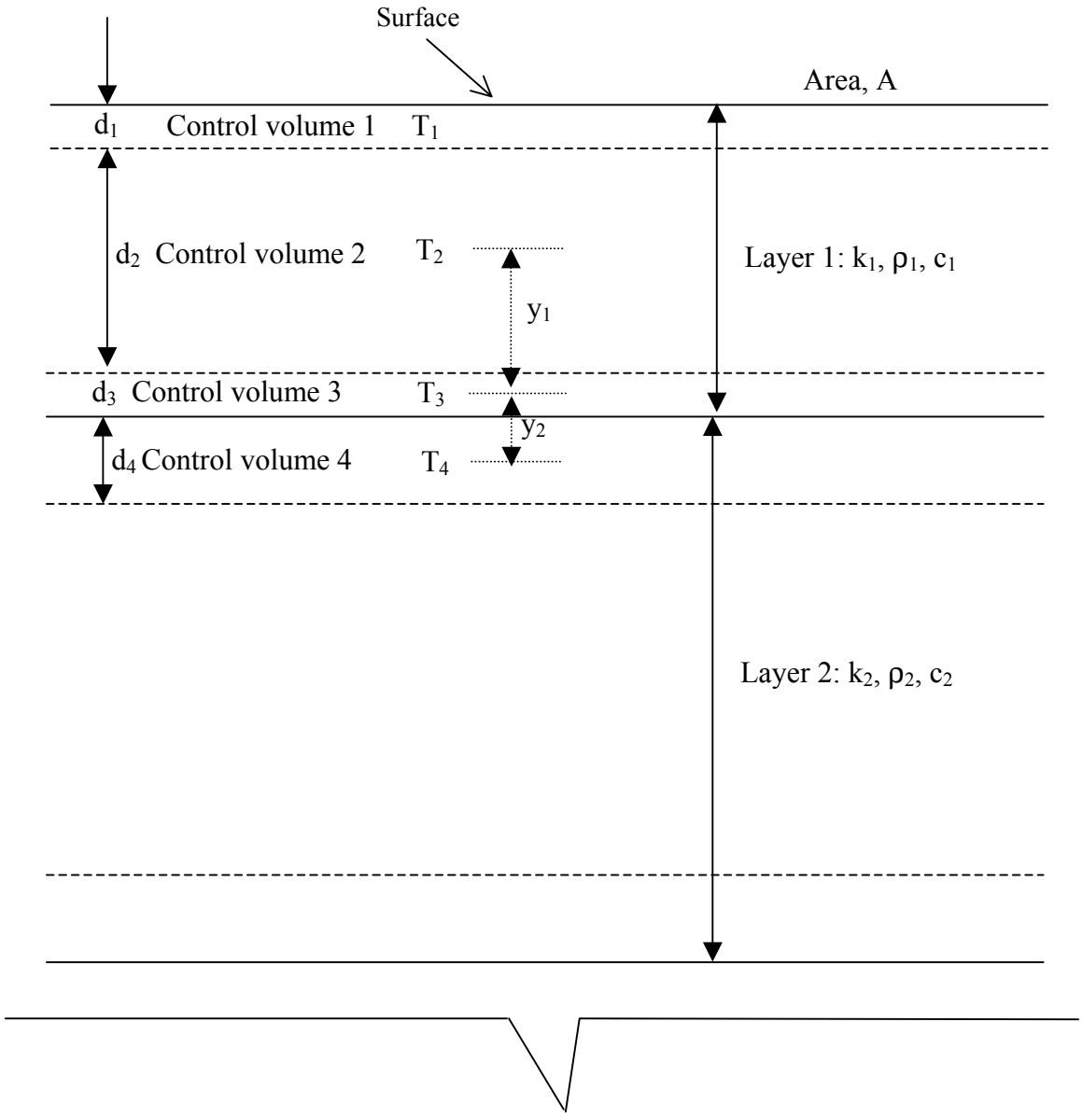


FIGURE 2-1. CONTROL VOLUMES FOR DEVELOPING THERMAL EQUATIONS

In developing the equations, it is assumed that the reader has a basic understanding of the principles of heat transfer. For an overview of the mathematical derivation of the three modes of heat transfer, i.e., conduction, convection, and radiation, the reader is referred to reference 1.

From figure 2-1, for control volume 3 with cross-sectional area A

$$\dot{E}_{in} = k_a \frac{T_2^{i+1} - T_3^{i+1}}{y_1} A \quad \text{where } y_1 = \frac{1}{2}(d_2 + d_3)$$

$$k_a = \frac{(\frac{d_2}{2} + \frac{d_3}{2})}{\frac{\frac{d_2}{2}}{k_1} + \frac{\frac{d_3}{2}}{k_1}}$$

$$\dot{E}_{out} = k_b \frac{T_3^{i+1} - T_4^{i+1}}{y_2} A \quad \text{where } y_2 = \frac{1}{2}(d_3 + d_4)$$

$$k_b = \frac{(\frac{d_3}{2} + \frac{d_4}{2})}{\frac{\frac{d_3}{2}}{k_1} + \frac{\frac{d4}{2}}{k_2}}$$

$$\Delta\dot{E} = m c_1 \frac{T_3^{i+1} - T_3^i}{\Delta t}$$

where: m = mass of the control volume = $\rho_1 A d_3$
ρ_1 = density of the control volume
c_1 = specific heat capacity of the control volume
Δt = time step

In the above equations, T^{i+1} represents new temperature, which is an unknown quantity, and T^i represents the previous temperature, which is a known quantity.

Substituting the above expressions for $\dot{E}_{in}$, $\dot{E}_{out}$, and $\Delta\dot{E}$ into equation 2-3 gives

$$k_a \frac{T_2^{i+1} - T_3^{i+1}}{y_1} A - k_b \frac{T_3^{i+1} - T_4^{i+1}}{y_2} A = \rho_1 A d_3 c_1 \frac{T_3^{i+1} - T_3^i}{\Delta t}$$

Eliminating A, and rearranging, one obtains:

$$a_1 T_2^{i+1} + a_2 T_3^{i+1} + a_3 T_4^{i+1} = a_4 T_3^i \qquad (2\text{-}4)$$

where:

$$a_1 = \frac{k_a}{y_1}$$

$$a_2 = \left(-\frac{k_a}{y_1} - \frac{k_b}{y_2} - \frac{\rho_1 d_3 c_1}{\Delta t} \right)$$

$$a_3 = \frac{k_b}{y_2}$$

$$a_4 = -\frac{\rho_1 d_3 c_1}{\Delta t}$$

Note that in equation 2-4, a_1, a_2, a_3, a_4, and T^i are known quantities. The unknowns are T_2^{i+1}, T_3^{i+1}, and T_4^{i+1}. It is observed that equation 2-4 is implicit, in that there are more than one unknown. To solve this equation, one needs to create another equation representing the control volume adjacent to the current one. This equation would contain other unknown temperatures. Thus, one needs to develop a series of equations representing all control volumes that were used to define the thermal system, before a unique solution for the set of new temperatures, T^{i+1} could be found.

The difference between IBFDM and EFFDM can be observed by studying the derivation of equation 2-4. Had $\dot{E}_{in}$ and $\dot{E}_{out}$ been defined in terms of the previous temperatures, the only unknown in equation 2-4 would have been T_3^{i+1}, and this would have rendered the equation explicit. Because $\dot{E}_{in}$ and $\dot{E}_{out}$ were expressed in terms of the new temperatures, which are unknown quantities, equation 2-4 was rendered implicit.

In THERMOD, a total of 39 control volumes were created, resulting in 117 unknown temperatures, T^{i+1}. Note that each control volume was designed to have three temperatures, as illustrated in the derivation of the equations above. Twenty-seven of the control volumes were within the structure where the only mode of heat transfer was by means of conduction, as was illustrated in the above sample equations. The remaining twelve control volumes represented surface elements where convection and radiation effects, in addition to conduction effects, were considered. The 117 equations were assembled and subsequently solved using the nonlinear Newton-Raphson iteration procedure. A description of this procedure is found in references 3 and 4. Note that the nonlinear solution procedure is required for two reasons. First, infrared radiation, a capability modeled in THERMOD, follows the Stefan-Boltzman Law, which is based on a nonlinear formulation, where radiation $R = \sigma T^4$. In this formulation, the temperature, T, is an unknown quantity. Second, the convection coefficient within the cabin was modeled to be dependent on temperatures, which again, are an unknown quantity.

The transient solution is initiated by treating the temperatures obtained from the steady-state analysis as the initial set of previous temperatures. The solved new temperatures are then treated as the previous temperatures in the next time step. The analysis is repeated until a solution satisfying a required set of tolerance in temperatures and functions is obtained. Once solved, the 117 temperatures are retrieved, from which only the 53 temperatures defining THERMOD are reported. (See figures 1-1 and 1-2 to locate these temperatures.)

As indicated, THERMOD is a thermal system with 67 unknowns, where 53 of the unknowns are temperatures and 14 are radiosity. Radiosity is defined as the radiative flux that leaves a surface, and it includes both the reflected irradiation as well as emission [6]. Because THERMOD depends on temperatures, it follows that radiosity will change with time in a transient environment. This change in radiosity is implemented in THERMOD by updating its value using the new temperatures determined at the end of each time step.

The various subroutines, their definitions, and the program flow chart addressing IBFDM are contained in appendix A.

The development of IBFDM required extensive rearrangement of the transient equations, substantial bookkeeping, a nonlinear solution of the resulting simultaneous equations, and data retrieval. These extra efforts were expected to increase the computing resources. This was indeed the case. The amount of computing time spent was vastly different for the previous two problems. The EFFDM solution process took less than 1 minute, while the IBFDM took about 90 minutes.

As was previously noted, the primary purpose of IBFDM was to overcome probable instability problems that may arise using EFFDM. The substantial increase in the computing effort of IBFDM, however, seems to be a worthwhile price to pay, given that a potential stability problem was solved and satisfactory results are expected. It is also noted that because IBFDM is inherently stable regardless of the time step duration, the computing effort may be substantially reduced by increasing the time step until accuracy of the solution is not affected.

3. NUMERICAL VALIDATION OF THERMOD.

This section presents the numerical validation of THERMOD with respect to FEMs. A total of eight problems were formulated and solved using the THERMOD program and then the FEM programs. The results from both methods of analysis were then compared.

It was beyond the scope of this project to develop a complete FEM thermal model of an aircraft. The FEM sample problems were, thus, kept as simple as possible and were yet able to capture the three fundamental modes of heat transfer mechanisms, i.e., conduction, convection, and radiation. The problems, where possible, addressed each transport mechanism individually first, then progressed into more complex thermal systems involving a combination of these mechanisms.

In developing sample input files for THERMOD, all 15 sets of data defining the entire thermal problem of an aircraft must be generated and used in all sample problems. This is because, unlike the FEM methods, THERMOD was not developed as a general-purpose thermal program. It was designed to solve a very specific thermal problem associated with an aircraft subjected to the thermal environment. While the solution process in itself is rather complex, the inputs to the program were designed to be simple and straightforward. Because of this constraint, aircraft problems in its entirety will be solved in THERMOD during this validation exercise. The FEM methods, however, are not subject to this constraint.

Of the eight validation problems solved, six involved steady-state analysis. The other two involved both steady-state and transient analyses. The FEM models of the six steady-state problems were analyzed using UAI/NASTRAN software. The FEM models of the two combined steady-state and transient problems were analyzed using MSC/NASTRAN software. The primary reason for using two different FEM packages was that the thermal module of the UAI/NASTRAN package was found to be deficient in the transient analysis. It lacked a time-dependent convective coefficient, which is needed in analyzing transient cooling, where air is forced over the aircraft while maneuvering according to various flight profile information. The MSC/NASTRAN thermal module was found to have this capability.

To have a better understanding of the sample problems presented in this section, it is helpful to be familiar with the THERMOD User's Manual [2], which gives a complete description of input data sets, variable definitions, formats, and other general information. Only information directly relevant to the validation problems will be discussed in detail in this section, while the discussion of other data will be kept to a minimum.

It is assumed that the reader have a working knowledge of the FEM methods, sufficient to decipher NASTRAN input data decks. The relevant FEM information pertaining to NASTRAN can be found in the following documents: UAI/NASTRAN User's Reference Manual [7], UAI/NASTRAN User's Guide [8], MSC/NASTRAN Quick Reference Guide [9], MSC/NASTRAN User's Guide [10], MSC/NASTRAN Command Reference Guide [11], and MSC/NASTRAN Thermal Analysis User's Guide [12].

3.1 SAMPLE PROBLEM 1.

The purpose of sample problem 1 was to illustrate the conduction mechanism of the heat transfer process. Table 3-1 shows the THERMOD input file, input.dat, of sample problem 1. As previously noted, a total of 15 sets of data must always be used to complete a successful run of THERMOD. These sets of data define a thermal problem of a complete aircraft.

TABLE 3-1. THERMOD INPUT FILE (input.dat) OF SAMPLE PROBLEM 1

```
198e-6,0.704
1, 0.020,125,0.300,0.30
2, 0.375,4.4,0.021,0.24
3, 0.020,125,0.300,0.30
4, 0.350,125,0.300,0.30
5, 10.70,0.067,0.016,0.24
6, 0.350,125,0.300,0.30
7, 0.020,125,0.300,0.30
8, 0.375,4.4,0.021,0.24
9, 0.020,125,0.300,0.30
10,0.030,125,0.300,0.30
11,0.375,4.4,0.021,0.24
12,0.020,125,0.300,0.30
13,0.250,10.,0.020,0.24
14,48.00,0.067,0.016,0.24
15,0.020,125,0.300,0.30
16,0.375,4.4,0.021,0.24
17,0.020,125,0.300,0.30
18,0.250,10.,0.020,0.24
19,30.00,0.067,0.016,0.24
20,5.000,10.,0.020,0.24
21,0.020,125,0.300,0.30
22,0.375,4.4,0.021,0.24
23,0.020,125,0.300,0.30
24,2.500,0.067,0.016,0.24
25,0.020,125,0.300,0.30
26,0.375,4.4,0.021,0.24
27,0.020,125,0.300,0.30
28,0.250,130,0.800,0.20
3.5,34.0,2.5,5.5,22.0,11.0,3.0,4.0,30,24,28
0.70,0.9,0.9,2.0,150,0.80,0.22
0.3,0.9,0.3,0.9,0.3,0.9,0.1,0.9
3,100
0.9,0.9,0.9,0.9
0.95,0.47,0.3,0.8,0.95,0.47,0.95,0.47
9
0,10,10,0,0,75,110,110,190,190
5,120,5,60,20,5,120,60,60
```

TABLE 3-1. THERMOD INPUT FILE (input.dat) OF SAMPLE PROBLEM 1 (Continued)

```
7
60 570.67 459.67 14 330 10 10 0.36
75 573.67 459.67 14 355 10 10 0.31
90 578.67 459.67 14 355 10 12 0.33
75 581.67 459.67 14 330 10 10 0.31
60 582.67 459.67 14 291 10 10 0.36
45 583.67 459.67 14 231 10 10 0.44
30 582.67 459.67 14 160 10 10 0.57
2,100,180,1
10,1.0,1.0
10,10,10,10,10,10,10,10,10,10,10,10,10,10,10,
10,10,10,10,10,10,10,10,10,10,10,10,10,10,10,
10,10,10,10,10,10,10,10,10,10,10,10,10,10,10,
10,10,10,10,10,10,10,10,10,10,10,10,10,10,10,
10,10,10,10,10,10,10
```

For comparison purposes with the FEM method, the focus was on the right wing of the aircraft. (The right wing is indicated by RHS in figure 1-1.) As illustrated in the input.dat file of table 3-1, the right wing was modeled as follows:

- Layer 1: 0.02-in.-thick top outer fiber glass skin
- Layer 2: 0.375-in.-thick top foam core
- Layer 3: 0.02-in.-thick top inner fiber glass skin
- Layer 4: 0.35-in.-thick top fiber glass spar cap
- Layer 5: 10.70-in.-deep air space between the top and bottom spar caps
- Layer 6: 0.35-in.-thick bottom fiber glass spar cap
- Layer 7: 0.02-in.-thick bottom inner fiber glass skin
- Layer 8: 0.375-in.-thick bottom foam core
- Layer 9: 0.02-in.-thick bottom outer fiber glass skin

The summary.dat file of table 3-2 summarizes the results of the THERMOD analysis. As observed in table 3-2, a total of seven time periods were involved in the THERMOD analysis. Steady-state temperature results obtained for time period 3 was chosen for comparison purposes with the FEM method. A total of 10 temperature locations were identified on the right wing, as illustrated in figure 1-1. These 10 temperatures from the top to the bottom are T1, T2…..T10. Their values were extracted from table 3-2 and summarized in table 3-3. The results indicated that the top surface of the wing, because of its exposure to the sun, was hotter than the lower surface, which was more sheltered. There was a significant difference in temperature between the upper cap (T5) and the lower cap (T6). This was attributed to the 10.70 in. of air (which has low thermal conductivity) that separates them.

TABLE 3-2. THERMOD OUTPUT FILE (summary.dat) OF SAMPLE PROBLEM 1

```
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
THERMOD:  A THERMAL PROGRAM FOR AIRCRAFTS
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$



 SUMMARY OF STEADY-STATE AND TRANSIENT ANALYSIS



 (Temperatures are shown for all time periods)


 TEMPERATURES AT THE END OF STEADY STATE ANALYSIS

        TEMPERATURES IN DEGREES FAHRENHEIT
         1     2     3     4     5     6     7

  1 124.0 132.5 136.1 134.0 126.4 115.2 102.8
  2 124.0 132.5 136.1 134.0 126.4 115.2 102.8
  3 123.7 132.2 135.8 133.7 126.2 115.3 103.0
  4 123.7 132.2 135.8 133.7 126.2 115.3 103.0
  5 123.7 132.2 135.8 133.7 126.2 115.3 103.0
  6 114.4 120.2 124.7 124.6 121.1 116.3 110.5
  7 114.3 120.2 124.7 124.6 121.1 116.4 110.5
  8 114.3 120.2 124.7 124.6 121.1 116.4 110.5
  9 114.1 119.9 124.4 124.3 121.0 116.4 110.7
 10 114.1 119.9 124.4 124.3 121.0 116.4 110.7
 11 122.1 131.4 135.9 132.9 124.8 113.5 101.4
 12 122.1 131.4 135.9 132.9 124.8 113.5 101.4
 13 121.9 131.1 135.6 132.7 124.7 113.6 101.6
 14 121.9 131.1 135.6 132.7 124.7 113.6 101.6
 15 121.9 131.1 135.6 132.7 124.7 113.6 101.6
 16 114.3 120.2 124.7 124.6 121.1 116.3 110.5
 17 114.3 120.2 124.7 124.6 121.1 116.3 110.5
 18 114.3 120.2 124.7 124.6 121.1 116.3 110.5
 19 114.1 119.9 124.4 124.3 121.0 116.4 110.7
 20 114.1 119.9 124.4 124.3 121.0 116.4 110.7
 21 205.8 225.9 231.9 222.2 200.7 169.4 134.2
 22 205.8 225.8 231.8 222.1 200.7 169.5 134.2
 23 207.4 216.5 217.2 213.6 202.4 180.2 143.1
 24 207.4 216.4 217.2 213.6 202.4 180.2 143.1
 25 208.4 209.9 206.9 207.6 203.6 187.7 149.4
 26 198.9 198.2 195.5 196.8 195.4 183.4 146.2
 27 150.5 153.0 154.4 155.5 153.6 146.5 127.6
 28 150.4 153.0 154.4 155.4 153.6 146.5 127.6
```

TABLE 3-2. THERMOD OUTPUT FILE (summary.dat) OF SAMPLE PROBLEM 1 (Continued)

```
  29 147.0 149.8 151.5 152.5 150.6 143.9 126.3
  30 147.0 149.8 151.5 152.5 150.6 143.9 126.3
  31 131.8 135.6 138.7 139.6 137.5 132.4 120.5
  32 131.8 135.6 138.7 139.6 137.5 132.4 120.5
  33 131.8 135.6 138.7 139.6 137.5 132.4 120.5
  34 131.8 135.6 138.7 139.6 137.5 132.4 120.5
  35 116.7 121.5 125.8 126.6 124.5 120.8 114.7
  36 116.7 121.5 125.8 126.6 124.4 120.8 114.7
  37 113.2 118.3 122.9 123.7 121.5 118.2 113.3
  38 113.2 118.3 122.9 123.7 121.4 118.2 113.3
  39 199.5 179.7 148.8 180.0 196.6 194.7 173.9
  40 199.5 179.7 148.9 180.1 196.6 194.6 173.9
  41 197.6 186.6 168.7 186.2 194.5 188.4 162.3
  42 197.6 186.6 168.8 186.2 194.5 188.4 162.3
  43 196.2 191.4 182.7 190.5 193.1 184.1 154.2
  44 191.8 188.5 182.6 187.8 189.2 180.4 151.1
  45 169.9 170.8 168.7 171.5 170.2 161.4 138.9
  46 169.8 170.7 168.7 171.5 170.0 161.3 138.8
  47 138.6 145.3 148.8 148.2 142.9 134.1 121.3
  48 138.4 145.2 148.7 148.0 142.7 133.9 121.2
  49 145.6 148.6 149.7 150.4 147.7 139.7 123.0
  50 147.6 150.5 151.3 152.1 149.5 141.3 123.9
  51 113.6 120.8 125.1 123.7 118.1 110.0 100.6
  52 108.2 115.1 119.2 118.0 112.7 105.1  96.2
  53 113.6 120.8 125.1 123.7 118.1 110.0 100.6

Maximum Structural Temperature for Period   1 = 207.37 Occurring
at Location  24
Maximum Structural Temperature for Period   2 = 225.86 Occurring
at Location  21
Maximum Structural Temperature for Period   3 = 231.88 Occurring
at Location  21
Maximum Structural Temperature for Period   4 = 222.15 Occurring
at Location  21
Maximum Structural Temperature for Period   5 = 202.43 Occurring
at Location  24
Maximum Structural Temperature for Period   6 = 194.68 Occurring
at Location  39
Maximum Structural Temperature for Period   7 = 173.92 Occurring
at Location  39

Maximum Structural Temperature Over All     7 Periods =231.88
Occurring at Location  21 at Period   3
```

TABLE 3-2. THERMOD OUTPUT FILE (summary.dat) OF SAMPLE PROBLEM 1 (Continued)

```
 TEMPERATURES AT THE END OF TRANSIENT ANALYSIS

        TEMPERATURES IN DEGREES FAHRENHEIT
          1     2     3     4     5     6     7

  1 112.9 116.8 121.7 123.8 123.4 122.5 119.8
  2 113.2 117.3 122.2 124.1 123.5 122.3 119.2
  3 122.9 131.1 134.8 133.0 126.0 115.7 104.1
  4 123.2 131.5 135.2 133.3 126.1 115.6 103.7
  5 123.2 131.6 135.2 133.3 126.0 115.4 103.5
  6 114.6 120.5 125.0 124.9 121.3 116.5 110.6
  7 114.3 120.1 124.6 124.6 121.3 116.7 111.0
  8 114.3 120.0 124.5 124.6 121.3 116.9 111.3
  9 112.7 116.6 121.6 123.8 123.6 123.1 120.9
 10 112.7 116.4 121.4 123.7 123.7 123.3 121.2
 11 112.7 116.8 121.7 123.8 123.3 122.4 119.7
 12 113.0 117.2 122.1 124.0 123.3 122.1 119.1
 13 121.3 130.1 134.6 132.1 124.6 114.2 102.9
 14 121.5 130.5 135.0 132.3 124.6 114.0 102.4
 15 121.5 130.6 135.0 132.3 124.6 113.8 102.2
 16 114.5 120.4 124.9 124.8 121.2 116.4 110.5
 17 114.3 120.1 124.6 124.6 121.2 116.6 111.0
 18 114.2 120.0 124.5 124.6 121.3 116.8 111.2
 19 112.7 116.6 121.6 123.8 123.6 123.1 120.9
 20 112.7 116.4 121.4 123.7 123.7 123.3 121.2
 21 125.4 131.3 136.7 137.5 134.8 130.9 124.7
 22 127.4 133.3 138.7 139.3 136.4 132.3 125.2
 23 181.2 187.5 192.2 187.4 180.5 171.4 140.3
 24 183.1 189.2 193.8 188.9 182.0 172.9 140.9
 25 200.7 202.6 205.1 200.1 195.7 189.2 147.8
 26 185.7 185.5 187.8 185.4 184.4 181.0 145.5
 27 150.7 153.2 154.6 155.7 153.8 146.7 127.7
 28 149.5 152.1 153.7 154.7 152.8 145.8 127.3
 29 146.5 149.3 151.2 152.1 150.2 143.7 126.3
 30 145.7 148.6 150.4 151.4 149.5 143.1 126.0
 31 131.5 135.1 138.2 139.3 137.7 133.2 121.9
 32 131.5 135.1 138.2 139.3 137.7 133.2 121.9
 33 131.5 135.1 138.2 139.3 137.7 133.2 121.9
 34 131.5 135.1 138.2 139.3 137.7 133.2 121.9
 35 117.2 121.6 125.9 127.3 125.8 123.2 117.7
 36 116.4 120.7 125.2 126.5 125.2 122.7 117.5
 37 112.1 115.7 120.6 123.1 123.4 123.4 121.5
 38 112.0 115.5 120.5 123.0 123.3 123.4 121.6
 39 121.2 122.3 123.8 129.2 131.3 131.5 127.8
 40 123.2 124.0 125.1 130.7 133.0 133.1 128.7
```

TABLE 3-2. THERMOD OUTPUT FILE (summary.dat) OF SAMPLE PROBLEM 1 (Continued)

```
  41 172.1 166.9 160.2 168.7 173.2 172.1 150.2
  42 173.6 168.3 161.6 170.0 174.5 173.3 150.8
  43 183.1 179.5 176.6 179.9 182.2 181.5 152.3
  44 179.2 177.0 176.6 177.6 178.7 178.0 149.3
  45 162.3 161.7 161.5 163.9 164.5 162.3 141.2
  46 160.8 160.3 160.1 162.6 163.2 161.0 140.6
  47 121.5 123.0 125.1 129.8 131.5 131.4 127.2
  48 120.0 121.6 123.8 128.6 130.3 130.3 126.7
  49 123.6 126.8 131.0 132.5 132.0 130.4 123.1
  50 127.8 130.8 134.8 136.0 135.3 133.2 123.9
  51 169.1 187.2 193.0 184.0 164.8 137.5 109.0
  52 157.9 174.6 180.0 172.0 154.5 129.7 103.8
  53 169.1 187.2 193.0 184.0 164.8 137.5 109.0

Maximum Structural Temperature for Period   1 = 183.07 Occurring
at Location  24
Maximum Structural Temperature for Period   2 = 189.17 Occurring
at Location  24
Maximum Structural Temperature for Period   3 = 193.83 Occurring
at Location  24
Maximum Structural Temperature for Period   4 = 188.86 Occurring
at Location  24
Maximum Structural Temperature for Period   5 = 181.98 Occurring
at Location  24
Maximum Structural Temperature for Period   6 = 173.32 Occurring
at Location  42
Maximum Structural Temperature for Period   7 = 150.75 Occurring
at Location  42

Maximum Structural Temperature Over All     7 Periods =193.83
Occurring at Location  24 at Period   3
```

TABLE 3-3. THERMOD-SIMULATED TEMPERATURES (°F) OF THE RIGHT WING OF SAMPLE PROBLEM 1

T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
136.1	136.1	135.8	135.8	135.8	124.7	124.7	124.7	124.4	124.4

An FEM model of the wing was developed based on the information used in the THERMOD model. One-half of the wing was modeled as a 17-ft-long structure with layer properties as indicated above. A total of 153 CQUAD4 elements, each 0.001 ft thick, was employed, resulting in a total of 324 grid points (nodes). Material properties, representing conductivity, were assigned using MAT4 cards. PSHELL cards were used to assign the thickness and material properties for each of the element.

Boundary conditions were imposed along the outer nodes of the model. Recall that the objective of this sample problem was to validate the conductive aspect of THERMOD. The FEM boundary conditions were then set such that all top surface nodes assumed the value of T1 (136.1°F), and all bottom surface nodes assumed the value of T10 (124.4°F), whose values were obtained from the earlier THERMOD analysis. The outer left and right most edges of the wing were assigned boundary temperatures of 124.4°F, thus completely encapsulating the FEM model. The temperature profile across the wing depth is now entirely due to conduction. Table 3-4 illustrates the FEM input file.

TABLE 3-4. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 1

```
ID D:\Natha,MSC/N
APP HEAT
SOL 1
TIME 10000
CEND
  TITLE = CONDUCTION IN RECTANGULAR ADIABATIC PLATE (t=0.001ft)
  SUBTITLE = 10.7 in gap filled by air; k=0.016BTU/hr/ft/degF
   SPC = 1
   THERMAL= ALL
   FLUX = ALL
   SPCF = ALL
BEGIN BULK
$ ***************************************************************************
$   Written by : MSC/NASTRAN for Windows
$   Version    : 6.00
$   Translator : UAI/NASTRAN
$   From Model : D:\Thermod_Validation\FEM\conduction_only.MOD
$   Date       : Mon Mar 06 11:27:09 2000
$ ***************************************************************************
$
PARAM,K6ROT,100.
PARAM,MAXRATIO,1.E+8
CORD2C         1       0      0.      0.      0.      0.      0.    1.+MSC/NC1
+MSC/NC1      1.      0.      1.
CORD2S         2       0      0.      0.      0.      0.      0.    1.+MSC/NC2
+MSC/NC2      1.      0.      1.
$ MSC/NASTRAN for Windows Constraint Set 1 : steady-state_bound-temp
SPC            1       1       1  124.4
SPC            1      20       1  124.4
SPC            1      21       1  124.4
SPC            1      22       1  124.4
SPC            1      23       1  124.4
SPC            1      24       1  124.4
SPC            1      25       1  124.4
SPC            1      26       1  124.4
SPC            1      27       1  124.4
SPC            1      28       1  124.4
SPC            1      29       1  124.4
SPC            1      30       1  124.4
SPC            1      31       1  124.4
SPC            1      32       1  124.4
SPC            1      33       1  124.4
SPC            1      34       1  124.4
SPC            1      35       1  124.4
SPC            1      36       1  124.4
SPC            1      37       1  124.4
```

TABLE 3-4. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 1 (Continued)

```
SPC             1      55       1  124.4
SPC             1      56       1  124.4
SPC             1      73       1  124.4
SPC             1     109       1  124.4
SPC             1     128       1  124.4
SPC             1     145       1  124.4
SPC             1     146       1  124.4
SPC             1     164       1  124.4
SPC             1     181       1  124.4
SPC             1     182       1  124.4
SPC             1     199       1  124.4
SPC             1     200       1  124.4
SPC             1     201       1  136.1
SPC             1     202       1  136.1
SPC             1     203       1  136.1
SPC             1     204       1  136.1
SPC             1     205       1  136.1
SPC             1     206       1  136.1
SPC             1     207       1  136.1
SPC             1     208       1  136.1
SPC             1     209       1  136.1
SPC             1     210       1  136.1
SPC             1     211       1  136.1
SPC             1     212       1  136.1
SPC             1     213       1  136.1
SPC             1     214       1  136.1
SPC             1     215       1  136.1
SPC             1     216       1  136.1
SPC             1     235       1  124.4
SPC             1     253       1  124.4
SPC             1     254       1  124.4
SPC             1     307       1  124.4
SPC             1     308       1  124.4
$ MSC/NASTRAN for Windows Property 1 : 0.02 in glass_outer_layer
PSHELL          1       1   0.001       1               1              0.
$ MSC/NASTRAN for Windows Property 2 : 3/8 in foam
PSHELL          2       2   0.001       2               2              0.
$ MSC/NASTRAN for Windows Property 3 : 0.02 in inner glass
PSHELL          3       1   0.001       1               1              0.
$ MSC/NASTRAN for Windows Property 4 : 0.350 in cap
PSHELL          4       1   0.001       1               1              0.
$ MSC/NASTRAN for Windows Property 5 : 10.70 in air space
PSHELL          5       3   0.001       3               3              0.
$ MSC/NASTRAN for Windows Property 6 : 0.350 in cap
PSHELL          6       1   0.001       1               1              0.
$ MSC/NASTRAN for Windows Property 7 : 0.02 in inner glass
PSHELL          7       1   0.001       1               1              0.
$ MSC/NASTRAN for Windows Property 8 : 3/8 in foam
PSHELL          8       2   0.001       2               2              0.
$ MSC/NASTRAN for Windows Property 9 : 0.02 in glass_outer_layer
PSHELL          9       1   0.001       1               1              0.
$ MSC/NASTRAN for Windows Material 1 : glass
MAT4            1     0.3      1.
$ MSC/NASTRAN for Windows Material 2 : foam
MAT4            2   0.021      1.
$ MSC/NASTRAN for Windows Material 3 : air
MAT4            3   0.016      1.
```

TABLE 3-4. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 1 (Continued)

```
GRID            1       0      0.      0.      0.      0
GRID            3       0      1.1.667E-3      0.      0
GRID            5       0      3.1.667E-3      0.      0
GRID            7       0      5.1.667E-3      0.      0
GRID            9       0      7.1.667E-3      0.      0
GRID           10       0      8.1.667E-3      0.      0
GRID           11       0      9.1.667E-3      0.      0
GRID           12       0     10.1.667E-3      0.      0
GRID           14       0     12.1.667E-3      0.      0
GRID           15       0     13.1.667E-3      0.      0
GRID           18       0     16.1.667E-3      0.      0
GRID           20       0     17.      0.      0.      0
GRID           21       0     16.      0.      0.      0
GRID           22       0     15.      0.      0.      0
GRID           23       0     14.      0.      0.      0
GRID           24       0     13.      0.      0.      0
GRID           25       0     12.      0.      0.      0
GRID           26       0     11.      0.      0.      0
GRID           27       0     10.      0.      0.      0
GRID           28       0      9.      0.      0.      0
GRID           29       0      8.      0.      0.      0
GRID           30       0      7.      0.      0.      0
GRID           31       0      6.      0.      0.      0
GRID           32       0      5.      0.      0.      0
GRID           33       0      4.      0.      0.      0
GRID           34       0      3.      0.      0.      0
GRID           35       0      2.      0.      0.      0
GRID           36       0      1.      0.      0.      0
GRID           37       0      0.1.667E-3      0.      0
GRID           41       0      3.0.032917      0.      0
GRID           44       0      6.0.032917      0.      0
GRID           45       0      7.0.032917      0.      0
GRID           47       0      9.0.032917      0.      0
GRID           48       0     10.0.032917      0.      0
GRID           50       0     12.0.032917      0.      0
GRID           51       0     13.0.032917      0.      0
GRID           52       0     14.0.032917      0.      0
GRID           53       0     15.0.032917      0.      0
GRID           54       0     16.0.032917      0.      0
GRID           55       0     17.0.032917      0.      0
GRID           56       0     17.1.667E-3      0.      0
GRID           58       0     15.1.667E-3      0.      0
GRID           59       0     14.1.667E-3      0.      0
GRID           62       0     11.1.667E-3      0.      0
GRID           67       0      6.1.667E-3      0.      0
GRID           69       0      4.1.667E-3      0.      0
GRID           71       0      2.1.667E-3      0.      0
GRID           73       0      0.0.032917      0.      0
GRID           75       0      1.0.034583      0.      0
GRID           76       0      2.0.034583      0.      0
GRID           77       0      3.0.034583      0.      0
GRID           78       0      4.0.034583      0.      0
GRID           79       0      5.0.034583      0.      0
GRID           80       0      6.0.034583      0.      0
GRID           83       0      9.0.034583      0.      0
GRID           85       0     11.0.034583      0.      0
GRID           87       0     13.0.034583      0.      0
```

TABLE 3-4. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 1 (Continued)

```
GRID            88       0     14.0.034583      0.        0
GRID            98       0     11.0.032917      0.        0
GRID           101       0      8.0.032917      0.        0
GRID           104       0      5.0.032917      0.        0
GRID           105       0      4.0.032917      0.        0
GRID           107       0      2.0.032917      0.        0
GRID           108       0      1.0.032917      0.        0
GRID           109       0      0.0.034583      0.        0
GRID           112       0      2. 0.06375      0.        0
GRID           115       0      5. 0.06375      0.        0
GRID           116       0      6. 0.06375      0.        0
GRID           118       0      8. 0.06375      0.        0
GRID           120       0     10. 0.06375      0.        0
GRID           121       0     11. 0.06375      0.        0
GRID           122       0     12. 0.06375      0.        0
GRID           123       0     13. 0.06375      0.        0
GRID           124       0     14. 0.06375      0.        0
GRID           125       0     15. 0.06375      0.        0
GRID           128       0     17.0.034583      0.        0
GRID           129       0     16.0.034583      0.        0
GRID           130       0     15.0.034583      0.        0
GRID           133       0     12.0.034583      0.        0
GRID           135       0     10.0.034583      0.        0
GRID           137       0      8.0.034583      0.        0
GRID           138       0      7.0.034583      0.        0
GRID           145       0      0. 0.06375      0.        0
GRID           146       0      0. 0.95542      0.        0
GRID           147       0      1. 0.95542      0.        0
GRID           150       0      4. 0.95542      0.        0
GRID           152       0      6. 0.95542      0.        0
GRID           160       0     14. 0.95542      0.        0
GRID           161       0     15. 0.95542      0.        0
GRID           164       0     17. 0.06375      0.        0
GRID           165       0     16. 0.06375      0.        0
GRID           172       0      9. 0.06375      0.        0
GRID           174       0      7. 0.06375      0.        0
GRID           177       0      4. 0.06375      0.        0
GRID           178       0      3. 0.06375      0.        0
GRID           180       0      1. 0.06375      0.        0
GRID           181       0      0. 1.01917      0.        0
GRID           182       0      0.  1.0175      0.        0
GRID           183       0      1.  1.0175      0.        0
GRID           184       0      2.  1.0175      0.        0
GRID           188       0      6.  1.0175      0.        0
GRID           193       0     11.  1.0175      0.        0
GRID           195       0     13.  1.0175      0.        0
GRID           196       0     14.  1.0175      0.        0
GRID           197       0     15.  1.0175      0.        0
GRID           198       0     16.  1.0175      0.        0
GRID           199       0     17.  1.0175      0.        0
GRID           200       0     17. 1.01917      0.        0
GRID           201       0     16. 1.01917      0.        0
GRID           202       0     15. 1.01917      0.        0
GRID           203       0     14. 1.01917      0.        0
GRID           204       0     13. 1.01917      0.        0
GRID           205       0     12. 1.01917      0.        0
GRID           206       0     11. 1.01917      0.        0
```

TABLE 3-4. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 1 (Continued)

```
GRID          207       0     10. 1.01917       0.        0
GRID          208       0      9. 1.01917       0.        0
GRID          209       0      8. 1.01917       0.        0
GRID          210       0      7. 1.01917       0.        0
GRID          211       0      6. 1.01917       0.        0
GRID          212       0      5. 1.01917       0.        0
GRID          213       0      4. 1.01917       0.        0
GRID          214       0      3. 1.01917       0.        0
GRID          215       0      2. 1.01917       0.        0
GRID          216       0      1. 1.01917       0.        0
GRID          219       0      1. 0.98625       0.        0
GRID          220       0      2. 0.98625       0.        0
GRID          221       0      3. 0.98625       0.        0
GRID          222       0      4. 0.98625       0.        0
GRID          223       0      5. 0.98625       0.        0
GRID          226       0      8. 0.98625       0.        0
GRID          227       0      9. 0.98625       0.        0
GRID          228       0     10. 0.98625       0.        0
GRID          229       0     11. 0.98625       0.        0
GRID          231       0     13. 0.98625       0.        0
GRID          232       0     14. 0.98625       0.        0
GRID          235       0     17. 0.98625       0.        0
GRID          241       0     12.  1.0175       0.        0
GRID          243       0     10.  1.0175       0.        0
GRID          244       0      9.  1.0175       0.        0
GRID          245       0      8.  1.0175       0.        0
GRID          246       0      7.  1.0175       0.        0
GRID          248       0      5.  1.0175       0.        0
GRID          249       0      4.  1.0175       0.        0
GRID          250       0      3.  1.0175       0.        0
GRID          253       0      0. 0.98625       0.        0
GRID          254       0      0. 0.98458       0.        0
GRID          257       0      3. 0.98458       0.        0
GRID          258       0      4. 0.98458       0.        0
GRID          259       0      5. 0.98458       0.        0
GRID          260       0      6. 0.98458       0.        0
GRID          264       0     10. 0.98458       0.        0
GRID          267       0     13. 0.98458       0.        0
GRID          268       0     14. 0.98458       0.        0
GRID          269       0     15. 0.98458       0.        0
GRID          270       0     16. 0.98458       0.        0
GRID          273       0     16. 0.98625       0.        0
GRID          274       0     15. 0.98625       0.        0
GRID          277       0     12. 0.98625       0.        0
GRID          282       0      7. 0.98625       0.        0
GRID          283       0      6. 0.98625       0.        0
GRID          292       0      2. 0.95542       0.        0
GRID          293       0      3. 0.95542       0.        0
GRID          295       0      5. 0.95542       0.        0
GRID          297       0      7. 0.95542       0.        0
GRID          298       0      8. 0.95542       0.        0
GRID          299       0      9. 0.95542       0.        0
GRID          300       0     10. 0.95542       0.        0
GRID          301       0     11. 0.95542       0.        0
GRID          302       0     12. 0.95542       0.        0
GRID          303       0     13. 0.95542       0.        0
GRID          306       0     16. 0.95542       0.        0
```

TABLE 3-4. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 1 (Continued)

```
GRID          307       0      17. 0.95542       0.        0
GRID          308       0      17. 0.98458       0.        0
GRID          313       0      12. 0.98458       0.        0
GRID          314       0      11. 0.98458       0.        0
GRID          316       0       9. 0.98458       0.        0
GRID          317       0       8. 0.98458       0.        0
GRID          318       0       7. 0.98458       0.        0
GRID          323       0       2. 0.98458       0.        0
GRID          324       0       1. 0.98458       0.        0
CQUAD4          1       9        1       37        3       36
CQUAD4          2       9       36        3       71       35
CQUAD4          3       9       35       71        5       34
CQUAD4          4       9       34        5       69       33
CQUAD4          5       9       33       69        7       32
CQUAD4          6       9       32        7       67       31
CQUAD4          7       9       31       67        9       30
CQUAD4          8       9       30        9       10       29
CQUAD4          9       9       29       10       11       28
CQUAD4         10       9       28       11       12       27
CQUAD4         11       9       27       12       62       26
CQUAD4         12       9       26       62       14       25
CQUAD4         13       9       25       14       15       24
CQUAD4         14       9       24       15       59       23
CQUAD4         15       9       23       59       58       22
CQUAD4         16       9       22       58       18       21
CQUAD4         17       9       21       18       56       20
CQUAD4         18       8       37       73      108        3
CQUAD4         19       8        3      108      107       71
CQUAD4         20       8       71      107       41        5
CQUAD4         21       8        5       41      105       69
CQUAD4         22       8       69      105      104        7
CQUAD4         23       8        7      104       44       67
CQUAD4         24       8       67       44       45        9
CQUAD4         25       8        9       45      101       10
CQUAD4         26       8       10      101       47       11
CQUAD4         27       8       11       47       48       12
CQUAD4         28       8       12       48       98       62
CQUAD4         29       8       62       98       50       14
CQUAD4         30       8       14       50       51       15
CQUAD4         31       8       15       51       52       59
CQUAD4         32       8       59       52       53       58
CQUAD4         33       8       58       53       54       18
CQUAD4         34       8       18       54       55       56
CQUAD4         35       7       73      109       75      108
CQUAD4         36       7      108       75       76      107
CQUAD4         37       7      107       76       77       41
CQUAD4         38       7       41       77       78      105
CQUAD4         39       7      105       78       79      104
CQUAD4         40       7      104       79       80       44
CQUAD4         41       7       44       80      138       45
CQUAD4         42       7       45      138      137      101
CQUAD4         43       7      101      137       83       47
CQUAD4         44       7       47       83      135       48
CQUAD4         45       7       48      135       85       98
CQUAD4         46       7       98       85      133       50
CQUAD4         47       7       50      133       87       51
CQUAD4         48       7       51       87       88       52
```

TABLE 3-4. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 1 (Continued)

```
CQUAD4      49       7      52       88      130       53
CQUAD4      50       7      53      130      129       54
CQUAD4      51       7      54      129      128       55
CQUAD4      52       6     109      145      180       75
CQUAD4      53       6      75      180      112       76
CQUAD4      54       6      76      112      178       77
CQUAD4      55       6      77      178      177       78
CQUAD4      56       6      78      177      115       79
CQUAD4      57       6      79      115      116       80
CQUAD4      58       6      80      116      174      138
CQUAD4      59       6     138      174      118      137
CQUAD4      60       6     137      118      172       83
CQUAD4      61       6      83      172      120      135
CQUAD4      62       6     135      120      121       85
CQUAD4      63       6      85      121      122      133
CQUAD4      64       6     133      122      123       87
CQUAD4      65       6      87      123      124       88
CQUAD4      66       6      88      124      125      130
CQUAD4      67       6     130      125      165      129
CQUAD4      68       6     129      165      164      128
CQUAD4      69       5     145      146      147      180
CQUAD4      70       5     180      147      292      112
CQUAD4      71       5     112      292      293      178
CQUAD4      72       5     178      293      150      177
CQUAD4      73       5     177      150      295      115
CQUAD4      74       5     115      295      152      116
CQUAD4      75       5     116      152      297      174
CQUAD4      76       5     174      297      298      118
CQUAD4      77       5     118      298      299      172
CQUAD4      78       5     172      299      300      120
CQUAD4      79       5     120      300      301      121
CQUAD4      80       5     121      301      302      122
CQUAD4      81       5     122      302      303      123
CQUAD4      82       5     123      303      160      124
CQUAD4      83       5     124      160      161      125
CQUAD4      84       5     125      161      306      165
CQUAD4      85       5     165      306      307      164
CQUAD4      86       1     182      181      216      183
CQUAD4      87       1     183      216      215      184
CQUAD4      88       1     184      215      214      250
CQUAD4      89       1     250      214      213      249
CQUAD4      90       1     249      213      212      248
CQUAD4      91       1     248      212      211      188
CQUAD4      92       1     188      211      210      246
CQUAD4      93       1     246      210      209      245
CQUAD4      94       1     245      209      208      244
CQUAD4      95       1     244      208      207      243
CQUAD4      96       1     243      207      206      193
CQUAD4      97       1     193      206      205      241
CQUAD4      98       1     241      205      204      195
CQUAD4      99       1     195      204      203      196
CQUAD4     100       1     196      203      202      197
CQUAD4     101       1     197      202      201      198
CQUAD4     102       1     198      201      200      199
CQUAD4     103       2     253      182      183      219
CQUAD4     104       2     219      183      184      220
CQUAD4     105       8     220      184      250      221
```

TABLE 3-4. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 1 (Continued)

```
CQUAD4      106       2       221     250     249     222
CQUAD4      107       2       222     249     248     223
CQUAD4      108       2       223     248     188     283
CQUAD4      109       2       283     188     246     282
CQUAD4      110       2       282     246     245     226
CQUAD4      111       2       226     245     244     227
CQUAD4      112       2       227     244     243     228
CQUAD4      113       2       228     243     193     229
CQUAD4      114       2       229     193     241     277
CQUAD4      115       2       277     241     195     231
CQUAD4      116       2       231     195     196     232
CQUAD4      117       2       232     196     197     274
CQUAD4      118       2       274     197     198     273
CQUAD4      119       2       273     198     199     235
CQUAD4      120       3       254     253     219     324
CQUAD4      121       3       324     219     220     323
CQUAD4      122       3       323     220     221     257
CQUAD4      123       3       257     221     222     258
CQUAD4      124       3       258     222     223     259
CQUAD4      125       3       259     223     283     260
CQUAD4      126       3       260     283     282     318
CQUAD4      127       3       318     282     226     317
CQUAD4      128       3       317     226     227     316
CQUAD4      129       3       316     227     228     264
CQUAD4      130       3       264     228     229     314
CQUAD4      131       3       314     229     277     313
CQUAD4      132       3       313     277     231     267
CQUAD4      133       3       267     231     232     268
CQUAD4      134       3       268     232     274     269
CQUAD4      135       3       269     274     273     270
CQUAD4      136       3       270     273     235     308
CQUAD4      137       4       146     254     324     147
CQUAD4      138       4       147     324     323     292
CQUAD4      139       4       292     323     257     293
CQUAD4      140       4       293     257     258     150
CQUAD4      141       4       150     258     259     295
CQUAD4      142       4       295     259     260     152
CQUAD4      143       4       152     260     318     297
CQUAD4      144       4       297     318     317     298
CQUAD4      145       4       298     317     316     299
CQUAD4      146       4       299     316     264     300
CQUAD4      147       4       300     264     314     301
CQUAD4      148       4       301     314     313     302
CQUAD4      149       4       302     313     267     303
CQUAD4      150       4       303     267     268     160
CQUAD4      151       4       160     268     269     161
CQUAD4      152       4       161     269     270     306
CQUAD4      153       4       306     270     308     307
ENDDATA
```

The results of the one-half FEM wing model analysis are presented in figure 3-1 in the form of a contour plot. The contours along the outer nodes are in agreement with the imposed boundary conditions. The contours of the inner layers appear to be indicative of the temperature profile of the THERMOD analysis.

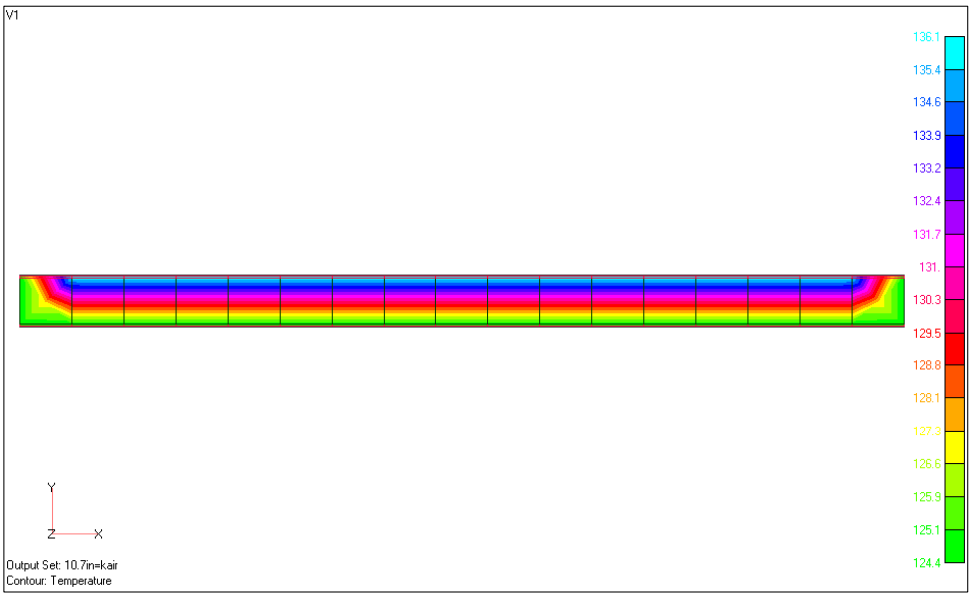


FIGURE 3-1. CONTOUR PLOT OF THE FEM OUTPUT OF SAMPLE PROBLEM 1

The truncated FEM output file is shown in table 3-5. The nodes, from top to bottom of the wing, located at the mid-span of the model are indicated by nodes 209, 245, 226, 317, 298, 118, 137, 101, 10, and 29. The temperatures of these nodes were extracted from this file and are summarized in table 3-6. Mid-span was chosen because it was sufficiently far away from any edge effects that might be present.

TABLE 3-5. TRUNCATED FEM OUTPUT FILE OF SAMPLE PROBLEM 1

```
1      CONDUCTION IN RECTANGULAR ADIABATIC PLATE (T=0.001FT)            MARCH    6, 2000    UAI/NASTRAN VERSION 20.1        PAGE
16
       10.7 IN GAP FILLED BY AIR; K=0.016BTU/HR/FT/DEGF
0

                                                T E M P E R A T U R E   V E C T O R

      POINT ID.   TYPE      ID    VALUE     ID+1 VALUE     ID+2 VALUE     ID+3 VALUE     ID+4 VALUE     ID+5 VALUE
             1    TEMP     1.244000E+02
             3    TEMP     1.244011E+02
             5    TEMP     1.244011E+02
             7    TEMP     1.244011E+02
             9    TEMP     1.244011E+02   1.244011E+02   1.244011E+02   1.244011E+02
            14    TEMP     1.244011E+02   1.244011E+02
            18    TEMP     1.244011E+02
            20    TEMP     1.244000E+02   1.244000E+02   1.244000E+02   1.244000E+02   1.244000E+02   1.244000E+02
            26    TEMP     1.244000E+02   1.244000E+02   1.244000E+02   1.244000E+02   1.244000E+02   1.244000E+02
            32    TEMP     1.244000E+02   1.244000E+02   1.244000E+02   1.244000E+02   1.244000E+02   1.244000E+02
            41    TEMP     1.246966E+02
            44    TEMP     1.246966E+02   1.246966E+02
            47    TEMP     1.246966E+02   1.246966E+02
            50    TEMP     1.246966E+02   1.246966E+02   1.246966E+02   1.246961E+02   1.246825E+02   1.244000E+02
            56    TEMP     1.244000E+02
            58    TEMP     1.244011E+02   1.244011E+02
            62    TEMP     1.244011E+02
            67    TEMP     1.244011E+02
            69    TEMP     1.244011E+02
            71    TEMP     1.244011E+02
            73    TEMP     1.244000E+02
            75    TEMP     1.246836E+02   1.246972E+02   1.246977E+02   1.246977E+02   1.246977E+02   1.246977E+02
            83    TEMP     1.246977E+02
            85    TEMP     1.246977E+02
            87    TEMP     1.246977E+02   1.246977E+02
```

TABLE 3-5. TRUNCATED FEM OUTPUT FILE OF SAMPLE PROBLEM 1 (Continued)

```
            98    TEMP     1.246966E+02
           101    TEMP     1.246966E+02
           104    TEMP     1.246966E+02   1.246966E+02
           107    TEMP     1.246961E+02   1.246825E+02   1.244000E+02
           112    TEMP     1.247165E+02
           115    TEMP     1.247170E+02   1.247170E+02
           118    TEMP     1.247170E+02
           120    TEMP     1.247170E+02   1.247170E+02   1.247170E+02   1.247170E+02   1.247170E+02   1.247165E+02
           128    TEMP     1.244000E+02   1.246836E+02   1.246972E+02
           133    TEMP     1.246977E+02
           135    TEMP     1.246977E+02
           137    TEMP     1.246977E+02   1.246977E+02
           145    TEMP     1.244000E+02   1.244000E+02   1.355065E+02
           150    TEMP     1.357830E+02
           152    TEMP     1.357830E+02
           160    TEMP     1.357829E+02   1.357764E+02
           164    TEMP     1.244000E+02   1.247021E+02
           172    TEMP     1.247170E+02
           174    TEMP     1.247170E+02
           177    TEMP     1.247170E+02   1.247170E+02
           180    TEMP     1.247021E+02   1.244000E+02   1.244000E+02   1.360979E+02   1.360989E+02
           188    TEMP     1.360989E+02
           193    TEMP     1.360989E+02
           195    TEMP     1.360989E+02   1.360989E+02   1.360989E+02   1.360979E+02   1.244000E+02   1.244000E+02
           201    TEMP     1.361000E+02   1.361000E+02   1.361000E+02   1.361000E+02   1.361000E+02   1.361000E+02
1      CONDUCTION IN RECTANGULAR ADIABATIC PLATE (T=0.001FT)              MARCH    6, 2000    UAI/NASTRAN VERSION 20.1         PAGE
17
       10.7 IN GAP FILLED BY AIR; K=0.016BTU/HR/FT/DEGF
0

                                                T E M P E R A T U R E   V E C T O R

       POINT ID.   TYPE       ID   VALUE      ID+1 VALUE      ID+2 VALUE      ID+3 VALUE      ID+4 VALUE      ID+5 VALUE
           207     TEMP     1.361000E+02   1.361000E+02   1.361000E+02   1.361000E+02   1.361000E+02   1.361000E+02
           213     TEMP     1.361000E+02   1.361000E+02   1.361000E+02   1.361000E+02
           219     TEMP     1.355396E+02   1.357971E+02   1.358033E+02   1.358034E+02   1.358034E+02
           226     TEMP     1.358034E+02   1.358034E+02   1.358034E+02   1.358034E+02
           231     TEMP     1.358034E+02   1.358033E+02
           235     TEMP     1.244000E+02
           241     TEMP     1.360989E+02
           243     TEMP     1.360989E+02   1.360989E+02   1.360989E+02   1.360989E+02
           248     TEMP     1.360989E+02   1.360989E+02   1.360989E+02
           253     TEMP     1.244000E+02   1.244000E+02
           257     TEMP     1.358022E+02   1.358023E+02   1.358023E+02   1.358023E+02
           264     TEMP     1.358023E+02
           267     TEMP     1.358023E+02   1.358022E+02   1.357960E+02   1.355375E+02
           273     TEMP     1.355396E+02   1.357971E+02
           277     TEMP     1.358034E+02
           282     TEMP     1.358034E+02   1.358034E+02
           292     TEMP     1.357764E+02   1.357829E+02
           295     TEMP     1.357830E+02
           297     TEMP     1.357830E+02   1.357830E+02   1.357830E+02   1.357830E+02   1.357830E+02   1.357830E+02
           303     TEMP     1.357830E+02
           306     TEMP     1.355065E+02   1.244000E+02   1.244000E+02
           313     TEMP     1.358023E+02   1.358023E+02
           316     TEMP     1.358023E+02   1.358023E+02   1.358023E+02
           323     TEMP     1.357960E+02   1.355375E+02
```

TABLE 3-6. FINITE ELEMENT METHOD-SIMULATED TEMPERATURES (°F) OF THE RIGHT WING OF SAMPLE PROBLEM 1

T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
136.1	136.1	135.8	135.8	135.8	124.7	124.7	124.7	124.4	124.4

When compared, the inner temperatures of tables 3-3 and 3-6 show excellent agreement, thus validating the conduction capability of the THERMOD program.

3.2 SAMPLE PROBLEM 2.

Sample problem 2 is similar to sample problem 1, except the 10.7-in.-deep air space between the spar caps was replaced with a fuel-filled space. The input.dat file is altered by changing the conductivity of layer 5 from 0.016 (Btu/hr)/(ft°F), that of air, to 0.081 (Btu/hr)/(ft°F), estimated to be that of oil [6]. All other thermal properties of the layer were kept the same as in sample problem 1.

Temperatures from the THERMOD run is shown in table 3-7, from which the steady-state temperatures T1, T2…..T10 (top to bottom of wing) were extracted and tabulated in table 3-8 for time period 3.

TABLE 3-7. THERMOD OUTPUT FILE (summary.dat) FOR SAMPLE PROBLEM 2

```
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
THERMOD:  A THERMAL PROGRAM FOR AIRCRAFTS
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$



 SUMMARY OF STEADY-STATE AND TRANSIENT ANALYSIS



 (Temperatures are shown for all time periods)


 TEMPERATURES AT THE END OF STEADY STATE ANALYSIS

        TEMPERATURES IN DEGREES FAHRENHEIT
         1     2     3     4     5     6     7

  1 123.7 132.2 135.9 133.8 126.3 115.2 102.9
  2 123.7 132.2 135.9 133.8 126.3 115.2 103.0
  3 122.7 131.0 134.7 132.8 125.7 115.4 103.8
  4 122.7 131.0 134.7 132.8 125.7 115.4 103.8
  5 122.7 130.9 134.6 132.7 125.7 115.4 103.8
  6 115.4 121.5 125.9 125.6 121.7 116.2 109.7
  7 115.3 121.4 125.8 125.5 121.6 116.2 109.8
  8 115.3 121.4 125.8 125.5 121.6 116.2 109.8
  9 114.3 120.2 124.6 124.6 121.1 116.4 110.6
 10 114.3 120.2 124.6 124.6 121.1 116.4 110.6
 11 122.0 131.2 135.6 132.8 124.7 113.6 101.6
 12 122.0 131.2 135.6 132.8 124.7 113.6 101.6
 13 121.1 130.0 134.5 131.9 124.3 113.8 102.5
 14 121.1 130.0 134.5 131.9 124.3 113.8 102.5
 15 121.1 129.9 134.4 131.8 124.3 113.9 102.6
 16 115.1 121.4 125.9 125.5 121.5 116.0 109.5
 17 115.1 121.3 125.8 125.4 121.4 116.0 109.6
 18 115.1 121.3 125.8 125.4 121.4 116.0 109.6
 19 114.3 120.1 124.6 124.5 121.1 116.3 110.5
 20 114.3 120.1 124.6 124.5 121.1 116.3 110.5
 21 205.8 225.9 231.9 222.2 200.7 169.4 134.2
 22 205.8 225.8 231.8 222.1 200.7 169.5 134.2
 23 207.4 216.5 217.2 213.6 202.4 180.2 143.1
 24 207.4 216.4 217.2 213.5 202.4 180.2 143.1
 25 208.4 209.9 206.9 207.6 203.6 187.7 149.4
```

TABLE 3-7. THERMOD OUTPUT FILE (summary.dat) FOR SAMPLE PROBLEM 2 (Continued)

```
  26 198.9 198.2 195.5 196.8 195.4 183.4 146.2
  27 150.5 153.0 154.4 155.5 153.6 146.5 127.6
  28 150.4 153.0 154.4 155.4 153.6 146.5 127.6
  29 147.0 149.8 151.5 152.5 150.6 143.9 126.3
  30 147.0 149.8 151.5 152.5 150.6 143.9 126.3
  31 131.8 135.6 138.7 139.6 137.5 132.4 120.5
  32 131.8 135.6 138.7 139.6 137.5 132.4 120.5
  33 131.8 135.6 138.7 139.6 137.5 132.4 120.5
  34 131.8 135.6 138.7 139.6 137.5 132.4 120.5
  35 116.7 121.5 125.8 126.6 124.5 120.8 114.7
  36 116.7 121.5 125.8 126.6 124.4 120.8 114.7
  37 113.2 118.3 122.9 123.7 121.5 118.2 113.3
  38 113.2 118.3 122.9 123.7 121.4 118.2 113.3
  39 199.5 179.7 148.8 180.0 196.6 194.7 173.9
  40 199.5 179.7 148.9 180.1 196.6 194.6 173.9
  41 197.6 186.6 168.7 186.2 194.5 188.4 162.3
  42 197.6 186.6 168.8 186.2 194.5 188.4 162.3
  43 196.2 191.4 182.7 190.5 193.1 184.1 154.2
  44 191.8 188.5 182.6 187.8 189.2 180.4 151.1
  45 169.9 170.8 168.7 171.5 170.1 161.4 138.9
  46 169.8 170.7 168.7 171.5 170.0 161.3 138.8
  47 138.6 145.3 148.8 148.2 142.9 134.1 121.3
  48 138.4 145.2 148.7 148.0 142.7 133.9 121.2
  49 145.6 148.6 149.7 150.4 147.7 139.7 123.0
  50 147.6 150.5 151.3 152.1 149.5 141.3 123.9
  51 113.6 120.9 125.1 123.7 118.1 110.0 100.6
  52 108.2 115.1 119.2 118.0 112.7 105.1  96.2
  53 113.6 120.9 125.1 123.7 118.1 110.0 100.6

Maximum Structural Temperature for Period   1 = 207.37 Occurring
at Location  24
Maximum Structural Temperature for Period   2 = 225.86 Occurring
at Location  21
Maximum Structural Temperature for Period   3 = 231.88 Occurring
at Location  21
Maximum Structural Temperature for Period   4 = 222.15 Occurring
at Location  21
Maximum Structural Temperature for Period   5 = 202.43 Occurring
at Location  24
Maximum Structural Temperature for Period   6 = 194.68 Occurring
at Location  39
Maximum Structural Temperature for Period   7 = 173.93 Occurring
at Location  39

Maximum Structural Temperature Over All     7 Periods =231.88
Occurring at Location  21 at Period   3
```

TABLE 3-7. THERMOD OUTPUT FILE (summary.dat) FOR SAMPLE PROBLEM 2 (Continued)

```
TEMPERATURES AT THE END OF TRANSIENT ANALYSIS

       TEMPERATURES IN DEGREES FAHRENHEIT
         1     2     3     4     5     6     7

  1 112.8 116.8 121.7 123.8 123.4 122.5 119.8
  2 113.2 117.3 122.1 124.1 123.5 122.3 119.3
  3 122.0 129.9 133.7 132.1 125.5 115.9 104.9
  4 122.3 130.3 134.1 132.3 125.6 115.7 104.5
  5 122.3 130.3 134.1 132.3 125.5 115.5 104.3
  6 115.5 121.7 126.1 125.8 121.9 116.4 109.8
  7 115.3 121.3 125.7 125.5 121.8 116.6 110.2
  8 115.2 121.2 125.6 125.5 121.9 116.7 110.5
  9 112.8 116.7 121.6 123.8 123.6 123.1 120.8
 10 112.7 116.5 121.5 123.8 123.7 123.3 121.2
 11 112.7 116.7 121.6 123.7 123.3 122.4 119.7
 12 113.0 117.2 122.1 124.0 123.3 122.1 119.2
 13 120.5 129.1 133.6 131.3 124.2 114.4 103.8
 14 120.7 129.4 133.9 131.5 124.3 114.2 103.3
 15 120.8 129.4 133.9 131.5 124.2 114.1 103.1
 16 115.3 121.6 126.0 125.6 121.6 116.1 109.6
 17 115.0 121.2 125.7 125.4 121.6 116.3 110.1
 18 115.0 121.1 125.6 125.4 121.7 116.5 110.4
 19 112.8 116.6 121.6 123.8 123.6 123.1 120.8
 20 112.7 116.5 121.5 123.8 123.7 123.3 121.2
 21 125.4 131.3 136.7 137.5 134.8 130.9 124.7
 22 127.4 133.3 138.7 139.3 136.4 132.3 125.2
 23 181.2 187.5 192.2 187.4 180.5 171.4 140.3
 24 183.1 189.2 193.8 188.9 182.0 172.9 140.9
 25 200.7 202.6 205.1 200.1 195.7 189.2 147.8
 26 185.7 185.5 187.8 185.4 184.4 181.0 145.5
 27 150.7 153.2 154.6 155.7 153.8 146.7 127.7
 28 149.5 152.1 153.7 154.7 152.8 145.8 127.3
 29 146.5 149.3 151.2 152.1 150.2 143.7 126.3
 30 145.7 148.6 150.4 151.4 149.5 143.1 126.0
 31 131.5 135.1 138.2 139.3 137.7 133.2 121.9
 32 131.5 135.1 138.2 139.3 137.7 133.2 121.9
 33 131.5 135.1 138.2 139.3 137.7 133.2 121.9
 34 131.5 135.1 138.2 139.3 137.7 133.2 121.9
 35 117.2 121.6 125.9 127.3 125.8 123.2 117.7
 36 116.4 120.7 125.2 126.5 125.2 122.7 117.5
 37 112.1 115.7 120.6 123.1 123.4 123.4 121.5
 38 112.0 115.5 120.5 123.0 123.3 123.4 121.6
 39 121.2 122.3 123.8 129.2 131.3 131.5 127.8
 40 123.2 124.0 125.1 130.7 133.0 133.1 128.7
 41 172.1 166.9 160.2 168.7 173.2 172.1 150.2
```

TABLE 3-7. THERMOD OUTPUT FILE (summary.dat) FOR SAMPLE PROBLEM 2 (Continued)

```
  42 173.6 168.3 161.5 170.0 174.5 173.3 150.8
  43 183.1 179.5 176.6 179.9 182.2 181.5 152.3
  44 179.2 177.0 176.6 177.6 178.7 178.0 149.3
  45 162.3 161.7 161.5 163.9 164.5 162.3 141.2
  46 160.8 160.3 160.1 162.6 163.2 161.0 140.6
  47 121.5 123.0 125.1 129.8 131.5 131.4 127.2
  48 120.0 121.6 123.8 128.6 130.3 130.3 126.7
  49 123.6 126.8 131.0 132.5 132.0 130.4 123.1
  50 127.8 130.8 134.8 136.0 135.3 133.2 123.9
  51 169.1 187.2 193.0 184.0 164.8 137.5 109.0
  52 157.8 174.5 180.0 172.0 154.5 129.7 103.8
  53 169.1 187.2 193.0 184.0 164.8 137.5 109.0

Maximum Structural Temperature for Period   1 = 183.07 Occurring
at Location  24
Maximum Structural Temperature for Period   2 = 189.17 Occurring
at Location  24
Maximum Structural Temperature for Period   3 = 193.83 Occurring
at Location  24
Maximum Structural Temperature for Period   4 = 188.85 Occurring
at Location  24
Maximum Structural Temperature for Period   5 = 181.98 Occurring
at Location  24
Maximum Structural Temperature for Period   6 = 173.32 Occurring
at Location  42
Maximum Structural Temperature for Period   7 = 150.76 Occurring
at Location  42

Maximum Structural Temperature Over All     7 Periods =193.83
Occurring at Location  24 at Period   3
```

TABLE 3-8. THERMOD-SIMULATED TEMPERATURES (°F) OF THE RIGHT WING OF SAMPLE PROBLEM 2

T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
135.9	135.9	134.7	134.7	134.6	125.9	125.8	125.8	124.6	124.6

The results of the one-half FEM wing model analysis are presented in figure 3-2 in the form of a contour plot. The contours along the outer nodes are in agreement with the imposed boundary conditions while the contours of the inner layers appear to be indicative of the temperature profile of the THERMOD analysis.



FIGURE 3-2. CONTOUR PLOT OF THE FEM OUTPUT OF SAMPLE PROBLEM 2

The truncated FEM output file is shown in table 3-9. The nodes, from top to bottom of the wing, located at mid-span of the model are indicated by nodes 209, 245, 226, 317, 298, 118, 137, 101, 10, and 29. The temperatures of these nodes were extracted from this file and are reproduced in table 3-10. Mid-span was chosen because it was sufficiently far away from any edge effects that might be present.

TABLE 3-9. TRUNCATED FEM OUTPUT FILE OF SAMPLE PROBLEM 2

```
1      CONDUCTION IN RECTANGULAR ADIABATIC PLATE (T=0.001FT)            MARCH    6, 2000    UAI/NASTRAN VERSION 20.1        PAGE
16
       10.7 IN GAP FILLED BY OIL; K=0.081BTU/HR/FT/DEGF
0

                                                T E M P E R A T U R E   V E C T O R

      POINT ID.   TYPE      ID   VALUE     ID+1 VALUE     ID+2 VALUE     ID+3 VALUE     ID+4 VALUE     ID+5 VALUE
             1    TEMP     1.246000E+02
             3    TEMP     1.246039E+02
             5    TEMP     1.246044E+02
             7    TEMP     1.246044E+02
             9    TEMP     1.246044E+02   1.246044E+02   1.246044E+02   1.246044E+02
            14    TEMP     1.246044E+02   1.246044E+02
            18    TEMP     1.246039E+02
            20    TEMP     1.246000E+02   1.246000E+02   1.246000E+02   1.246000E+02   1.246000E+02   1.246000E+02
            26    TEMP     1.246000E+02   1.246000E+02   1.246000E+02   1.246000E+02   1.246000E+02   1.246000E+02
            32    TEMP     1.246000E+02   1.246000E+02   1.246000E+02   1.246000E+02   1.246000E+02   1.246000E+02
            41    TEMP     1.257877E+02
            44    TEMP     1.257885E+02   1.257885E+02
            47    TEMP     1.257885E+02   1.257885E+02
            50    TEMP     1.257885E+02   1.257885E+02   1.257877E+02   1.257777E+02   1.256599E+02   1.246000E+02
            56    TEMP     1.246000E+02
            58    TEMP     1.246044E+02   1.246044E+02
            62    TEMP     1.246044E+02
            67    TEMP     1.246044E+02
            69    TEMP     1.246044E+02
            71    TEMP     1.246044E+02
            73    TEMP     1.246000E+02
            75    TEMP     1.256639E+02   1.257821E+02   1.257921E+02   1.257929E+02   1.257929E+02   1.257929E+02
            83    TEMP     1.257929E+02
            85    TEMP     1.257929E+02
            87    TEMP     1.257929E+02   1.257921E+02
```

TABLE 3-9. TRUNCATED FEM OUTPUT FILE OF SAMPLE PROBLEM 2 (Continued)

```
            98    TEMP     1.257885E+02
           101    TEMP     1.257885E+02
           104    TEMP     1.257885E+02   1.257885E+02
           107    TEMP     1.257777E+02   1.256599E+02   1.246000E+02
           112    TEMP     1.258588E+02
           115    TEMP     1.258703E+02   1.258703E+02
           118    TEMP     1.258703E+02
           120    TEMP     1.258703E+02   1.258703E+02   1.258703E+02   1.258702E+02   1.258694E+02   1.258588E+02
           128    TEMP     1.246000E+02   1.256639E+02   1.257821E+02
           133    TEMP     1.257929E+02
           135    TEMP     1.257929E+02
           137    TEMP     1.257929E+02   1.257929E+02
           145    TEMP     1.246000E+02   1.246000E+02   1.340483E+02
           150    TEMP     1.346296E+02
           152    TEMP     1.346297E+02
           160    TEMP     1.346277E+02   1.345958E+02
           164    TEMP     1.246000E+02   1.257333E+02
           172    TEMP     1.258703E+02
           174    TEMP     1.258703E+02
           177    TEMP     1.258702E+02   1.258694E+02
           180    TEMP     1.257333E+02   1.246000E+02   1.246000E+02   1.358935E+02   1.358954E+02
           188    TEMP     1.358956E+02
           193    TEMP     1.358956E+02
           195    TEMP     1.358956E+02   1.358956E+02   1.358954E+02   1.358935E+02   1.246000E+02   1.246000E+02
           201    TEMP     1.359000E+02   1.359000E+02   1.359000E+02   1.359000E+02   1.359000E+02   1.359000E+02
1      CONDUCTION IN RECTANGULAR ADIABATIC PLATE (T=0.001FT)              MARCH    6, 2000    UAI/NASTRAN VERSION 20.1         PAGE
17
       10.7 IN GAP FILLED BY OIL; K=0.081BTU/HR/FT/DEGF
0

                                                T E M P E R A T U R E   V E C T O R

       POINT ID.   TYPE       ID   VALUE      ID+1 VALUE     ID+2 VALUE     ID+3 VALUE     ID+4 VALUE     ID+5 VALUE
           207     TEMP     1.359000E+02   1.359000E+02   1.359000E+02   1.359000E+02   1.359000E+02   1.359000E+02
           213     TEMP     1.359000E+02   1.359000E+02   1.359000E+02   1.359000E+02
           219     TEMP     1.341632E+02   1.346795E+02   1.347096E+02   1.347113E+02   1.347115E+02
           226     TEMP     1.347115E+02   1.347115E+02   1.347115E+02   1.347115E+02
           231     TEMP     1.347113E+02   1.347096E+02
           235     TEMP     1.246000E+02
           241     TEMP     1.358956E+02
           243     TEMP     1.358956E+02   1.358956E+02   1.358956E+02   1.358956E+02
           248     TEMP     1.358956E+02   1.358956E+02   1.358956E+02
           253     TEMP     1.246000E+02   1.246000E+02
           257     TEMP     1.347052E+02   1.347069E+02   1.347070E+02   1.347070E+02
           264     TEMP     1.347070E+02
           267     TEMP     1.347069E+02   1.347052E+02   1.346750E+02   1.341568E+02
           273     TEMP     1.341632E+02   1.346795E+02
           277     TEMP     1.347115E+02
           282     TEMP     1.347115E+02   1.347115E+02
           292     TEMP     1.345958E+02   1.346277E+02
           295     TEMP     1.346297E+02
           297     TEMP     1.346297E+02   1.346297E+02   1.346297E+02   1.346297E+02   1.346297E+02   1.346297E+02
           303     TEMP     1.346296E+02
           306     TEMP     1.340483E+02   1.246000E+02   1.246000E+02
           313     TEMP     1.347070E+02   1.347070E+02
           316     TEMP     1.347070E+02   1.347070E+02   1.347070E+02
           323     TEMP     1.346750E+02   1.341568E+02
```

When compared, the inner temperatures of tables 3-8 and 3-10 show excellent agreement, again validating the conduction capability of the THERMOD program.

TABLE 3-10. FINITE ELEMENT METHOD-SIMULATED TEMPERATURES (°F) OF THE RIGHT WING OF SAMPLE PROBLEM 2

T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
135.9	135.9	134.7	134.7	134.6	125.9	125.8	125.8	124.6	124.6

3.3 SAMPLE PROBLEM 3.

Sample problem 3, isolated and studied the effects of surface convection. Convection was introduced into the system by surface airflow. Depending on the ambient and surface temperatures, heat may either be added or removed from the system.

As in sample problems 1 and 2, a complete aircraft problem was solved using the THERMOD program. A particular item of interest was that the absorptivity and emissivity of all external surfaces, i.e., the fuselage, wing, and tarmac surfaces, were assigned 1.0 and 0.0 values, respectively. Such surfaces absorb all heat and do not emit any energy (no radiation). The only way for surface heat transfer to take place was through conduction and convection. Table 3-11 shows the THERMOD input file for this sample problem.

TABLE 3-11. THERMOD INPUT FILE (input.dat) OF SAMPLE PROBLEM 3

```
198e-6,0.704
1, 0.020,125,0.300,0.30
2, 0.375,4.4,0.021,0.24
3, 0.020,125,0.300,0.30
4, 0.350,125,0.300,0.30
5, 10.70,0.067,0.016,0.24
6, 0.350,125,0.300,0.30
7, 0.020,125,0.300,0.30
8, 0.375,4.4,0.021,0.24
9, 0.020,125,0.300,0.30
10,0.030,125,0.300,0.30
11,0.375,4.4,0.021,0.24
12,0.020,125,0.300,0.30
13,0.250,10.,0.020,0.24
14,48.00,0.067,0.016,0.24
15,0.020,125,0.300,0.30
16,0.375,4.4,0.021,0.24
17,0.020,125,0.300,0.30
18,0.250,10.,0.020,0.24
19,30.00,0.067,0.016,0.24
20,5.000,10.,0.020,0.24
21,0.020,125,0.300,0.30
22,0.375,4.4,0.021,0.24
23,0.020,125,0.300,0.30
24,2.500,0.067,0.016,0.24
25,0.020,125,0.300,0.30
26,0.375,4.4,0.021,0.24
27,0.020,125,0.300,0.30
28,0.250,130,0.800,0.20
3.5,34.0,2.5,5.5,22.0,11.0,3.0,4.0,30,24,28
0.70,1.0,0.0,2.0,150,0.80,0.22
0.3,0.9,0.3,0.9,0.3,0.9,0.1,0.9
3,100
0.9,0.9,0.9,0.9
1.0,0.0,1.0,0.0,1.0,0.0,1.0,0.0
9
0,10,10,0,0,75,110,110,190,190
5,120,5,60,20,5,120,60,60
7
60 570.67 459.67 14 330 10 10 0.36
```

TABLE 3-11. THERMOD INPUT FILE (input.dat) OF SAMPLE PROBLEM 3 (Continued)

```
75 573.67 459.67 14 355 10 10 0.31
90 578.67 459.67 14 355 10 12 0.33
75 581.67 459.67 14 330 10 10 0.31
60 582.67 459.67 14 291 10 10 0.36
45 583.67 459.67 14 231 10 10 0.44
30 582.67 459.67 14 160 10 10 0.57
2,100,180,1
10,1.0,1.0
10,10,10,10,10,10,10,10,10,10,10,10,10,10,10,
10,10,10,10,10,10,10,10,10,10,10,10,10,10,10,
10,10,10,10,10,10,10,10,10,10,10,10,10,10,10,
10,10,10,10,10,10,10,10,10,10,10,10,10,10,10,
10,10,10,10,10,10,10
```

Temperatures from the THERMOD run is shown in table 3-12, from which the steady-state temperatures T1, T2…..T10 (top to bottom of wing) for time period 3 were extracted and tabulated in table 3-13.

TABLE 3-12. THERMOD OUTPUT FILE (summary.dat) FOR SAMPLE PROBLEM 3

```
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
 THERMOD:  A THERMAL PROGRAM FOR AIRCRAFTS
 $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$



 SUMMARY OF STEADY-STATE AND TRANSIENT ANALYSIS



 (Temperatures are shown for all time periods)


 TEMPERATURES AT THE END OF STEADY STATE ANALYSIS

        TEMPERATURES IN DEGREES FAHRENHEIT
         1     2     3     4     5     6     7

   1 321.1 366.1 380.0 356.4 308.3 244.1 181.8
   2 321.1 366.1 380.0 356.3 308.3 244.1 181.8
   3 315.9 359.8 373.5 350.5 303.7 241.1 180.3
   4 315.8 359.8 373.4 350.5 303.6 241.1 180.3
   5 315.5 359.4 373.0 350.1 303.3 240.9 180.2
   6 119.2 123.9 129.2 131.2 130.3 128.7 125.3
   7 118.9 123.5 128.8 130.8 130.0 128.5 125.2
   8 118.9 123.5 128.8 130.8 129.9 128.5 125.2
```

TABLE 3-12. THERMOD OUTPUT FILE (summary.dat) FOR SAMPLE PROBLEM 3 (Continued)

```
  9 113.6 117.2 122.3 124.9 125.3 125.5 123.7
 10 113.6 117.1 122.3 124.9 125.3 125.5 123.7
 11 321.1 366.1 380.0 356.4 308.3 244.1 181.8
 12 321.1 366.1 380.0 356.3 308.3 244.1 181.8
 13 315.9 359.8 373.5 350.5 303.7 241.1 180.3
 14 315.8 359.8 373.4 350.5 303.6 241.1 180.3
 15 315.5 359.4 373.0 350.1 303.3 240.9 180.2
 16 119.2 123.9 129.2 131.2 130.3 128.7 125.3
 17 118.9 123.5 128.8 130.8 130.0 128.5 125.2
 18 118.9 123.5 128.8 130.8 129.9 128.5 125.2
 19 113.6 117.2 122.3 124.9 125.3 125.5 123.7
 20 113.6 117.1 122.3 124.9 125.3 125.5 123.7
 21 277.2 308.5 317.8 302.4 269.0 222.0 171.4
 22 277.1 308.3 317.6 302.2 268.9 221.9 171.4
 23 244.4 257.4 258.7 253.9 238.6 210.2 166.7
 24 244.3 257.2 258.5 253.7 238.5 210.2 166.7
 25 221.4 221.6 217.3 219.9 217.3 202.0 163.4
 26 194.1 189.2 184.0 189.0 192.2 184.4 150.1
 27 147.9 147.4 147.9 151.8 153.7 150.8 135.0
 28 147.9 147.4 147.9 151.8 153.7 150.8 135.0
 29 144.6 144.4 145.3 149.1 151.0 148.4 134.0
 30 144.6 144.4 145.3 149.1 151.0 148.4 134.0
 31 130.2 131.3 134.0 137.5 138.9 137.9 129.2
 32 130.2 131.3 134.0 137.5 138.9 137.9 129.2
 33 130.2 131.3 134.0 137.5 138.9 137.9 129.2
 34 130.2 131.3 134.0 137.5 138.9 137.9 129.2
 35 115.7 118.3 122.7 125.8 126.9 127.4 124.5
 36 115.7 118.3 122.7 125.8 126.9 127.4 124.5
 37 112.4 115.3 120.1 123.1 124.2 125.0 123.5
 38 112.4 115.3 120.1 123.1 124.2 125.0 123.5
 39 210.7 173.9 128.8 177.2 210.2 219.4 200.8
 40 210.7 174.0 129.0 177.3 210.2 219.3 200.6
 41 200.6 178.8 152.2 180.6 199.7 201.5 178.1
 42 200.6 178.8 152.3 180.6 199.6 201.4 178.0
 43 193.6 182.2 168.6 183.0 192.3 189.0 162.3
 44 186.0 177.5 168.6 178.6 185.6 182.2 156.6
 45 161.4 156.6 152.3 160.0 165.0 163.1 145.6
 46 161.3 156.5 152.2 159.9 164.9 163.0 145.5
 47 126.1 126.8 129.0 133.4 135.6 135.7 129.8
 48 125.9 126.6 128.8 133.2 135.4 135.6 129.7
 49 126.2 124.5 123.5 127.4 129.7 127.1 114.5
 50 128.7 126.7 125.5 129.6 132.0 129.2 115.7
 51 188.8 207.4 215.7 208.8 191.6 168.5 144.8
 52 183.9 201.5 209.6 203.3 187.3 165.7 143.4
 53 188.8 207.4 215.7 208.8 191.6 168.5 144.8
```

TABLE 3-12. THERMOD OUTPUT FILE (summary.dat) FOR SAMPLE PROBLEM 3 (Continued)

```
Maximum Structural Temperature for Period   1 = 321.12 Occurring
at Location   1
Maximum Structural Temperature for Period   2 = 366.11 Occurring
at Location   1
Maximum Structural Temperature for Period   3 = 380.01 Occurring
at Location   1
Maximum Structural Temperature for Period   4 = 356.36 Occurring
at Location   1
Maximum Structural Temperature for Period   5 = 308.29 Occurring
at Location   1
Maximum Structural Temperature for Period   6 = 244.09 Occurring
at Location   1
Maximum Structural Temperature for Period   7 = 200.77 Occurring
at Location  39

Maximum Structural Temperature Over All     7 Periods =380.01
Occurring at Location   1 at Period   3


 TEMPERATURES AT THE END OF TRANSIENT ANALYSIS

        TEMPERATURES IN DEGREES FAHRENHEIT
         1     2     3     4     5     6     7

   1 129.1 135.7 141.4 142.2 138.9 134.3 128.1
   2 134.7 142.5 148.5 148.5 143.9 137.6 129.6
   3 301.7 342.8 355.8 334.6 291.1 233.0 176.4
   4 306.4 348.5 361.8 340.0 295.3 235.7 177.7
   5 306.1 348.2 361.4 339.7 295.1 235.5 177.6
   6 124.1 129.7 135.2 136.6 134.5 131.5 126.7
   7 118.8 123.3 128.7 130.7 129.9 128.4 125.2
   8 118.6 123.1 128.4 130.4 129.7 128.3 125.1
   9 111.4 114.5 119.6 122.5 123.4 124.3 123.1
  10 111.2 114.3 119.3 122.3 123.2 124.1 123.1
  11 129.1 135.7 141.4 142.2 138.9 134.3 128.1
  12 134.7 142.5 148.5 148.5 143.9 137.6 129.6
  13 301.7 342.8 355.8 334.6 291.1 233.0 176.4
  14 306.4 348.5 361.8 340.0 295.3 235.7 177.7
  15 306.1 348.2 361.4 339.7 295.1 235.5 177.6
  16 124.1 129.7 135.2 136.6 134.5 131.5 126.7
  17 118.8 123.3 128.7 130.7 129.9 128.4 125.2
  18 118.6 123.1 128.4 130.4 129.7 128.3 125.1
  19 111.4 114.5 119.6 122.5 123.4 124.3 123.1
  20 111.2 114.3 119.3 122.3 123.2 124.1 123.1
  21 130.8 137.4 142.9 143.7 140.4 135.8 128.8
  22 133.5 140.4 145.8 146.4 142.7 137.7 129.7
  23 203.9 216.1 216.0 215.1 202.6 188.7 155.1
```

TABLE 3-12. THERMOD OUTPUT FILE (summary.dat) FOR SAMPLE PROBLEM 3 (Continued)

```
  24 205.8 217.8 217.4 216.7 204.1 190.2 155.8
  25 210.8 216.5 210.1 213.7 205.9 197.6 157.6
  26 186.1 186.3 181.1 186.4 185.3 182.1 149.5
  27 148.1 147.5 148.0 151.9 153.9 150.9 135.1
  28 147.0 146.6 147.2 151.1 153.0 150.2 134.8
  29 144.2 144.1 145.1 148.9 150.7 148.2 133.9
  30 143.4 143.4 144.4 148.2 150.0 147.6 133.6
  31 129.7 131.0 133.7 137.1 138.6 137.6 129.1
  32 129.7 131.0 133.7 137.1 138.6 137.6 129.1
  33 129.7 131.0 133.7 137.1 138.6 137.6 129.1
  34 129.7 131.0 133.7 137.1 138.6 137.6 129.1
  35 116.0 118.5 122.9 126.0 127.2 127.6 124.6
  36 115.2 117.8 122.3 125.4 126.5 127.0 124.4
  37 111.3 114.3 119.2 122.2 123.2 124.2 123.1
  38 111.2 114.1 119.1 122.1 123.1 124.1 123.1
  39 119.2 119.2 120.3 126.8 130.2 131.8 129.2
  40 121.4 120.9 121.3 128.3 132.0 133.7 130.5
  41 174.2 164.5 149.6 167.4 176.6 178.9 159.7
  42 175.8 166.0 150.9 168.8 178.0 180.2 160.4
  43 185.3 179.9 167.2 180.8 185.2 186.1 160.0
  44 178.6 175.6 167.2 176.9 179.3 179.9 154.7
  45 159.1 156.3 150.9 159.8 163.2 163.9 146.6
  46 157.5 154.8 149.6 158.4 161.9 162.6 145.9
  47 119.0 119.6 121.3 127.1 129.9 131.4 128.6
  48 117.6 118.3 120.3 125.9 128.8 130.2 127.9
  49 116.9 118.7 121.3 124.6 125.7 125.5 119.8
  50 120.3 121.9 123.7 127.3 128.2 127.8 120.4
  51 306.1 348.1 361.3 339.6 295.0 235.5 177.6
  52 288.9 327.5 340.0 320.5 279.9 225.7 172.8
  53 306.1 348.1 361.3 339.6 295.0 235.5 177.6

Maximum Structural Temperature for Period   1 = 306.45 Occurring
at Location   4
Maximum Structural Temperature for Period   2 = 348.51 Occurring
at Location   4
Maximum Structural Temperature for Period   3 = 361.78 Occurring
at Location   4
Maximum Structural Temperature for Period   4 = 339.99 Occurring
at Location   4
Maximum Structural Temperature for Period   5 = 295.35 Occurring
at Location   4
Maximum Structural Temperature for Period   6 = 235.71 Occurring
at Location   4
Maximum Structural Temperature for Period   7 = 177.71 Occurring
at Location   4
Maximum Structural Temperature Over All    7 Periods =361.78
Occurring at Location   4 at Period   3
```

TABLE 3-13. THERMOD-SIMULATED TEMPERATURES (°F) OF THE RIGHT WING OF SAMPLE PROBLEM 3

T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
380.0	380.0	373.5	373.4	373.0	129.2	128.8	128.8	122.3	122.3

As in sample problems 1 and 2, a one-half wing structure was modeled using the UAI/NASTRAN FEM program. Boundary conditions were imposed based on the THERMOD-simulated data for period 3. The wing top was constrained to 380.0°F, and the wing sides were constrained to 124.4°F, which happens to be the highest ambient temperature (time period 6 of table 3-11). Because the ratio of the wing length to its depth is sufficiently high, edge effects due to the wing sides (and the boundary temperature used) are insignificant, as the FEM results show. The bottom wing surface was free of any constraint, except that it was subjected to convection, with a film coefficient h = 1.3433 (Btu/hr)/(ft^2°F). This film coefficient was calculated internally by the THERMOD program and is based on the theory of airflow on a flat surface and a wind speed of 14 ft/sec.

The FEM input file is shown in table 3-14. The boundary conditions were imposed by the SPC cards. An ambient temperature of 119.0°F (pertaining to period 3 of the THERMOD input) was applied through the scalar point, SPOINT, bulk data. The boundary elements, CHBDY, through which convection is realized, were modeled using the LINE elements connecting the nodes at the wing bottom. Property cards PHBDY and material cards MAT4 simulated the film coefficient and other element properties.

TABLE 3-14. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 3

```
ID D:\Natha,MSC/N
APP HEAT
SOL 1
TIME 10000
CEND
  TITLE = CONDUCTION & CONVECTION IN RECT. ADIABATIC PLATE (t=0.001ft)
  SUBTITLE = 10.7 in air gap; k=0.016BTU/hr/ft/degF; h=1.3433BTU/hr/ft^2/degF
   SPC = 1
   THERMAL= ALL
   FLUX = ALL
   SPCF = ALL
BEGIN BULK
$ ************************************************************************
$   Written by : MSC/NASTRAN for Windows
$   Version    : 6.00
$   Translator : UAI/NASTRAN
$   From Model : D:\Thermod_Validation\FEM\conduction&convection.MOD
$   Date       : Tue Mar 07 08:27:39 2000
$ ************************************************************************
$
PARAM,K6ROT,100.
PARAM,MAXRATIO,1.E+8
CORD2C         1       0      0.      0.      0.      0.      0.    1.+MSC/NC1
+MSC/NC1      1.      0.      1.
CORD2S         2       0      0.      0.      0.      0.      0.    1.+MSC/NC2
+MSC/NC2      1.      0.      1.
```

TABLE 3-14. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 3 (Continued)

```
$ MSC/NASTRAN for Windows Constraint Set 1 : bound_temp&ambient constr
SPC             1      37       1  124.4
SPC             1      55       1  124.4
SPC             1      56       1  124.4
SPC             1      73       1  124.4
SPC             1     109       1  124.4
SPC             1     128       1  124.4
SPC             1     145       1  124.4
SPC             1     146       1  124.4
SPC             1     164       1  124.4
SPC             1     181       1  124.4
SPC             1     182       1  124.4
SPC             1     199       1  124.4
SPC             1     200       1  124.4
SPC             1     201       1  380.0
SPC             1     202       1  380.0
SPC             1     203       1  380.0
SPC             1     204       1  380.0
SPC             1     205       1  380.0
SPC             1     206       1  380.0
SPC             1     207       1  380.0
SPC             1     208       1  380.0
SPC             1     209       1  380.0
SPC             1     210       1  380.0
SPC             1     211       1  380.0
SPC             1     212       1  380.0
SPC             1     213       1  380.0
SPC             1     214       1  380.0
SPC             1     215       1  380.0
SPC             1     216       1  380.0
SPC             1     235       1  124.4
SPC             1     253       1  124.4
SPC             1     254       1  124.4
SPC             1     307       1  124.4
SPC             1     308       1  124.4
spc,1,500,1,119.0
spoint,500
chbdy,1000,100,line,1,36,,,,500,500
chbdy,1001,100,line,36,35,,,,500,500
chbdy,1002,100,line,35,34,,,,500,500
chbdy,1003,100,line,34,33,,,,500,500
chbdy,1004,100,line,33,32,,,,500,500
chbdy,1005,100,line,32,31,,,,500,500
chbdy,1006,100,line,31,30,,,,500,500
chbdy,1007,100,line,30,29,,,,500,500
chbdy,1008,100,line,29,28,,,,500,500
chbdy,1009,100,line,28,27,,,,500,500
chbdy,1010,100,line,27,26,,,,500,500
chbdy,1011,100,line,26,25,,,,500,500
chbdy,1012,100,line,25,24,,,,500,500
chbdy,1013,100,line,24,23,,,,500,500
chbdy,1014,100,line,23,22,,,,500,500
chbdy,1015,100,line,22,21,,,,500,500
chbdy,1016,100,line,21,20,,,,500,500
phbdy,100,200,0.001
mat4,200,1.3433
$mat4,200,0.0001
```

TABLE 3-14. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 3 (Continued)

```
$
$ MSC/NASTRAN for Windows Property 1 : 0.02 in glass_outer_layer
PSHELL         1       1   0.001       1               1              0.
$ MSC/NASTRAN for Windows Property 2 : 3/8 in foam
PSHELL         2       2   0.001       2               2              0.
$ MSC/NASTRAN for Windows Property 3 : 0.02 in inner glass
PSHELL         3       1   0.001       1               1              0.
$ MSC/NASTRAN for Windows Property 4 : 0.350 in cap
PSHELL         4       1   0.001       1               1              0.
$ MSC/NASTRAN for Windows Property 5 : 10.70 in air space
PSHELL         5       3   0.001       3               3              0.
$ MSC/NASTRAN for Windows Property 6 : 0.350 in cap
PSHELL         6       1   0.001       1               1              0.
$ MSC/NASTRAN for Windows Property 7 : 0.02 in inner glass
PSHELL         7       1   0.001       1               1              0.
$ MSC/NASTRAN for Windows Property 8 : 3/8 in foam
PSHELL         8       2   0.001       2               2              0.
$ MSC/NASTRAN for Windows Property 9 : 0.02 in glass_outer_layer
PSHELL         9       1   0.001       1               1              0.
$ MSC/NASTRAN for Windows Property 10 : 10.70 in oil
PSHELL        10       4   0.001       4               4              0.
$ MSC/NASTRAN for Windows Material 1 : glass
MAT4           1     0.3      1.
$ MSC/NASTRAN for Windows Material 2 : foam
MAT4           2   0.021      1.
$ MSC/NASTRAN for Windows Material 3 : air
MAT4           3   0.016      1.
$ MSC/NASTRAN for Windows Material 4 : oil
MAT4           4   0.081      1.
GRID           1       0      0.      0.      0.       0
GRID           3       0      1.1.667E-3      0.       0
GRID           5       0      3.1.667E-3      0.       0
GRID           7       0      5.1.667E-3      0.       0
GRID           9       0      7.1.667E-3      0.       0
GRID          10       0      8.1.667E-3      0.       0
GRID          11       0      9.1.667E-3      0.       0
GRID          12       0     10.1.667E-3      0.       0
GRID          14       0     12.1.667E-3      0.       0
GRID          15       0     13.1.667E-3      0.       0
GRID          18       0     16.1.667E-3      0.       0
GRID          20       0     17.       0.     0.       0
GRID          21       0     16.       0.     0.       0
GRID          22       0     15.       0.     0.       0
GRID          23       0     14.       0.     0.       0
GRID          24       0     13.       0.     0.       0
GRID          25       0     12.       0.     0.       0
GRID          26       0     11.       0.     0.       0
GRID          27       0     10.       0.     0.       0
GRID          28       0      9.       0.     0.       0
GRID          29       0      8.       0.     0.       0
GRID          30       0      7.       0.     0.       0
GRID          31       0      6.       0.     0.       0
GRID          32       0      5.       0.     0.       0
GRID          33       0      4.       0.     0.       0
GRID          34       0      3.       0.     0.       0
GRID          35       0      2.       0.     0.       0
GRID          36       0      1.       0.     0.       0
```

TABLE 3-14. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 3 (Continued)

```
GRID            37       0      0.1.667E-3      0.       0
GRID            41       0       3.0.032917     0.       0
GRID            44       0       6.0.032917     0.       0
GRID            45       0       7.0.032917     0.       0
GRID            47       0       9.0.032917     0.       0
GRID            48       0      10.0.032917     0.       0
GRID            50       0      12.0.032917     0.       0
GRID            51       0      13.0.032917     0.       0
GRID            52       0      14.0.032917     0.       0
GRID            53       0      15.0.032917     0.       0
GRID            54       0      16.0.032917     0.       0
GRID            55       0      17.0.032917     0.       0
GRID            56       0      17.1.667E-3     0.       0
GRID            58       0      15.1.667E-3     0.       0
GRID            59       0      14.1.667E-3     0.       0
GRID            62       0      11.1.667E-3     0.       0
GRID            67       0       6.1.667E-3     0.       0
GRID            69       0       4.1.667E-3     0.       0
GRID            71       0       2.1.667E-3     0.       0
GRID            73       0       0.0.032917     0.       0
GRID            75       0       1.0.034583     0.       0
GRID            76       0       2.0.034583     0.       0
GRID            77       0       3.0.034583     0.       0
GRID            78       0       4.0.034583     0.       0
GRID            79       0       5.0.034583     0.       0
GRID            80       0       6.0.034583     0.       0
GRID            83       0       9.0.034583     0.       0
GRID            85       0      11.0.034583     0.       0
GRID            87       0      13.0.034583     0.       0
GRID            88       0      14.0.034583     0.       0
GRID            98       0      11.0.032917     0.       0
GRID           101       0       8.0.032917     0.       0
GRID           104       0       5.0.032917     0.       0
GRID           105       0       4.0.032917     0.       0
GRID           107       0       2.0.032917     0.       0
GRID           108       0       1.0.032917     0.       0
GRID           109       0       0.0.034583     0.       0
GRID           112       0       2. 0.06375     0.       0
GRID           115       0       5. 0.06375     0.       0
GRID           116       0       6. 0.06375     0.       0
GRID           118       0       8. 0.06375     0.       0
GRID           120       0      10. 0.06375     0.       0
GRID           121       0      11. 0.06375     0.       0
GRID           122       0      12. 0.06375     0.       0
GRID           123       0      13. 0.06375     0.       0
GRID           124       0      14. 0.06375     0.       0
GRID           125       0      15. 0.06375     0.       0
GRID           128       0      17.0.034583     0.       0
GRID           129       0      16.0.034583     0.       0
GRID           130       0      15.0.034583     0.       0
GRID           133       0      12.0.034583     0.       0
GRID           135       0      10.0.034583     0.       0
GRID           137       0       8.0.034583     0.       0
GRID           138       0       7.0.034583     0.       0
GRID           145       0       0. 0.06375     0.       0
GRID           146       0       0. 0.95542     0.       0
GRID           147       0       1. 0.95542     0.       0
```

TABLE 3-14. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 3 (Continued)

```
GRID          150       0      4. 0.95542       0.       0
GRID          152       0      6. 0.95542       0.       0
GRID          160       0     14. 0.95542       0.       0
GRID          161       0     15. 0.95542       0.       0
GRID          164       0     17. 0.06375       0.       0
GRID          165       0     16. 0.06375       0.       0
GRID          172       0      9. 0.06375       0.       0
GRID          174       0      7. 0.06375       0.       0
GRID          177       0      4. 0.06375       0.       0
GRID          178       0      3. 0.06375       0.       0
GRID          180       0      1. 0.06375       0.       0
GRID          181       0      0. 1.01917       0.       0
GRID          182       0      0.  1.0175       0.       0
GRID          183       0      1.  1.0175       0.       0
GRID          184       0      2.  1.0175       0.       0
GRID          188       0      6.  1.0175       0.       0
GRID          193       0     11.  1.0175       0.       0
GRID          195       0     13.  1.0175       0.       0
GRID          196       0     14.  1.0175       0.       0
GRID          197       0     15.  1.0175       0.       0
GRID          198       0     16.  1.0175       0.       0
GRID          199       0     17.  1.0175       0.       0
GRID          200       0     17. 1.01917       0.       0
GRID          201       0     16. 1.01917       0.       0
GRID          202       0     15. 1.01917       0.       0
GRID          203       0     14. 1.01917       0.       0
GRID          204       0     13. 1.01917       0.       0
GRID          205       0     12. 1.01917       0.       0
GRID          206       0     11. 1.01917       0.       0
GRID          207       0     10. 1.01917       0.       0
GRID          208       0      9. 1.01917       0.       0
GRID          209       0      8. 1.01917       0.       0
GRID          210       0      7. 1.01917       0.       0
GRID          211       0      6. 1.01917       0.       0
GRID          212       0      5. 1.01917       0.       0
GRID          213       0      4. 1.01917       0.       0
GRID          214       0      3. 1.01917       0.       0
GRID          215       0      2. 1.01917       0.       0
GRID          216       0      1. 1.01917       0.       0
GRID          219       0      1. 0.98625       0.       0
GRID          220       0      2. 0.98625       0.       0
GRID          221       0      3. 0.98625       0.       0
GRID          222       0      4. 0.98625       0.       0
GRID          223       0      5. 0.98625       0.       0
GRID          226       0      8. 0.98625       0.       0
GRID          227       0      9. 0.98625       0.       0
GRID          228       0     10. 0.98625       0.       0
GRID          229       0     11. 0.98625       0.       0
GRID          231       0     13. 0.98625       0.       0
GRID          232       0     14. 0.98625       0.       0
GRID          235       0     17. 0.98625       0.       0
GRID          241       0     12.  1.0175       0.       0
GRID          243       0     10.  1.0175       0.       0
GRID          244       0      9.  1.0175       0.       0
GRID          245       0      8.  1.0175       0.       0
GRID          246       0      7.  1.0175       0.       0
GRID          248       0      5.  1.0175       0.       0
```

TABLE 3-14. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 3 (Continued)

```
GRID          249       0      4.  1.0175       0.       0
GRID          250       0      3.  1.0175       0.       0
GRID          253       0      0. 0.98625       0.       0
GRID          254       0      0. 0.98458       0.       0
GRID          257       0      3. 0.98458       0.       0
GRID          258       0      4. 0.98458       0.       0
GRID          259       0      5. 0.98458       0.       0
GRID          260       0      6. 0.98458       0.       0
GRID          264       0     10. 0.98458       0.       0
GRID          267       0     13. 0.98458       0.       0
GRID          268       0     14. 0.98458       0.       0
GRID          269       0     15. 0.98458       0.       0
GRID          270       0     16. 0.98458       0.       0
GRID          273       0     16. 0.98625       0.       0
GRID          274       0     15. 0.98625       0.       0
GRID          277       0     12. 0.98625       0.       0
GRID          282       0      7. 0.98625       0.       0
GRID          283       0      6. 0.98625       0.       0
GRID          292       0      2. 0.95542       0.       0
GRID          293       0      3. 0.95542       0.       0
GRID          295       0      5. 0.95542       0.       0
GRID          297       0      7. 0.95542       0.       0
GRID          298       0      8. 0.95542       0.       0
GRID          299       0      9. 0.95542       0.       0
GRID          300       0     10. 0.95542       0.       0
GRID          301       0     11. 0.95542       0.       0
GRID          302       0     12. 0.95542       0.       0
GRID          303       0     13. 0.95542       0.       0
GRID          306       0     16. 0.95542       0.       0
GRID          307       0     17. 0.95542       0.       0
GRID          308       0     17. 0.98458       0.       0
GRID          313       0     12. 0.98458       0.       0
GRID          314       0     11. 0.98458       0.       0
GRID          316       0      9. 0.98458       0.       0
GRID          317       0      8. 0.98458       0.       0
GRID          318       0      7. 0.98458       0.       0
GRID          323       0      2. 0.98458       0.       0
GRID          324       0      1. 0.98458       0.       0
CQUAD4          1       9       1       37       3      36
CQUAD4          2       9      36        3      71      35
CQUAD4          3       9      35       71       5      34
CQUAD4          4       9      34        5      69      33
CQUAD4          5       9      33       69       7      32
CQUAD4          6       9      32        7      67      31
CQUAD4          7       9      31       67       9      30
CQUAD4          8       9      30        9      10      29
CQUAD4          9       9      29       10      11      28
CQUAD4         10       9      28       11      12      27
CQUAD4         11       9      27       12      62      26
CQUAD4         12       9      26       62      14      25
CQUAD4         13       9      25       14      15      24
CQUAD4         14       9      24       15      59      23
CQUAD4         15       9      23       59      58      22
CQUAD4         16       9      22       58      18      21
CQUAD4         17       9      21       18      56      20
CQUAD4         18       8      37       73     108       3
CQUAD4         19       8       3      108     107      71
```

TABLE 3-14. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 3 (Continued)

```
CQUAD4          20        8        71       107        41         5
CQUAD4          21        8         5        41       105        69
CQUAD4          22        8        69       105       104         7
CQUAD4          23        8         7       104        44        67
CQUAD4          24        8        67        44        45         9
CQUAD4          25        8         9        45       101        10
CQUAD4          26        8        10       101        47        11
CQUAD4          27        8        11        47        48        12
CQUAD4          28        8        12        48        98        62
CQUAD4          29        8        62        98        50        14
CQUAD4          30        8        14        50        51        15
CQUAD4          31        8        15        51        52        59
CQUAD4          32        8        59        52        53        58
CQUAD4          33        8        58        53        54        18
CQUAD4          34        8        18        54        55        56
CQUAD4          35        7        73       109        75       108
CQUAD4          36        7       108        75        76       107
CQUAD4          37        7       107        76        77        41
CQUAD4          38        7        41        77        78       105
CQUAD4          39        7       105        78        79       104
CQUAD4          40        7       104        79        80        44
CQUAD4          41        7        44        80       138        45
CQUAD4          42        7        45       138       137       101
CQUAD4          43        7       101       137        83        47
CQUAD4          44        7        47        83       135        48
CQUAD4          45        7        48       135        85        98
CQUAD4          46        7        98        85       133        50
CQUAD4          47        7        50       133        87        51
CQUAD4          48        7        51        87        88        52
CQUAD4          49        7        52        88       130        53
CQUAD4          50        7        53       130       129        54
CQUAD4          51        7        54       129       128        55
CQUAD4          52        6       109       145       180        75
CQUAD4          53        6        75       180       112        76
CQUAD4          54        6        76       112       178        77
CQUAD4          55        6        77       178       177        78
CQUAD4          56        6        78       177       115        79
CQUAD4          57        6        79       115       116        80
CQUAD4          58        6        80       116       174       138
CQUAD4          59        6       138       174       118       137
CQUAD4          60        6       137       118       172        83
CQUAD4          61        6        83       172       120       135
CQUAD4          62        6       135       120       121        85
CQUAD4          63        6        85       121       122       133
CQUAD4          64        6       133       122       123        87
CQUAD4          65        6        87       123       124        88
CQUAD4          66        6        88       124       125       130
CQUAD4          67        6       130       125       165       129
CQUAD4          68        6       129       165       164       128
CQUAD4          69        5       145       146       147       180
CQUAD4          70        5       180       147       292       112
CQUAD4          71        5       112       292       293       178
CQUAD4          72        5       178       293       150       177
CQUAD4          73        5       177       150       295       115
CQUAD4          74        5       115       295       152       116
CQUAD4          75        5       116       152       297       174
CQUAD4          76        5       174       297       298       118
```

TABLE 3-14. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 3 (Continued)

```
CQUAD4      77       5      118      298      299      172
CQUAD4      78       5      172      299      300      120
CQUAD4      79       5      120      300      301      121
CQUAD4      80       5      121      301      302      122
CQUAD4      81       5      122      302      303      123
CQUAD4      82       5      123      303      160      124
CQUAD4      83       5      124      160      161      125
CQUAD4      84       5      125      161      306      165
CQUAD4      85       5      165      306      307      164
CQUAD4      86       1      182      181      216      183
CQUAD4      87       1      183      216      215      184
CQUAD4      88       1      184      215      214      250
CQUAD4      89       1      250      214      213      249
CQUAD4      90       1      249      213      212      248
CQUAD4      91       1      248      212      211      188
CQUAD4      92       1      188      211      210      246
CQUAD4      93       1      246      210      209      245
CQUAD4      94       1      245      209      208      244
CQUAD4      95       1      244      208      207      243
CQUAD4      96       1      243      207      206      193
CQUAD4      97       1      193      206      205      241
CQUAD4      98       1      241      205      204      195
CQUAD4      99       1      195      204      203      196
CQUAD4     100       1      196      203      202      197
CQUAD4     101       1      197      202      201      198
CQUAD4     102       1      198      201      200      199
CQUAD4     103       2      253      182      183      219
CQUAD4     104       2      219      183      184      220
CQUAD4     105       8      220      184      250      221
CQUAD4     106       2      221      250      249      222
CQUAD4     107       2      222      249      248      223
CQUAD4     108       2      223      248      188      283
CQUAD4     109       2      283      188      246      282
CQUAD4     110       2      282      246      245      226
CQUAD4     111       2      226      245      244      227
CQUAD4     112       2      227      244      243      228
CQUAD4     113       2      228      243      193      229
CQUAD4     114       2      229      193      241      277
CQUAD4     115       2      277      241      195      231
CQUAD4     116       2      231      195      196      232
CQUAD4     117       2      232      196      197      274
CQUAD4     118       2      274      197      198      273
CQUAD4     119       2      273      198      199      235
CQUAD4     120       3      254      253      219      324
CQUAD4     121       3      324      219      220      323
CQUAD4     122       3      323      220      221      257
CQUAD4     123       3      257      221      222      258
CQUAD4     124       3      258      222      223      259
CQUAD4     125       3      259      223      283      260
CQUAD4     126       3      260      283      282      318
CQUAD4     127       3      318      282      226      317
CQUAD4     128       3      317      226      227      316
CQUAD4     129       3      316      227      228      264
CQUAD4     130       3      264      228      229      314
CQUAD4     131       3      314      229      277      313
CQUAD4     132       3      313      277      231      267
CQUAD4     133       3      267      231      232      268
```

TABLE 3-14. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 3 (Continued)

```
CQUAD4      134       3      268      232      274      269
CQUAD4      135       3      269      274      273      270
CQUAD4      136       3      270      273      235      308
CQUAD4      137       4      146      254      324      147
CQUAD4      138       4      147      324      323      292
CQUAD4      139       4      292      323      257      293
CQUAD4      140       4      293      257      258      150
CQUAD4      141       4      150      258      259      295
CQUAD4      142       4      295      259      260      152
CQUAD4      143       4      152      260      318      297
CQUAD4      144       4      297      318      317      298
CQUAD4      145       4      298      317      316      299
CQUAD4      146       4      299      316      264      300
CQUAD4      147       4      300      264      314      301
CQUAD4      148       4      301      314      313      302
CQUAD4      149       4      302      313      267      303
CQUAD4      150       4      303      267      268      160
CQUAD4      151       4      160      268      269      161
CQUAD4      152       4      161      269      270      306
CQUAD4      153       4      306      270      308      307
ENDDATA
```

The results of the one-half FEM wing model analysis are presented in figure 3-3 in the form of a contour plot. The contours along the outer nodes are in agreement with the imposed boundary conditions, while the contours of the inner layers appear to be indicative of the temperature profile of the THERMOD analysis. Also note the surface boundary conditions enforced on the top and sides of the wing.

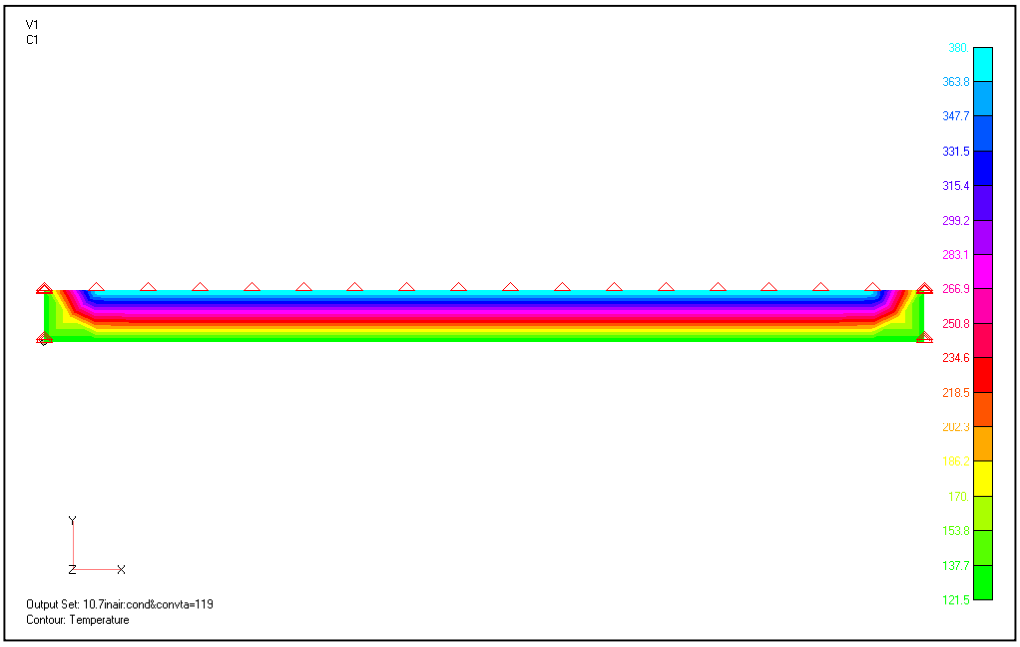


FIGURE 3-3. CONTOUR PLOT OF THE FEM OUTPUT OF SAMPLE PROBLEM 3

The truncated FEM output file is shown in table 3-15. The nodes, from top to bottom of the wing, located at mid-span of the model are indicated by nodes 209, 245, 226, 317, 298, 118, 137, 101, 10, and 29. The temperatures of these nodes were extracted from this file and are reproduced in table 3-16. Mid-span was chosen because it was sufficiently far away from any edge effects that might be present.

TABLE 3-15. TRUNCATED FEM OUTPUT FILE OF SAMPLE PROBLEM 3

```
1      CONDUCTION & CONVECTION IN RECT. ADIABATIC PLATE (T=0.001FT)    AUGUST  15, 2000   UAI/NASTRAN VERSION 20.1         PAGE
16
      10.7 IN AIR GAP; K=0.016BTU/HR/FT/DEGF; H=1.3433BTU/HR/FT^2/DEGF
0

                                                T E M P E R A T U R E   V E C T O R

      POINT ID.   TYPE      ID   VALUE     ID+1 VALUE     ID+2 VALUE     ID+3 VALUE     ID+4 VALUE     ID+5 VALUE
             1    TEMP     1.243670E+02
             3    TEMP     1.215624E+02
             5    TEMP     1.222429E+02
             7    TEMP     1.222786E+02
             9    TEMP     1.222806E+02   1.222807E+02   1.222807E+02   1.222806E+02
            14    TEMP     1.222786E+02   1.222896E+02
            18    TEMP     1.215624E+02
            20    TEMP     1.243670E+02   1.215388E+02   1.224165E+02   1.222185E+02   1.222653E+02   1.222543E+02
            26    TEMP     1.222569E+02   1.222563E+02   1.222564E+02   1.222564E+02   1.222563E+02   1.222569E+02
            32    TEMP     1.222543E+02   1.222653E+02   1.222185E+02   1.224165E+02   1.215388E+02   1.244000E+02
            41    TEMP     1.287578E+02
            44    TEMP     1.287905E+02   1.287900E+02
            47    TEMP     1.287901E+02   1.287900E+02
            50    TEMP     1.287883E+02   1.287975E+02   1.287578E+02   1.289130E+02   1.278674E+02   1.244000E+02
            56    TEMP     1.244000E+02
            58    TEMP     1.224406E+02   1.222429E+02
            62    TEMP     1.222812E+02
            67    TEMP     1.222812E+02
            69    TEMP     1.222896E+02
            71    TEMP     1.224406E+02
            73    TEMP     1.244000E+02
            75    TEMP     1.278909E+02   1.289371E+02   1.287821E+02   1.288218E+02   1.288126E+02   1.288148E+02
            83    TEMP     1.288144E+02
            85    TEMP     1.288148E+02
            87    TEMP     1.288218E+02   1.287821E+02
            98    TEMP     1.287905E+02
           101    TEMP     1.287901E+02
           104    TEMP     1.287883E+02   1.287975E+02
           107    TEMP     1.289130E+02   1.278674E+02   1.244000E+02
           112    TEMP     1.293606E+02
           115    TEMP     1.292379E+02   1.292401E+02
           118    TEMP     1.292397E+02
           120    TEMP     1.292395E+02   1.292401E+02   1.292379E+02   1.292470E+02   1.292076E+02   1.293606E+02
           128    TEMP     1.244000E+02   1.278909E+02   1.289371E+02
           133    TEMP     1.288126E+02
           135    TEMP     1.288143E+02
           137    TEMP     1.288144E+02   1.288143E+02
           145    TEMP     1.244000E+02   1.244000E+02   3.669625E+02
           150    TEMP     3.730168E+02
           152    TEMP     3.730167E+02
           160    TEMP     3.730125E+02   3.728751E+02
           164    TEMP     1.244000E+02   1.283041E+02
           172    TEMP     1.292397E+02
           174    TEMP     1.292395E+02
           177    TEMP     1.292470E+02   1.292076E+02
           180    TEMP     1.283041E+02   1.244000E+02   1.244000E+02   3.799533E+02   3.799752E+02
           188    TEMP     3.799756E+02
           193    TEMP     3.799756E+02
           195    TEMP     3.799756E+02   3.799756E+02   3.799752E+02   3.799533E+02   1.244000E+02   1.244000E+02
           201    TEMP     3.800000E+02   3.800000E+02   3.800000E+02   3.800000E+02   3.800000E+02   3.800000E+02
1      CONDUCTION & CONVECTION IN RECT. ADIABATIC PLATE (T=0.001FT)    AUGUST  15, 2000   UAI/NASTRAN VERSION 20.1         PAGE
17
      10.7 IN AIR GAP; K=0.016BTU/HR/FT/DEGF; H=1.3433BTU/HR/FT^2/DEGF
0

                                                T E M P E R A T U R E   V E C T O R

      POINT ID.   TYPE      ID   VALUE     ID+1 VALUE     ID+2 VALUE     ID+3 VALUE     ID+4 VALUE     ID+5 VALUE
           207    TEMP     3.800000E+02   3.800000E+02   3.800000E+02   3.800000E+02   3.800000E+02   3.800000E+02
           213    TEMP     3.800000E+02   3.800000E+02   3.800000E+02   3.800000E+02
           219    TEMP     3.676886E+02   3.733311E+02   3.734622E+02   3.734663E+02   3.734662E+02
           226    TEMP     3.734662E+02   3.734662E+02   3.734662E+02   3.734663E+02
           231    TEMP     3.734663E+02   3.734622E+02
           235    TEMP     1.244000E+02
           241    TEMP     3.799756E+02
           243    TEMP     3.799756E+02   3.799756E+02   3.799756E+02   3.799756E+02
           248    TEMP     3.799756E+02   3.799756E+02   3.799756E+02
           253    TEMP     1.244000E+02   1.244000E+02
           257    TEMP     3.734379E+02   3.734420E+02   3.734419E+02   3.734419E+02
           264    TEMP     3.734419E+02
```

TABLE 3-15. TRUNCATED FEM OUTPUT FILE OF SAMPLE PROBLEM 3 (Continued)

```
      267    TEMP    3.734420E+02   3.734379E+02   3.733062E+02   3.676435E+02
      273    TEMP    3.676886E+02   3.733311E+02
      277    TEMP    3.734662E+02
      282    TEMP    3.734662E+02   3.734663E+02
      292    TEMP    3.728751E+02   3.730125E+02
      295    TEMP    3.730167E+02
      297    TEMP    3.730167E+02   3.730167E+02   3.730167E+02   3.730167E+02   3.730167E+02   3.730167E+02
      303    TEMP    3.730168E+02
      306    TEMP    3.669625E+02   1.244000E+02   1.244000E+02
      313    TEMP    3.734419E+02   3.734419E+02
      316    TEMP    3.734419E+02   3.734419E+02   3.734419E+02
      323    TEMP    3.733062E+02   3.676435E+02
      500    TEMP    1.190000E+02
```

When compared, the temperatures of tables 3-13 and 3-16 show excellent agreement, validating the conduction and convection capabilities of the THERMOD program.

TABLE 3-16. FINITE ELEMENT METHOD-SIMULATED TEMPERATURES (°F) OF THE RIGHT WING OF SAMPLE PROBLEM 3

T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
380.0	380.0	373.5	373.4	373.0	129.2	128.8	128.8	122.3	122.3

3.4 SAMPLE PROBLEM 4.

The primary purpose of sample problem 4 was to study the effects of solar radiation on an aircraft. As in sample problems 1 and 2, THERMOD was set up to solve a complete aircraft problem, while the FEM method was confined to the wing model.

An aircraft parked in the open is subjected to three types of radiation: direct solar radiation, diffused solar radiation, and infrared radiation.

- The direct solar radiation rays are in the visible regions of the energy spectrum, have a fixed incident angle, are of short wavelengths, and are characterized by high energy levels.
- The diffused solar radiation is also in the visible region of the energy spectrum but does not have a fixed incident angle. It is diffused in nature.
- The infrared radiation falls in the nonvisible region of the energy spectrum. It is of long wavelength and characterized by low energy level.
- The direct solar radiation type is explored in sample problem 4.

In addition, all external surfaces, except the wing surface, were assigned absorptivity and emissivity values of 1.0 and 0.0, respectively. The values for the wing surface were 0.9 and 0.0, respectively. A 0.0 emissivity value prevents the emission of infrared energy, thereby removing its influence on the thermal system. For the same reason, the sky radiation was assigned an absolute temperature of 0.0. The conduction and convection heat transfer modes, however, were left intact, as in sample problem 3. The THERMOD input file, input.dat, is illustrated in table 3-17.

TABLE 3-17. THERMOD INPUT FILE (input.dat) OF SAMPLE PROBLEM 4

```
198e-6,0.704
1, 0.020,125,0.300,0.30
2, 0.375,4.4,0.021,0.24
3, 0.020,125,0.300,0.30
4, 0.350,125,0.300,0.30
5, 10.70,0.067,0.016,0.24
6, 0.350,125,0.300,0.30
7, 0.020,125,0.300,0.30
8, 0.375,4.4,0.021,0.24
9, 0.020,125,0.300,0.30
10,0.030,125,0.300,0.30
11,0.375,4.4,0.021,0.24
12,0.020,125,0.300,0.30
13,0.250,10.,0.020,0.24
14,48.00,0.067,0.016,0.24
15,0.020,125,0.300,0.30
16,0.375,4.4,0.021,0.24
17,0.020,125,0.300,0.30
18,0.250,10.,0.020,0.24
19,30.00,0.067,0.016,0.24
20,5.000,10.,0.020,0.24
21,0.020,125,0.300,0.30
22,0.375,4.4,0.021,0.24
23,0.020,125,0.300,0.30
24,2.500,0.067,0.016,0.24
25,0.020,125,0.300,0.30
26,0.375,4.4,0.021,0.24
27,0.020,125,0.300,0.30
28,0.250,130,0.800,0.20
3.5,34.0,2.5,5.5,22.0,11.0,3.0,4.0,30,24,28
0.70,1.0,0.0,2.0,150,0.80,0.22
0.3,0.9,0.3,0.9,0.3,0.9,0.1,0.9
3,100
0.9,0.9,0.0,0.0
1.0,0.0,0.9,0.0,1.0,0.0,1.0,0.0
9
0,10,10,0,0,75,110,110,190,190
5,120,5,60,20,5,120,60,60
7
60 570.67 450.00 14 330 10 10 0.36
75 573.67 0.0000 14 355 10 10 0.31
90 578.67 0.0000 14 355 10 12 0.33
75 581.67 0.0000 14 330 10 10 0.31
60 582.67 0.0000 14 291 10 10 0.36
45 583.67 0.0000 14 231 10 10 0.44
30 582.67 0.0000 14 160 10 10 0.57
```

TABLE 3-17. THERMOD INPUT FILE (input.dat) OF SAMPLE PROBLEM 4 (Continued)

```
2,100,180,1
10,1.0,1.0
10,10,10,10,10,10,10,10,10,10,10,10,10,10,10,
10,10,10,10,10,10,10,10,10,10,10,10,10,10,10,
10,10,10,10,10,10,10,10,10,10,10,10,10,10,10,
10,10,10,10,10,10,10,10,10,10,10,10,10,10,10,
10,10,10,10,10,10,10
```

Temperatures from the THERMOD run is shown in table 3-18, from which the steady-state temperatures T1, T2…..T10 (top to bottom of wing) for time period 3 were extracted and tabulated in table 3-19.

TABLE 3-18. THERMOD OUTPUT FILE (summary.dat) FOR SAMPLE PROBLEM 4

```
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
THERMOD:  A THERMAL PROGRAM FOR AIRCRAFTS
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$



 SUMMARY OF STEADY-STATE AND TRANSIENT ANALYSIS



 (Temperatures are shown for all time periods)


 TEMPERATURES AT THE END OF STEADY STATE ANALYSIS

        TEMPERATURES IN DEGREES FAHRENHEIT
         1     2     3     4     5     6     7

   1 300.1 340.9 353.9 332.9 289.8 232.1 175.9
   2 300.1 340.9 353.9 332.9 289.7 232.1 175.9
   3 295.4 335.2 348.0 327.6 285.6 229.4 174.6
   4 295.4 335.2 348.0 327.6 285.6 229.4 174.6
   5 295.1 334.8 347.6 327.3 285.3 229.2 174.5
   6 118.4 122.9 128.2 130.3 129.5 128.2 125.1
   7 118.1 122.5 127.8 129.9 129.3 128.1 125.0
   8 118.1 122.5 127.8 129.9 129.3 128.1 125.0
   9 113.4 116.9 122.0 124.6 125.1 125.4 123.7
  10 113.4 116.8 121.9 124.6 125.1 125.3 123.7
  11 300.1 340.9 353.9 332.9 289.8 232.1 175.9
  12 300.1 340.9 353.9 332.9 289.7 232.1 175.9
  13 295.4 335.2 348.0 327.6 285.6 229.4 174.6
  14 295.4 335.2 348.0 327.6 285.6 229.4 174.6
```

TABLE 3-18. THERMOD OUTPUT FILE (summary.dat) FOR SAMPLE PROBLEM 4 (Continued)

```
  15 295.1 334.8 347.6 327.3 285.3 229.2 174.5
  16 118.4 122.9 128.2 130.3 129.5 128.2 125.1
  17 118.1 122.5 127.8 129.9 129.3 128.1 125.0
  18 118.1 122.5 127.8 129.9 129.3 128.1 125.0
  19 113.4 116.9 122.0 124.6 125.1 125.4 123.7
  20 113.4 116.8 121.9 124.6 125.1 125.3 123.7
  21 277.3 306.8 316.0 300.7 267.3 220.2 169.5
  22 277.2 306.6 315.8 300.5 267.2 220.2 169.5
  23 244.7 251.8 252.7 248.1 232.9 204.4 160.4
  24 244.6 251.6 252.5 247.9 232.8 204.3 160.4
  25 221.9 213.2 208.4 211.3 208.8 193.3 154.0
  26 194.0 172.3 166.4 172.1 175.6 167.8 132.5
  27 147.9 139.9 140.0 144.2 146.4 143.5 127.2
  28 147.9 139.9 140.0 144.2 146.4 143.4 127.2
  29 144.6 137.6 138.2 142.2 144.3 141.7 126.8
  30 144.6 137.5 138.2 142.2 144.3 141.7 126.8
  31 130.1 127.4 129.9 133.5 135.1 134.1 125.2
  32 130.1 127.4 129.9 133.5 135.1 134.1 125.2
  33 130.1 127.4 129.9 133.5 135.1 134.1 125.2
  34 130.1 127.4 129.9 133.5 135.1 134.1 125.2
  35 115.7 117.3 121.7 124.8 126.0 126.5 123.5
  36 115.7 117.3 121.7 124.8 126.0 126.5 123.5
  37 112.4 115.0 119.8 122.8 123.9 124.7 123.2
  38 112.4 115.0 119.8 122.8 123.9 124.7 123.2
  39 219.3 175.9 125.8 178.9 215.2 225.3 205.4
  40 219.2 175.9 125.9 178.9 215.1 225.2 205.2
  41 205.0 171.8 142.0 173.4 194.6 197.1 173.1
  42 204.9 171.8 142.1 173.4 194.5 197.0 173.0
  43 194.9 168.9 153.4 169.6 180.1 177.3 150.4
  44 186.3 163.3 153.4 164.4 172.1 169.1 143.4
  45 161.6 147.1 142.1 150.5 156.0 154.3 136.7
  46 161.4 147.0 142.0 150.4 155.9 154.2 136.7
  47 126.1 123.9 125.9 130.5 132.9 133.1 127.1
  48 125.9 123.8 125.8 130.4 132.8 133.0 127.1
  49 124.3  92.5  91.1  95.6  98.2  95.5  81.8
  50 126.8  95.1  93.4  98.1 100.9  97.9  83.4
  51 188.8 207.4 215.7 208.8 191.6 168.5 144.8
  52 183.9 201.5 209.6 203.3 187.3 165.7 143.4
  53 188.8 207.4 215.7 208.8 191.6 168.5 144.8

Maximum Structural Temperature for Period   1 = 300.11 Occurring
at Location   1
Maximum Structural Temperature for Period   2 = 340.91 Occurring
at Location   1
Maximum Structural Temperature for Period   3 = 353.91 Occurring
at Location   1
```

TABLE 3-18. THERMOD OUTPUT FILE (summary.dat) FOR SAMPLE PROBLEM 4 (Continued)

```
Maximum Structural Temperature for Period   4 = 332.93 Occurring
at Location   1
Maximum Structural Temperature for Period   5 = 289.76 Occurring
at Location   1
Maximum Structural Temperature for Period   6 = 232.09 Occurring
at Location   1
Maximum Structural Temperature for Period   7 = 205.42 Occurring
at Location  39

Maximum Structural Temperature Over All     7 Periods =353.91
Occurring at Location   1 at Period   3


 TEMPERATURES AT THE END OF TRANSIENT ANALYSIS

        TEMPERATURES IN DEGREES FAHRENHEIT
         1     2     3     4     5     6     7

  1 127.3 133.5 139.2 140.1 137.3 133.3 127.6
  2 132.4 139.6 145.5 145.8 141.8 136.2 129.0
  3 282.6 319.9 332.1 313.4 274.3 222.1 171.0
  4 286.9 325.1 337.5 318.2 278.1 224.5 172.2
  5 286.6 324.7 337.2 317.9 277.9 224.4 172.2
  6 122.7 128.1 133.6 135.1 133.4 130.7 126.3
  7 118.0 122.4 127.7 129.8 129.2 128.0 125.0
  8 117.8 122.2 127.5 129.6 129.0 127.9 124.9
  9 111.4 114.5 119.5 122.4 123.4 124.2 123.1
 10 111.2 114.2 119.3 122.2 123.2 124.1 123.1
 11 127.3 133.5 139.2 140.1 137.3 133.3 127.6
 12 132.4 139.6 145.5 145.8 141.8 136.2 129.0
 13 282.6 319.9 332.1 313.4 274.3 222.1 171.0
 14 286.9 325.1 337.5 318.2 278.1 224.5 172.2
 15 286.6 324.7 337.2 317.9 277.9 224.4 172.2
 16 122.7 128.1 133.6 135.1 133.4 130.7 126.3
 17 118.0 122.4 127.7 129.8 129.2 128.0 125.0
 18 117.8 122.2 127.5 129.6 129.0 127.9 124.9
 19 111.4 114.5 119.5 122.4 123.4 124.2 123.1
 20 111.2 114.2 119.3 122.2 123.2 124.1 123.1
 21 130.8 137.1 142.6 143.4 140.3 135.5 128.5
 22 133.6 139.9 145.2 145.9 142.5 137.2 129.2
 23 204.0 207.7 207.2 206.6 198.8 180.2 146.1
 24 205.9 209.0 208.1 207.7 200.0 181.2 146.3
 25 210.6 196.6 189.5 193.7 192.8 177.7 137.0
 26 186.0 169.5 163.5 169.5 173.2 165.7 132.1
 27 148.1 140.0 140.1 144.3 146.5 143.5 127.2
 28 147.0 139.3 139.6 143.7 145.8 143.0 127.1
 29 144.2 137.3 138.0 142.1 144.1 141.6 126.8
```

TABLE 3-18. THERMOD OUTPUT FILE (summary.dat) FOR SAMPLE PROBLEM 4 (Continued)

```
  30 143.4 136.8 137.5 141.6 143.6 141.1 126.7
  31 129.7 127.1 129.7 133.3 134.9 133.9 125.1
  32 129.7 127.1 129.7 133.3 134.9 133.9 125.1
  33 129.7 127.1 129.7 133.3 134.9 133.9 125.1
  34 129.7 127.1 129.7 133.3 134.9 133.9 125.1
  35 116.0 117.5 121.9 125.0 126.2 126.6 123.6
  36 115.2 116.9 121.4 124.5 125.6 126.2 123.5
  37 111.3 114.2 119.2 122.2 123.2 124.2 123.0
  38 111.2 114.1 119.1 122.1 123.1 124.1 123.0
  39 119.9 119.2 119.9 126.8 130.5 132.1 129.4
  40 122.1 120.6 120.6 128.0 132.2 133.8 130.5
  41 176.5 157.0 140.1 159.8 172.7 173.0 153.5
  42 178.1 158.2 141.0 160.8 173.8 174.0 153.9
  43 186.5 166.5 152.0 167.4 177.3 174.3 148.1
  44 178.8 161.5 152.0 162.8 170.1 166.9 141.7
  45 159.6 147.2 141.0 150.7 157.1 155.7 138.3
  46 158.0 146.1 140.1 149.7 156.0 154.7 137.9
  47 119.5 119.2 120.6 126.7 129.9 131.3 128.4
  48 118.1 118.2 119.9 125.8 128.9 130.4 127.9
  49 116.2 106.1 108.7 112.2 113.7 113.2 107.3
  50 119.5 107.0 108.8 112.6 114.3 113.3 105.7
  51 306.1 348.1 361.3 339.6 295.0 235.5 177.6
  52 288.9 327.5 340.0 320.5 279.9 225.7 172.8
  53 306.1 348.1 361.3 339.6 295.0 235.5 177.6

Maximum Structural Temperature for Period   1 = 286.91 Occurring
at Location   4
Maximum Structural Temperature for Period   2 = 325.06 Occurring
at Location   4
Maximum Structural Temperature for Period   3 = 337.51 Occurring
at Location   4
Maximum Structural Temperature for Period   4 = 318.20 Occurring
at Location   4
Maximum Structural Temperature for Period   5 = 278.12 Occurring
at Location   4
Maximum Structural Temperature for Period   6 = 224.54 Occurring
at Location   4
Maximum Structural Temperature for Period   7 = 172.24 Occurring
at Location   4

Maximum Structural Temperature Over All     7 Periods =337.51
Occurring at Location   4 at Period   3
```

TABLE 3-19. THERMOD-SIMULATED TEMPERATURES (°F) OF THE RIGHT WING OF SAMPLE PROBLEM 4

T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
353.9	353.9	348.0	348.0	347.6	128.2	127.8	127.8	122.0	121.9

As in sample problems 1 through 3, a one-half wing structure was modeled using the UAI/NASTRAN FEM program. Two types of loads were applied to the model. These loads, based on period 3 of the THERMOD input file, were direct solar radiation of 355 Btu/hr/ft^2 and convection with a film coefficient of h = 1.3433 (Btu/hr)/(ft^2°F). The film coefficient was calculated internally by the THERMOD program and was based on the theory of airflow on a flat surface and a wind speed of 14 ft/sec. The radiation load was applied perpendicular to the top surface only, while both the top and bottom surfaces were subjected to convection forces. The ambient temperature was maintained at 119°F (578.67°R).

The FEM input file is shown in table 3-20. The ambient temperature of 119°F was imposed through the SPC case control card. The ambient temperature boundary condition was scalar in nature and implemented through the SPOINT bulk data. The boundary elements, CHBDY, through which solar radiation and convection effects were applied, were modeled using the LINE boundary shape type, connecting the boundary nodes along the wing top and wing bottom. The SPACE designation in the CHBDY boundary element indicates that this element emits infrared radiation to a black body, in which case, no VIEW bulk data were required. Property cards PHBDY and the material cards MAT4, define absorptivity, emissivity, film coefficient, and conductivity values. Because of the involvement of infrared radiation, through emission, this sample problem was rendered nonlinear. This required the Stefan-Boltzman constant and an initial set of temperatures, which were implemented through the PARAM and TEMPERATURE statements, respectively.

TABLE 3-20. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 4

```
ID D:\Natha,MSC/N
APP HEAT
SOL 3
TIME 10000
CEND
  TITLE = direct_radiation_conduction_noemission_convection (t=0.001ft)
  SUBTITLE = 10.7 in gap filled by air; k=0.016BTU/hr/ft/degF
   load=1
   SPC = 1
   temperature(estimate)=2
   THERMAL= ALL
   FLUX = ALL
   SPCF = ALL
BEGIN BULK
$ ******************************************************************************
$   Written by : MSC/NASTRAN for Windows
$   Version    : 6.00
$   Translator : UAI/NASTRAN
$   From Model : D:\Thermod_Validation\FEM\conduction_only.MOD
$   Date       : Mon Mar 06 11:27:09 2000
$ ******************************************************************************
```

TABLE 3-20. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 4 (Continued)

```
$
PARAM,K6ROT,100.
PARAM,MAXRATIO,1.E+8
param,sigma,1.714e-9
param,tabs,0.0
param,maxit,10
CORD2C         1       0      0.      0.      0.      0.      0.    1.+MSC/NC1
+MSC/NC1      1.      0.      1.
CORD2S         2       0      0.      0.      0.      0.      0.    1.+MSC/NC2
+MSC/NC2      1.      0.      1.
$
$ MSC/NASTRAN for Windows Property 1 : 0.02 in glass_outer_layer
PSHELL         1       1   0.001       1               1              0.
$ MSC/NASTRAN for Windows Property 2 : 3/8 in foam
PSHELL         2       2   0.001       2               2              0.
$ MSC/NASTRAN for Windows Property 3 : 0.02 in inner glass
PSHELL         3       1   0.001       1               1              0.
$ MSC/NASTRAN for Windows Property 4 : 0.350 in cap
PSHELL         4       1   0.001       1               1              0.
$ MSC/NASTRAN for Windows Property 5 : 10.70 in air space
PSHELL         5       3   0.001       3               3              0.
$ MSC/NASTRAN for Windows Property 6 : 0.350 in cap
PSHELL         6       1   0.001       1               1              0.
$ MSC/NASTRAN for Windows Property 7 : 0.02 in inner glass
PSHELL         7       1   0.001       1               1              0.
$ MSC/NASTRAN for Windows Property 8 : 3/8 in foam
PSHELL         8       2   0.001       2               2              0.
$ MSC/NASTRAN for Windows Property 9 : 0.02 in glass_outer_layer
PSHELL         9       1   0.001       1               1              0.
$ MSC/NASTRAN for Windows Material 1 : glass
MAT4           1     0.3       1.
$ MSC/NASTRAN for Windows Material 2 : foam
MAT4           2   0.021       1.
$ MSC/NASTRAN for Windows Material 3 : air
MAT4           3   0.016       1.
$
chbdy,1001,100,line,200,201,,,space,500,500,,,0.0,1.0,0.0
chbdy,1002,100,line,201,202,,,space,500,500,,,0.0,1.0,0.0
chbdy,1003,100,line,202,203,,,space,500,500,,,0.0,1.0,0.0
chbdy,1004,100,line,203,204,,,space,500,500,,,0.0,1.0,0.0
chbdy,1005,100,line,204,205,,,space,500,500,,,0.0,1.0,0.0
chbdy,1006,100,line,205,206,,,space,500,500,,,0.0,1.0,0.0
chbdy,1007,100,line,206,207,,,space,500,500,,,0.0,1.0,0.0
chbdy,1008,100,line,207,208,,,space,500,500,,,0.0,1.0,0.0
chbdy,1009,100,line,208,209,,,space,500,500,,,0.0,1.0,0.0
chbdy,1010,100,line,209,210,,,space,500,500,,,0.0,1.0,0.0
chbdy,1011,100,line,210,211,,,space,500,500,,,0.0,1.0,0.0
chbdy,1012,100,line,211,212,,,space,500,500,,,0.0,1.0,0.0
chbdy,1013,100,line,212,213,,,space,500,500,,,0.0,1.0,0.0
chbdy,1014,100,line,213,214,,,space,500,500,,,0.0,1.0,0.0
chbdy,1015,100,line,214,215,,,space,500,500,,,0.0,1.0,0.0
chbdy,1016,100,line,215,216,,,space,500,500,,,0.0,1.0,0.0
chbdy,1017,100,line,216,181,,,space,500,500,,,0.0,1.0,0.0
phbdy,100,200,0.001,0.0,0.9
mat4,200,1.3433
spoint,500
spc,1,500,1,578.67
```

TABLE 3-20. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 4 (Continued)

```
$
$ Direct radiation load from a distant source: load case 1
qvect,1,355.0,0.0,-1.0,0.0,1001,thru,1017
$
$ view ids
$view,1,yes,yes,1,1,0.0
$
chbdy,2001,300,line,20,21,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2002,300,line,21,22,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2003,300,line,22,23,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2004,300,line,23,24,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2005,300,line,24,25,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2006,300,line,25,26,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2007,300,line,26,27,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2008,300,line,27,28,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2009,300,line,28,29,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2010,300,line,29,30,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2011,300,line,30,31,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2012,300,line,31,32,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2013,300,line,32,33,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2014,300,line,33,34,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2015,300,line,34,35,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2016,300,line,35,36,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2017,300,line,36,1,,,space,500,500,,,0.0,-1.0,0.0
phbdy,300,400,0.001,0.0,0.9
mat4,400,1.3433
$
temp,2,1,578.67,3,578.67,5,578.67
temp,2,7,578.67,9,578.67,10,578.67
temp,2,11,578.67,12,578.67,14,578.67
temp,2,15,578.67,18,578.67,20,578.67
temp,2,21,578.67,22,578.67,23,578.67
temp,2,24,578.67,25,578.67,26,578.67
temp,2,27,578.67,28,578.67,29,578.67
temp,2,30,578.67,31,578.67,32,578.67
temp,2,33,578.67,34,578.67,35,578.67
temp,2,36,578.67,37,578.67,41,578.67
temp,2,44,578.67,45,578.67,47,578.67
temp,2,48,578.67,50,578.67,51,578.67
temp,2,52,578.67,53,578.67,54,578.67
temp,2,55,578.67,56,578.67,58,578.67
temp,2,59,578.67,62,578.67,67,578.67
temp,2,69,578.67,71,578.67,73,578.67
temp,2,75,578.67,76,578.67,77,578.67
temp,2,78,578.67,79,578.67,80,578.67
temp,2,83,578.67,85,578.67,87,578.67
temp,2,88,578.67,98,578.67,101,578.67
temp,2,104,578.67,105,578.67,107,578.67
temp,2,108,578.67,109,578.67,112,578.67
temp,2,115,578.67,116,578.67,118,578.67
temp,2,120,578.67,121,578.67,122,578.67
temp,2,123,578.67,124,578.67,125,578.67
temp,2,128,578.67,129,578.67,130,578.67
temp,2,133,578.67,135,578.67,137,578.67
temp,2,138,578.67,145,578.67,146,578.67
temp,2,147,578.67,150,578.67,152,578.67
temp,2,160,578.67,161,578.67,164,578.67
```

TABLE 3-20. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 4 (Continued)

```
temp,2,165,578.67,172,578.67,174,578.67
temp,2,177,578.67,178,578.67,180,578.67
temp,2,181,578.67,182,578.67,183,578.67
temp,2,184,578.67,188,578.67,193,578.67
temp,2,195,578.67,196,578.67,197,578.67
temp,2,198,578.67,199,578.67,200,578.67
temp,2,201,578.67,202,578.67,203,578.67
temp,2,204,578.67,205,578.67,206,578.67
temp,2,207,578.67,208,578.67,209,578.67
temp,2,210,578.67,211,578.67,212,578.67
temp,2,213,578.67,214,578.67,215,578.67
temp,2,216,578.67,219,578.67,220,578.67
temp,2,221,578.67,222,578.67,223,578.67
temp,2,226,578.67,227,578.67,228,578.67
temp,2,229,578.67,231,578.67,232,578.67
temp,2,235,578.67,241,578.67,243,578.67
temp,2,244,578.67,245,578.67,246,578.67
temp,2,248,578.67,249,578.67,250,578.67
temp,2,253,578.67,254,578.67,257,578.67
temp,2,258,578.67,259,578.67,260,578.67
temp,2,264,578.67,267,578.67,268,578.67
temp,2,269,578.67,270,578.67,273,578.67
temp,2,274,578.67,277,578.67,282,578.67
temp,2,283,578.67,292,578.67,293,578.67
temp,2,295,578.67,297,578.67,298,578.67
temp,2,299,578.67,300,578.67,301,578.67
temp,2,302,578.67,303,578.67,306,578.67
temp,2,307,578.67,308,578.67,313,578.67
temp,2,314,578.67,316,578.67,317,578.67
temp,2,318,578.67,323,578.67,324,578.67
temp,2,500,578.67
$
GRID            1       0      0.      0.      0.       0
GRID            3       0      1.1.667E-3      0.       0
GRID            5       0      3.1.667E-3      0.       0
GRID            7       0      5.1.667E-3      0.       0
GRID            9       0      7.1.667E-3      0.       0
GRID           10       0      8.1.667E-3      0.       0
GRID           11       0      9.1.667E-3      0.       0
GRID           12       0     10.1.667E-3      0.       0
GRID           14       0     12.1.667E-3      0.       0
GRID           15       0     13.1.667E-3      0.       0
GRID           18       0     16.1.667E-3      0.       0
GRID           20       0     17.      0.      0.       0
GRID           21       0     16.      0.      0.       0
GRID           22       0     15.      0.      0.       0
GRID           23       0     14.      0.      0.       0
GRID           24       0     13.      0.      0.       0
GRID           25       0     12.      0.      0.       0
GRID           26       0     11.      0.      0.       0
GRID           27       0     10.      0.      0.       0
GRID           28       0      9.      0.      0.       0
GRID           29       0      8.      0.      0.       0
GRID           30       0      7.      0.      0.       0
GRID           31       0      6.      0.      0.       0
GRID           32       0      5.      0.      0.       0
GRID           33       0      4.      0.      0.       0
```

TABLE 3-20. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 4 (Continued)

```
GRID            34        0      3.      0.      0.        0
GRID            35        0      2.      0.      0.        0
GRID            36        0      1.      0.      0.        0
GRID            37        0      0.1.667E-3      0.        0
GRID            41        0      3.0.032917      0.        0
GRID            44        0      6.0.032917      0.        0
GRID            45        0      7.0.032917      0.        0
GRID            47        0      9.0.032917      0.        0
GRID            48        0     10.0.032917      0.        0
GRID            50        0     12.0.032917      0.        0
GRID            51        0     13.0.032917      0.        0
GRID            52        0     14.0.032917      0.        0
GRID            53        0     15.0.032917      0.        0
GRID            54        0     16.0.032917      0.        0
GRID            55        0     17.0.032917      0.        0
GRID            56        0     17.1.667E-3      0.        0
GRID            58        0     15.1.667E-3      0.        0
GRID            59        0     14.1.667E-3      0.        0
GRID            62        0     11.1.667E-3      0.        0
GRID            67        0      6.1.667E-3      0.        0
GRID            69        0      4.1.667E-3      0.        0
GRID            71        0      2.1.667E-3      0.        0
GRID            73        0      0.0.032917      0.        0
GRID            75        0      1.0.034583      0.        0
GRID            76        0      2.0.034583      0.        0
GRID            77        0      3.0.034583      0.        0
GRID            78        0      4.0.034583      0.        0
GRID            79        0      5.0.034583      0.        0
GRID            80        0      6.0.034583      0.        0
GRID            83        0      9.0.034583      0.        0
GRID            85        0     11.0.034583      0.        0
GRID            87        0     13.0.034583      0.        0
GRID            88        0     14.0.034583      0.        0
GRID            98        0     11.0.032917      0.        0
GRID           101        0      8.0.032917      0.        0
GRID           104        0      5.0.032917      0.        0
GRID           105        0      4.0.032917      0.        0
GRID           107        0      2.0.032917      0.        0
GRID           108        0      1.0.032917      0.        0
GRID           109        0      0.0.034583      0.        0
GRID           112        0      2. 0.06375      0.        0
GRID           115        0      5. 0.06375      0.        0
GRID           116        0      6. 0.06375      0.        0
GRID           118        0      8. 0.06375      0.        0
GRID           120        0     10. 0.06375      0.        0
GRID           121        0     11. 0.06375      0.        0
GRID           122        0     12. 0.06375      0.        0
GRID           123        0     13. 0.06375      0.        0
GRID           124        0     14. 0.06375      0.        0
GRID           125        0     15. 0.06375      0.        0
GRID           128        0     17.0.034583      0.        0
GRID           129        0     16.0.034583      0.        0
GRID           130        0     15.0.034583      0.        0
GRID           133        0     12.0.034583      0.        0
GRID           135        0     10.0.034583      0.        0
GRID           137        0      8.0.034583      0.        0
GRID           138        0      7.0.034583      0.        0
```

TABLE 3-20. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 4 (Continued)

```
GRID          145       0      0. 0.06375      0.        0
GRID          146       0      0. 0.95542      0.        0
GRID          147       0      1. 0.95542      0.        0
GRID          150       0      4. 0.95542      0.        0
GRID          152       0      6. 0.95542      0.        0
GRID          160       0     14. 0.95542      0.        0
GRID          161       0     15. 0.95542      0.        0
GRID          164       0     17. 0.06375      0.        0
GRID          165       0     16. 0.06375      0.        0
GRID          172       0      9. 0.06375      0.        0
GRID          174       0      7. 0.06375      0.        0
GRID          177       0      4. 0.06375      0.        0
GRID          178       0      3. 0.06375      0.        0
GRID          180       0      1. 0.06375      0.        0
GRID          181       0      0. 1.01917      0.        0
GRID          182       0      0.  1.0175      0.        0
GRID          183       0      1.  1.0175      0.        0
GRID          184       0      2.  1.0175      0.        0
GRID          188       0      6.  1.0175      0.        0
GRID          193       0     11.  1.0175      0.        0
GRID          195       0     13.  1.0175      0.        0
GRID          196       0     14.  1.0175      0.        0
GRID          197       0     15.  1.0175      0.        0
GRID          198       0     16.  1.0175      0.        0
GRID          199       0     17.  1.0175      0.        0
GRID          200       0     17. 1.01917      0.        0
GRID          201       0     16. 1.01917      0.        0
GRID          202       0     15. 1.01917      0.        0
GRID          203       0     14. 1.01917      0.        0
GRID          204       0     13. 1.01917      0.        0
GRID          205       0     12. 1.01917      0.        0
GRID          206       0     11. 1.01917      0.        0
GRID          207       0     10. 1.01917      0.        0
GRID          208       0      9. 1.01917      0.        0
GRID          209       0      8. 1.01917      0.        0
GRID          210       0      7. 1.01917      0.        0
GRID          211       0      6. 1.01917      0.        0
GRID          212       0      5. 1.01917      0.        0
GRID          213       0      4. 1.01917      0.        0
GRID          214       0      3. 1.01917      0.        0
GRID          215       0      2. 1.01917      0.        0
GRID          216       0      1. 1.01917      0.        0
GRID          219       0      1. 0.98625      0.        0
GRID          220       0      2. 0.98625      0.        0
GRID          221       0      3. 0.98625      0.        0
GRID          222       0      4. 0.98625      0.        0
GRID          223       0      5. 0.98625      0.        0
GRID          226       0      8. 0.98625      0.        0
GRID          227       0      9. 0.98625      0.        0
GRID          228       0     10. 0.98625      0.        0
GRID          229       0     11. 0.98625      0.        0
GRID          231       0     13. 0.98625      0.        0
GRID          232       0     14. 0.98625      0.        0
GRID          235       0     17. 0.98625      0.        0
GRID          241       0     12.  1.0175      0.        0
GRID          243       0     10.  1.0175      0.        0
GRID          244       0      9.  1.0175      0.        0
```

TABLE 3-20. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 4 (Continued)

```
GRID           245       0       8.  1.0175       0.        0
GRID           246       0       7.  1.0175       0.        0
GRID           248       0       5.  1.0175       0.        0
GRID           249       0       4.  1.0175       0.        0
GRID           250       0       3.  1.0175       0.        0
GRID           253       0       0. 0.98625       0.        0
GRID           254       0       0. 0.98458       0.        0
GRID           257       0       3. 0.98458       0.        0
GRID           258       0       4. 0.98458       0.        0
GRID           259       0       5. 0.98458       0.        0
GRID           260       0       6. 0.98458       0.        0
GRID           264       0      10. 0.98458       0.        0
GRID           267       0      13. 0.98458       0.        0
GRID           268       0      14. 0.98458       0.        0
GRID           269       0      15. 0.98458       0.        0
GRID           270       0      16. 0.98458       0.        0
GRID           273       0      16. 0.98625       0.        0
GRID           274       0      15. 0.98625       0.        0
GRID           277       0      12. 0.98625       0.        0
GRID           282       0       7. 0.98625       0.        0
GRID           283       0       6. 0.98625       0.        0
GRID           292       0       2. 0.95542       0.        0
GRID           293       0       3. 0.95542       0.        0
GRID           295       0       5. 0.95542       0.        0
GRID           297       0       7. 0.95542       0.        0
GRID           298       0       8. 0.95542       0.        0
GRID           299       0       9. 0.95542       0.        0
GRID           300       0      10. 0.95542       0.        0
GRID           301       0      11. 0.95542       0.        0
GRID           302       0      12. 0.95542       0.        0
GRID           303       0      13. 0.95542       0.        0
GRID           306       0      16. 0.95542       0.        0
GRID           307       0      17. 0.95542       0.        0
GRID           308       0      17. 0.98458       0.        0
GRID           313       0      12. 0.98458       0.        0
GRID           314       0      11. 0.98458       0.        0
GRID           316       0       9. 0.98458       0.        0
GRID           317       0       8. 0.98458       0.        0
GRID           318       0       7. 0.98458       0.        0
GRID           323       0       2. 0.98458       0.        0
GRID           324       0       1. 0.98458       0.        0
CQUAD4           1       9        1       37        3       36
CQUAD4           2       9       36        3       71       35
CQUAD4           3       9       35       71        5       34
CQUAD4           4       9       34        5       69       33
CQUAD4           5       9       33       69        7       32
CQUAD4           6       9       32        7       67       31
CQUAD4           7       9       31       67        9       30
CQUAD4           8       9       30        9       10       29
CQUAD4           9       9       29       10       11       28
CQUAD4          10       9       28       11       12       27
CQUAD4          11       9       27       12       62       26
CQUAD4          12       9       26       62       14       25
CQUAD4          13       9       25       14       15       24
CQUAD4          14       9       24       15       59       23
CQUAD4          15       9       23       59       58       22
CQUAD4          16       9       22       58       18       21
```

TABLE 3-20. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 4 (Continued)

```
CQUAD4         17         9         21         18         56         20
CQUAD4         18         8         37         73        108          3
CQUAD4         19         8          3        108        107         71
CQUAD4         20         8         71        107         41          5
CQUAD4         21         8          5         41        105         69
CQUAD4         22         8         69        105        104          7
CQUAD4         23         8          7        104         44         67
CQUAD4         24         8         67         44         45          9
CQUAD4         25         8          9         45        101         10
CQUAD4         26         8         10        101         47         11
CQUAD4         27         8         11         47         48         12
CQUAD4         28         8         12         48         98         62
CQUAD4         29         8         62         98         50         14
CQUAD4         30         8         14         50         51         15
CQUAD4         31         8         15         51         52         59
CQUAD4         32         8         59         52         53         58
CQUAD4         33         8         58         53         54         18
CQUAD4         34         8         18         54         55         56
CQUAD4         35         7         73        109         75        108
CQUAD4         36         7        108         75         76        107
CQUAD4         37         7        107         76         77         41
CQUAD4         38         7         41         77         78        105
CQUAD4         39         7        105         78         79        104
CQUAD4         40         7        104         79         80         44
CQUAD4         41         7         44         80        138         45
CQUAD4         42         7         45        138        137        101
CQUAD4         43         7        101        137         83         47
CQUAD4         44         7         47         83        135         48
CQUAD4         45         7         48        135         85         98
CQUAD4         46         7         98         85        133         50
CQUAD4         47         7         50        133         87         51
CQUAD4         48         7         51         87         88         52
CQUAD4         49         7         52         88        130         53
CQUAD4         50         7         53        130        129         54
CQUAD4         51         7         54        129        128         55
CQUAD4         52         6        109        145        180         75
CQUAD4         53         6         75        180        112         76
CQUAD4         54         6         76        112        178         77
CQUAD4         55         6         77        178        177         78
CQUAD4         56         6         78        177        115         79
CQUAD4         57         6         79        115        116         80
CQUAD4         58         6         80        116        174        138
CQUAD4         59         6        138        174        118        137
CQUAD4         60         6        137        118        172         83
CQUAD4         61         6         83        172        120        135
CQUAD4         62         6        135        120        121         85
CQUAD4         63         6         85        121        122        133
CQUAD4         64         6        133        122        123         87
CQUAD4         65         6         87        123        124         88
CQUAD4         66         6         88        124        125        130
CQUAD4         67         6        130        125        165        129
CQUAD4         68         6        129        165        164        128
CQUAD4         69         5        145        146        147        180
CQUAD4         70         5        180        147        292        112
CQUAD4         71         5        112        292        293        178
CQUAD4         72         5        178        293        150        177
CQUAD4         73         5        177        150        295        115
```

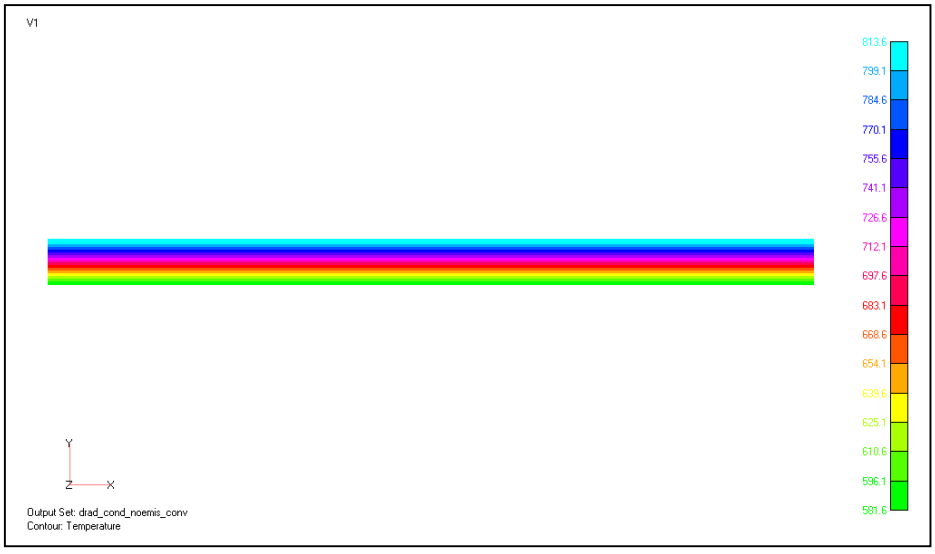
TABLE 3-20. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 4 (Continued)

```
CQUAD4      74       5      115      295      152      116
CQUAD4      75       5      116      152      297      174
CQUAD4      76       5      174      297      298      118
CQUAD4      77       5      118      298      299      172
CQUAD4      78       5      172      299      300      120
CQUAD4      79       5      120      300      301      121
CQUAD4      80       5      121      301      302      122
CQUAD4      81       5      122      302      303      123
CQUAD4      82       5      123      303      160      124
CQUAD4      83       5      124      160      161      125
CQUAD4      84       5      125      161      306      165
CQUAD4      85       5      165      306      307      164
CQUAD4      86       1      182      181      216      183
CQUAD4      87       1      183      216      215      184
CQUAD4      88       1      184      215      214      250
CQUAD4      89       1      250      214      213      249
CQUAD4      90       1      249      213      212      248
CQUAD4      91       1      248      212      211      188
CQUAD4      92       1      188      211      210      246
CQUAD4      93       1      246      210      209      245
CQUAD4      94       1      245      209      208      244
CQUAD4      95       1      244      208      207      243
CQUAD4      96       1      243      207      206      193
CQUAD4      97       1      193      206      205      241
CQUAD4      98       1      241      205      204      195
CQUAD4      99       1      195      204      203      196
CQUAD4     100       1      196      203      202      197
CQUAD4     101       1      197      202      201      198
CQUAD4     102       1      198      201      200      199
CQUAD4     103       2      253      182      183      219
CQUAD4     104       2      219      183      184      220
CQUAD4     105       8      220      184      250      221
CQUAD4     106       2      221      250      249      222
CQUAD4     107       2      222      249      248      223
CQUAD4     108       2      223      248      188      283
CQUAD4     109       2      283      188      246      282
CQUAD4     110       2      282      246      245      226
CQUAD4     111       2      226      245      244      227
CQUAD4     112       2      227      244      243      228
CQUAD4     113       2      228      243      193      229
CQUAD4     114       2      229      193      241      277
CQUAD4     115       2      277      241      195      231
CQUAD4     116       2      231      195      196      232
CQUAD4     117       2      232      196      197      274
CQUAD4     118       2      274      197      198      273
CQUAD4     119       2      273      198      199      235
CQUAD4     120       3      254      253      219      324
CQUAD4     121       3      324      219      220      323
CQUAD4     122       3      323      220      221      257
CQUAD4     123       3      257      221      222      258
CQUAD4     124       3      258      222      223      259
CQUAD4     125       3      259      223      283      260
CQUAD4     126       3      260      283      282      318
CQUAD4     127       3      318      282      226      317
CQUAD4     128       3      317      226      227      316
CQUAD4     129       3      316      227      228      264
CQUAD4     130       3      264      228      229      314
```

TABLE 3-20. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 4 (Continued)

```
CQUAD4      131       3      314      229      277      313
CQUAD4      132       3      313      277      231      267
CQUAD4      133       3      267      231      232      268
CQUAD4      134       3      268      232      274      269
CQUAD4      135       3      269      274      273      270
CQUAD4      136       3      270      273      235      308
CQUAD4      137       4      146      254      324      147
CQUAD4      138       4      147      324      323      292
CQUAD4      139       4      292      323      257      293
CQUAD4      140       4      293      257      258      150
CQUAD4      141       4      150      258      259      295
CQUAD4      142       4      295      259      260      152
CQUAD4      143       4      152      260      318      297
CQUAD4      144       4      297      318      317      298
CQUAD4      145       4      298      317      316      299
CQUAD4      146       4      299      316      264      300
CQUAD4      147       4      300      264      314      301
CQUAD4      148       4      301      314      313      302
CQUAD4      149       4      302      313      267      303
CQUAD4      150       4      303      267      268      160
CQUAD4      151       4      160      268      269      161
CQUAD4      152       4      161      269      270      306
CQUAD4      153       4      306      270      308      307
ENDDATA
```

The results of the one-half FEM wing model analysis are presented in figure 3-4 in the form of a contour plot. The contours appear to be indicative of the temperature profile of the THERMOD analysis. The top surface, which was subjected to direct solar radiation, is certainly much hotter than the bottom surface.



Note that the temperatures are in absolute terms (°R).

FIGURE 3-4. CONTOUR PLOT OF THE FEM OUTPUT OF SAMPLE PROBLEM 4

The truncated FEM output file is shown in table 3-21. The nodes, from top to bottom of the wing, located at mid-span of the model are indicated by nodes 209, 245, 226, 317, 298, 118, 137, 101, 10, and 29. The temperatures of these nodes were extracted from this file and are reproduced in table 3-22. Mid-span was chosen because it was sufficiently far away from any edge effects that might be present. Note that temperatures in table 3-22 were reduced from absolute temperatures (°R) to °F.

TABLE 3-21. TRUNCATED FEM OUTPUT FILE OF SAMPLE PROBLEM 4

```
1      DIRECT_RADIATION_CONDUCTION_NOEMISSION_CONVECTION (T=0.001FT      MARCH  15, 2000    UAI/NASTRAN VERSION 20.1         PAGE
18
       10.7 IN GAP FILLED BY AIR; K=0.016BTU/HR/FT/DEGF
0

                                                T E M P E R A T U R E   V E C T O R

       POINT ID.   TYPE      ID   VALUE     ID+1 VALUE     ID+2 VALUE     ID+3 VALUE     ID+4 VALUE     ID+5 VALUE
             1     TEMP     5.816010E+02
             3     TEMP     5.816228E+02
             5     TEMP     5.816228E+02
             7     TEMP     5.816228E+02
             9     TEMP     5.816228E+02   5.816228E+02   5.816228E+02   5.816228E+02
            14     TEMP     5.816228E+02   5.816228E+02
            18     TEMP     5.816228E+02
            20     TEMP     5.816010E+02   5.816010E+02   5.816010E+02   5.816010E+02   5.816010E+02   5.816010E+02
            26     TEMP     5.816010E+02   5.816010E+02   5.816010E+02   5.816010E+02   5.816010E+02   5.816010E+02
            32     TEMP     5.816010E+02   5.816010E+02   5.816010E+02   5.816010E+02   5.816010E+02   5.816228E+02
            41     TEMP     5.874816E+02
            44     TEMP     5.874816E+02   5.874816E+02
            47     TEMP     5.874816E+02   5.874816E+02
            50     TEMP     5.874816E+02   5.874816E+02   5.874816E+02   5.874816E+02   5.874816E+02   5.874816E+02
            56     TEMP     5.816228E+02
            58     TEMP     5.816228E+02   5.816228E+02
            62     TEMP     5.816228E+02
            67     TEMP     5.816228E+02
            69     TEMP     5.816228E+02
            71     TEMP     5.816228E+02
            73     TEMP     5.874816E+02
            75     TEMP     5.875035E+02   5.875035E+02   5.875035E+02   5.875035E+02   5.875035E+02   5.875035E+02
            83     TEMP     5.875035E+02
            85     TEMP     5.875035E+02
            87     TEMP     5.875035E+02   5.875035E+02
            98     TEMP     5.874816E+02
           101     TEMP     5.874816E+02
           104     TEMP     5.874816E+02   5.874816E+02
           107     TEMP     5.874816E+02   5.874816E+02   5.875035E+02
           112     TEMP     5.878863E+02
           115     TEMP     5.878863E+02   5.878863E+02
           118     TEMP     5.878863E+02
           120     TEMP     5.878863E+02   5.878863E+02   5.878863E+02   5.878863E+02   5.878863E+02   5.878863E+02
           128     TEMP     5.875035E+02   5.875035E+02   5.875035E+02
           133     TEMP     5.875035E+02
           135     TEMP     5.875035E+02
           137     TEMP     5.875035E+02   5.875035E+02
           145     TEMP     5.878863E+02   8.073008E+02   8.073008E+02
           150     TEMP     8.073008E+02
           152     TEMP     8.073008E+02
           160     TEMP     8.073008E+02   8.073008E+02
           164     TEMP     5.878863E+02   5.878863E+02
           172     TEMP     5.878863E+02
           174     TEMP     5.878863E+02
           177     TEMP     5.878863E+02   5.878863E+02
           180     TEMP     5.878863E+02   8.135862E+02   8.135643E+02   8.135643E+02   8.135643E+02
           188     TEMP     8.135643E+02
           193     TEMP     8.135643E+02
           195     TEMP     8.135643E+02   8.135643E+02   8.135643E+02   8.135643E+02   8.135643E+02   8.135862E+02
           201     TEMP     8.135862E+02   8.135862E+02   8.135862E+02   8.135862E+02   8.135862E+02   8.135862E+02
1      DIRECT_RADIATION_CONDUCTION_NOEMISSION_CONVECTION (T=0.001FT      MARCH  15, 2000    UAI/NASTRAN VERSION 20.1         PAGE
19
       10.7 IN GAP FILLED BY AIR; K=0.016BTU/HR/FT/DEGF
0

                                                T E M P E R A T U R E   V E C T O R

       POINT ID.   TYPE      ID   VALUE     ID+1 VALUE     ID+2 VALUE     ID+3 VALUE     ID+4 VALUE     ID+5 VALUE
           207     TEMP     8.135862E+02   8.135862E+02   8.135862E+02   8.135862E+02   8.135862E+02   8.135862E+02
           213     TEMP     8.135862E+02   8.135862E+02   8.135862E+02   8.135862E+02
           219     TEMP     8.077054E+02   8.077054E+02   8.077054E+02   8.077054E+02   8.077054E+02
           226     TEMP     8.077054E+02   8.077054E+02   8.077054E+02   8.077054E+02
           231     TEMP     8.077054E+02   8.077054E+02
           235     TEMP     8.077054E+02
           241     TEMP     8.135643E+02
           243     TEMP     8.135643E+02   8.135643E+02   8.135643E+02   8.135643E+02
           248     TEMP     8.135643E+02   8.135643E+02   8.135643E+02
           253     TEMP     8.077054E+02   8.076835E+02
           257     TEMP     8.076835E+02   8.076835E+02   8.076835E+02   8.076835E+02
           264     TEMP     8.076835E+02
           267     TEMP     8.076835E+02   8.076835E+02   8.076835E+02   8.076835E+02
           273     TEMP     8.077054E+02   8.077054E+02
```

TABLE 3-21. TRUNCATED FEM OUTPUT FILE OF SAMPLE PROBLEM 4 (Continued)

```
          277    TEMP     8.077054E+02
          282    TEMP     8.077054E+02   8.077054E+02
          292    TEMP     8.073008E+02   8.073008E+02
          295    TEMP     8.073008E+02
          297    TEMP     8.073008E+02   8.073008E+02   8.073008E+02   8.073008E+02   8.073008E+02
          303    TEMP     8.073008E+02
          306    TEMP     8.073008E+02   8.073008E+02   8.076835E+02
          313    TEMP     8.076835E+02   8.076835E+02
          316    TEMP     8.076835E+02   8.076835E+02   8.076835E+02
          323    TEMP     8.076835E+02   8.076835E+02
          500    TEMP     5.786700E+02
```

When compared, the temperatures of tables 3-19 and 3-22 show excellent agreement, validating the radiation, conduction, and convection capabilities of the THERMOD program.

TABLE 3-22. FINITE ELEMENT METHOD-SIMULATED TEMPERATURES (°F) OF THE RIGHT WING OF SAMPLE PROBLEM 4

T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
353.9	353.9	348.0	348.0	347.6	128.2	127.8	127.8	122.0	121.9

3.5 SAMPLE PROBLEM 5.

In sample problem 4, the combined effects of conduction, convection, and direct solar radiation were studied. The wing surfaces, in addition to other external surfaces however, were assigned 0.0 emissivity values, meaning that the surfaces were rendered incapable of emitting infrared radiation. The purpose of sample problem 5 was to study and validate the effects of infrared emission. This was done by removing the emission restriction on the wing surfaces of sample problem 4, by changing it from 0.0 to 0.9. This action was expected to result in lower wing temperatures than in sample problem 4. As in sample problems 1 through 4, THERMOD was set up to solve a complete aircraft problem, while the FEM method was confined to the wing model.

To ensure consistency with the FEM wing model, the wing in the THERMOD model was isolated from infrared radiation effects from the fuselage and tarmac surfaces by assigning emissivity values of 0.0. As in sample problem 4, the sky radiation was assigned an absolute temperature of 0.0 to preclude infrared radiation from the sky. The conduction and convection heat transfer modes, however, were left intact, as in sample problem 4.

Despite the above setup, particularly the efforts to isolate the wing, a preliminary comparative study of the THERMOD and FEM results showed significant differences in wing temperatures. This discrepancy was resolved by further isolating the wing from the tarmac effects by increasing the height of the wing from the tarmac to 100.0 ft from its current 2.5 ft. In addition, the infrared reflection effects from the fuselage surface were reduced by decreasing the cabin height from 4 ft to 0.1 ft.

Despite these additions, temperature differences still existed between the THERMOD and FEM wing models, particularly on elements on the wing top surface. The temperatures on the wing bottom surface were found to be in excellent agreement, however. This led to the believe that the fillet effect, which has been modeled as an integral part of THERMOD, could be a plausible cause of this problem. The fillet effect is defined as the effect found in the fuselage-wing

junctions, usually covered by fairing, that serves to increase the local temperatures because the surface is concave. A concave surface is viewed as a partial cavity, and in thermal processes, it is the nature of cavities to increase temperatures regardless of the paint color. In THERMOD, the fillet was modeled as a quadrant. Its temperature-increasing effect was confined to direct solar radiation only. This explains why only the top wing surface temperatures were different in the THERMOD and FEM models.

The fillet effect was removed from the wing top by assigning a 0.0 value in the second field of input data set 6, in essence eliminating the fillet effect. See the THERMOD User's Reference Manual for further details on the input requirements for fillet effects. With the removal of the fillet effect, there was excellent agreement in the temperatures of the THERMOD and FEM wing models. The THERMOD input file, input.dat, is illustrated in table 3-23.

TABLE 3-23. THERMOD INPUT FILE (input.dat) OF SAMPLE PROBLEM 5

```
198e-6,0.704
1, 0.020,125,0.300,0.30
2, 0.375,4.4,0.021,0.24
3, 0.020,125,0.300,0.30
4, 0.350,125,0.300,0.30
5, 10.70,0.067,0.016,0.24
6, 0.350,125,0.300,0.30
7, 0.020,125,0.300,0.30
8, 0.375,4.4,0.021,0.24
9, 0.020,125,0.300,0.30
10,0.030,125,0.300,0.30
11,0.375,4.4,0.021,0.24
12,0.020,125,0.300,0.30
13,0.250,10.,0.020,0.24
14,48.00,0.067,0.016,0.24
15,0.020,125,0.300,0.30
16,0.375,4.4,0.021,0.24
17,0.020,125,0.300,0.30
18,0.250,10.,0.020,0.24
19,30.00,0.067,0.016,0.24
20,5.000,10.,0.020,0.24
21,0.020,125,0.300,0.30
22,0.375,4.4,0.021,0.24
23,0.020,125,0.300,0.30
24,2.500,0.067,0.016,0.24
25,0.020,125,0.300,0.30
26,0.375,4.4,0.021,0.24
27,0.020,125,0.300,0.30
```

TABLE 3-23. THERMOD INPUT FILE (input.dat) OF SAMPLE PROBLEM 5 (Continued)

```
28,0.250,130,0.800,0.20
3.5,34.0,100.0,5.5,22.0,11.0,0.1,4.0,30,24,28
0.70,1.0,0.0,2.0,150,0.80,0.22
0.3,0.9,0.3,0.9,0.3,0.9,0.1,0.9
3,0.0
0.9,0.9,0.0,0.0
1.0,0.0,0.9,0.9,1.0,0.0,1.0,0.0
9
0,10,10,0,0,75,110,110,190,190
5,120,5,60,20,5,120,60,60
7
60 570.67 0.0000 14 330 10 10 0.36
75 573.67 0.0000 14 355 10 10 0.31
90 578.67 0.0000 14 355 10 12 0.33
75 581.67 0.0000 14 330 10 10 0.31
60 582.67 0.0000 14 291 10 10 0.36
45 583.67 0.0000 14 231 10 10 0.44
30 582.67 0.0000 14 160 10 10 0.57
1,0.02,180,10
10,1.0,1.0
10,10,10,10,10,10,10,10,10,10,10,10,10,10,10,
10,10,10,10,10,10,10,10,10,10,10,10,10,10,10,
10,10,10,10,10,10,10,10,10,10,10,10,10,10,10,
10,10,10,10,10,10,10,10,10,10,10,10,10,10,10,
10,10,10,10,10,10,10
```

Temperatures from the THERMOD run is shown in table 3-24, from which the steady-state temperatures T1, T2…..T10 (top to bottom of wing) for time period 3 were extracted and tabulated in table 3-25.

TABLE 3-24. THERMOD OUTPUT FILE (summary.dat) FOR SAMPLE PROBLEM 5

```
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
THERMOD:  A THERMAL PROGRAM FOR AIRCRAFTS
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$



 SUMMARY OF STEADY-STATE AND TRANSIENT ANALYSIS



 (Temperatures are shown for all time periods)


 TEMPERATURES AT THE END OF STEADY STATE ANALYSIS
```

TABLE 3-24. THERMOD OUTPUT FILE (summary.dat) FOR SAMPLE PROBLEM 5 (Continued)

```
        TEMPERATURES IN DEGREES FAHRENHEIT
          1     2     3     4     5     6     7

 1 146.4 166.2 172.3 162.4 141.2 111.0  79.4
 2 146.4 166.2 172.3 162.4 141.2 111.0  79.4
 3 143.7 163.1 169.1 159.5 138.8 109.4  78.6
 4 143.7 163.1 169.1 159.5 138.8 109.4  78.6
 5 143.5 162.9 168.9 159.3 138.7 109.3  78.5
 6  43.4  45.9  49.1  50.6  50.5  50.0  48.3
 7  43.2  45.7  48.9  50.4  50.3  49.9  48.3
 8  43.2  45.7  48.9  50.4  50.3  49.9  48.3
 9  40.5  42.5  45.7  47.5  47.9  48.3  47.5
10  40.5  42.5  45.7  47.5  47.9  48.3  47.5
11 146.4 166.2 172.3 162.4 141.2 111.0  79.4
12 146.4 166.2 172.3 162.4 141.2 111.0  79.4
13 143.7 163.1 169.1 159.5 138.8 109.4  78.6
14 143.7 163.1 169.1 159.5 138.8 109.4  78.6
15 143.5 162.9 168.9 159.3 138.7 109.3  78.5
16  43.4  45.9  49.1  50.6  50.5  50.0  48.3
17  43.2  45.7  48.9  50.4  50.3  49.9  48.3
18  43.2  45.7  48.9  50.4  50.3  49.9  48.3
19  40.5  42.5  45.7  47.5  47.9  48.3  47.5
20  40.5  42.5  45.7  47.5  47.9  48.3  47.5
21 273.7 307.6 319.4 301.1 265.1 215.9 166.4
22 273.5 307.4 319.2 300.9 265.0 215.8 166.4
23 232.5 254.2 264.3 249.5 225.7 189.9 149.9
24 232.4 254.0 264.1 249.3 225.5 189.8 149.9
25 203.6 216.8 225.7 213.3 198.0 171.7 138.4
26 161.0 169.1 177.3 167.7 158.3 140.2 115.4
27 133.2 138.5 144.9 142.3 138.7 131.2 119.6
28 133.2 138.5 144.9 142.3 138.7 131.2 119.6
29 131.2 136.3 142.6 140.5 137.3 130.5 119.9
30 131.2 136.3 142.6 140.5 137.3 130.5 119.9
31 122.5 126.7 132.4 132.5 131.1 127.7 121.2
32 122.5 126.7 132.4 132.5 131.1 127.7 121.2
33 122.5 126.7 132.4 132.5 131.1 127.7 121.2
34 122.5 126.7 132.4 132.5 131.1 127.7 121.2
35 113.8 117.1 122.3 124.6 125.0 124.9 122.6
36 113.8 117.1 122.3 124.6 125.0 124.9 122.6
37 111.8 114.9 120.0 122.8 123.6 124.3 122.9
38 111.8 114.9 120.0 122.8 123.6 124.3 122.9
39 214.6 176.2 128.7 178.9 212.9 221.3 202.5
40 214.4 176.2 128.8 178.8 212.8 221.1 202.3
41 189.0 172.6 151.6 173.4 187.0 183.5 163.2
42 188.9 172.6 151.7 173.3 186.9 183.4 163.0
43 171.1 170.1 167.7 169.5 168.8 157.0 135.6
```

TABLE 3-24. THERMOD OUTPUT FILE (summary.dat) FOR SAMPLE PROBLEM 5 (Continued)

```
  44 161.2 164.1 167.7 163.8 160.0 148.1 129.4
  45 144.7 147.6 151.7 150.1 147.8 140.2 127.3
  46 144.7 147.5 151.6 150.0 147.8 140.2 127.3
  47 121.1 124.1 128.8 130.4 130.4 128.9 124.3
  48 121.0 123.9 128.7 130.3 130.3 128.8 124.3
  49  88.4  92.9  98.4  95.3  91.9  84.7  74.4
  50  90.9  95.5 101.1  97.8  94.1  86.4  75.6
  51 188.8 207.4 215.7 208.8 191.6 168.5 144.8
  52 183.9 201.5 209.6 203.3 187.3 165.7 143.4
  53 188.8 207.4 215.7 208.8 191.6 168.5 144.8

Maximum Structural Temperature for Period   1 = 273.69 Occurring
at Location  21
Maximum Structural Temperature for Period   2 = 307.55 Occurring
at Location  21
Maximum Structural Temperature for Period   3 = 319.43 Occurring
at Location  21
Maximum Structural Temperature for Period   4 = 301.07 Occurring
at Location  21
Maximum Structural Temperature for Period   5 = 265.15 Occurring
at Location  21
Maximum Structural Temperature for Period   6 = 221.30 Occurring
at Location  39
Maximum Structural Temperature for Period   7 = 202.48 Occurring
at Location  39

Maximum Structural Temperature Over All     7 Periods =319.43
Occurring at Location  21 at Period   3


 TEMPERATURES AT THE END OF TRANSIENT ANALYSIS

        TEMPERATURES IN DEGREES FAHRENHEIT
         1     2     3     4     5     6     7

   1 114.4 119.2 124.3 126.0 124.8 122.8 119.0
   2 115.2 120.3 125.5 126.9 125.2 122.4 117.9
   3 141.2 159.5 165.4 156.6 137.5 110.5  81.8
   4 142.0 160.7 166.7 157.5 137.9 110.2  80.7
   5 142.7 161.7 167.7 158.3 138.1 109.8  79.6
   6  45.1  47.7  51.0  52.4  52.4  52.0  50.2
   7  46.7  49.2  52.5  54.1  54.1  53.7  52.0
   8  48.4  50.9  54.3  55.9  55.9  55.6  53.9
   9 103.2 106.0 110.8 113.6 114.5 115.4 114.4
  10 104.8 107.7 112.5 115.4 116.3 117.3 116.3
  11 114.4 119.2 124.3 126.0 124.8 122.8 119.0
  12 115.2 120.3 125.5 126.9 125.2 122.4 117.9
```

TABLE 3-24. THERMOD OUTPUT FILE (summary.dat) FOR SAMPLE PROBLEM 5 (Continued)

```
  13 141.2 159.5 165.4 156.6 137.5 110.5  81.8
  14 142.0 160.7 166.7 157.5 137.9 110.2  80.7
  15 142.7 161.7 167.7 158.3 138.1 109.8  79.6
  16  45.1  47.7  51.0  52.4  52.4  52.0  50.2
  17  46.7  49.2  52.5  54.1  54.1  53.7  52.0
  18  48.4  50.9  54.3  55.9  55.9  55.6  53.9
  19 103.2 106.0 110.8 113.6 114.5 115.4 114.4
  20 104.8 107.7 112.5 115.4 116.3 117.3 116.3
  21 124.8 130.4 136.0 137.2 135.0 131.8 126.7
  22 126.6 132.4 138.1 139.0 136.5 132.7 126.9
  23 180.2 193.0 200.8 192.9 180.0 159.6 135.1
  24 181.6 194.5 202.3 194.2 181.1 160.2 135.2
  25 175.0 185.3 192.9 184.5 173.4 154.2 129.7
  26 150.4 157.7 164.8 158.5 151.3 137.2 117.3
  27 133.3 138.6 145.0 142.4 138.7 131.2 119.6
  28 132.8 138.0 144.4 141.9 138.5 131.1 119.6
  29 131.2 136.3 142.6 140.5 137.3 130.5 119.9
  30 131.2 136.3 142.6 140.5 137.3 130.5 119.9
  31 122.5 126.6 132.3 132.5 131.1 127.7 121.2
  32 122.5 126.6 132.3 132.5 131.1 127.7 121.2
  33 122.5 126.6 132.3 132.5 131.1 127.7 121.2
  34 122.5 126.6 132.3 132.5 131.1 127.7 121.2
  35 113.7 117.0 122.1 124.5 125.0 124.9 122.6
  36 113.7 116.9 122.0 124.5 125.0 124.9 122.6
  37 111.2 114.2 119.2 122.2 123.1 124.1 123.0
  38 111.1 114.1 119.1 122.1 123.1 124.0 123.0
  39 116.0 117.1 119.8 124.8 127.3 128.6 126.6
  40 117.3 118.2 120.5 125.8 128.3 129.4 127.0
  41 153.0 149.4 144.5 152.4 156.1 151.2 137.7
  42 154.0 150.4 145.5 153.2 156.8 151.7 137.7
  43 153.1 155.0 156.3 156.8 155.0 145.8 129.8
  44 149.5 152.6 156.3 154.7 151.8 142.8 128.0
  45 141.2 143.0 145.5 146.4 145.5 139.4 127.8
  46 140.3 142.1 144.5 145.5 144.8 139.0 127.7
  47 116.4 117.7 120.5 125.3 127.5 128.5 126.3
  48 115.6 116.9 119.8 124.6 126.9 128.1 126.3
  49 105.5 108.7 113.7 115.5 115.7 115.1 112.5
  50 106.3 109.7 114.9 116.3 116.1 114.9 111.5
  51 306.1 348.1 361.3 339.6 295.0 235.5 177.6
  52 288.9 327.5 340.0 320.5 279.9 225.7 172.8
  53 306.1 348.1 361.3 339.6 295.0 235.5 177.6

Maximum Structural Temperature for Period   1 = 181.56 Occurring
at Location  24
Maximum Structural Temperature for Period   2 = 194.50 Occurring
at Location  24
```

TABLE 3-24. THERMOD OUTPUT FILE (summary.dat) FOR SAMPLE PROBLEM 5 (Continued)

```
Maximum Structural Temperature for Period   3 = 202.33 Occurring
at Location  24
Maximum Structural Temperature for Period   4 = 194.16 Occurring
at Location  24
Maximum Structural Temperature for Period   5 = 181.07 Occurring
at Location  24
Maximum Structural Temperature for Period   6 = 160.21 Occurring
at Location  24
Maximum Structural Temperature for Period   7 = 137.74 Occurring
at Location  42

Maximum Structural Temperature Over All     7 Periods =202.33
Occurring at Location  24 at Period   3
```

TABLE 3-25. THERMOD-SIMULATED TEMPERATURES (°F) OF THE RIGHT WING OF SAMPLE PROBLEM 5

T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
172.3	172.3	169.1	169.1	168.9	49.1	48.9	48.9	45.7	45.7

As in sample problems 1 through 4, a one-half wing structure was modeled using the UAI/NASTRAN FEM program. Two types of loads were applied to the model. These loads, based on period 3 of the THERMOD input file, were direct solar radiation of 355 Btu/hr/ft^2 and convection with a film coefficient of h = 1.3433 (Btu/hr)/(ft^2°F). This film coefficient was calculated internally by the THERMOD program and was based on the theory of airflow on a flat surface and a wind speed of 14 ft/sec. The radiation load was applied perpendicular to the top surface only, while both the top and bottom surfaces were subjected to convection forces. The ambient temperature was maintained at 119°F (578.67°R). Unlike sample problem 4, the wings were assigned a nonzero emissivity value of 0.9, allowing the wings to emit infrared radiation, thereby, reducing the wing temperatures.

The FEM input file is shown in table 3-26. The ambient temperature of 119°F was imposed through the SPC case control card. The ambient temperature boundary condition was scalar in nature and was implemented through the SPOINT bulk data. The boundary elements, CHBDY, through which solar radiation and convection effects were applied, were modeled using the LINE boundary shape type, connecting the boundary nodes along the wing top and bottom. The SPACE designation in the CHBDY boundary element indicates that this element emits infrared radiation to a black body, in which case, no VIEW bulk data was required. Property cards PHBDY and the material cards MAT4, define absorptivity, emissivity, film coefficient, and conductivity values. Note that unlike sample problem 4 where wings were prevented from emitting radiation, an emissivity value of 0.9 was assigned to the wing in sample problems, as indicated in the PHBDY card. Because of the involvement of infrared radiation, through emission, this sample problem was rendered nonlinear. This required the Stefan-Boltzman constant, σ, and an initial set of temperatures, which were implemented through the PARAM and TEMPERATURE statements, respectively.

TABLE 3-26. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 5

```
ID D:\Natha,MSC/N
APP HEAT
SOL 3
TIME 10000
CEND
  TITLE = direct_radiation_conduction_emission_convection (t=0.001ft)
  SUBTITLE = 10.7 in gap filled by air; k=0.016BTU/hr/ft/degF
   load=1
   SPC = 1
   temperature(estimate)=2
   THERMAL= ALL
   FLUX = ALL
   SPCF = ALL
BEGIN BULK
$ ***********************************************************************
$   Written by : MSC/NASTRAN for Windows
$   Version    : 6.00
$   Translator : UAI/NASTRAN
$   From Model : D:\Thermod_Validation\FEM\conduction_only.MOD
$   Date       : Mon Mar 06 11:27:09 2000
$ ***********************************************************************
$
PARAM,K6ROT,100.
PARAM,MAXRATIO,1.E+8
param,sigma,1.714e-9
param,tabs,0.0
param,maxit,10
CORD2C         1       0      0.      0.      0.      0.      0.    1.+MSC/NC1
+MSC/NC1      1.      0.      1.
CORD2S         2       0      0.      0.      0.      0.      0.    1.+MSC/NC2
+MSC/NC2      1.      0.      1.
$
$ MSC/NASTRAN for Windows Property 1 : 0.02 in glass_outer_layer
PSHELL         1       1   0.001       1               1              0.
$ MSC/NASTRAN for Windows Property 2 : 3/8 in foam
PSHELL         2       2   0.001       2               2              0.
$ MSC/NASTRAN for Windows Property 3 : 0.02 in inner glass
PSHELL         3       1   0.001       1               1              0.
$ MSC/NASTRAN for Windows Property 4 : 0.350 in cap
PSHELL         4       1   0.001       1               1              0.
$ MSC/NASTRAN for Windows Property 5 : 10.70 in air space
PSHELL         5       3   0.001       3               3              0.
$ MSC/NASTRAN for Windows Property 6 : 0.350 in cap
PSHELL         6       1   0.001       1               1              0.
$ MSC/NASTRAN for Windows Property 7 : 0.02 in inner glass
PSHELL         7       1   0.001       1               1              0.
$ MSC/NASTRAN for Windows Property 8 : 3/8 in foam
PSHELL         8       2   0.001       2               2              0.
$ MSC/NASTRAN for Windows Property 9 : 0.02 in glass_outer_layer
PSHELL         9       1   0.001       1               1              0.
$ MSC/NASTRAN for Windows Material 1 : glass
MAT4           1     0.3       1.
$ MSC/NASTRAN for Windows Material 2 : foam
MAT4           2   0.021       1.
```

TABLE 3-26. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 5 (Continued)

```
$ MSC/NASTRAN for Windows Material 3 : air
MAT4           3   0.016      1.
$
chbdy,1001,100,line,200,201,,,space,500,500,,,0.0,1.0,0.0
chbdy,1002,100,line,201,202,,,space,500,500,,,0.0,1.0,0.0
chbdy,1003,100,line,202,203,,,space,500,500,,,0.0,1.0,0.0
chbdy,1004,100,line,203,204,,,space,500,500,,,0.0,1.0,0.0
chbdy,1005,100,line,204,205,,,space,500,500,,,0.0,1.0,0.0
chbdy,1006,100,line,205,206,,,space,500,500,,,0.0,1.0,0.0
chbdy,1007,100,line,206,207,,,space,500,500,,,0.0,1.0,0.0
chbdy,1008,100,line,207,208,,,space,500,500,,,0.0,1.0,0.0
chbdy,1009,100,line,208,209,,,space,500,500,,,0.0,1.0,0.0
chbdy,1010,100,line,209,210,,,space,500,500,,,0.0,1.0,0.0
chbdy,1011,100,line,210,211,,,space,500,500,,,0.0,1.0,0.0
chbdy,1012,100,line,211,212,,,space,500,500,,,0.0,1.0,0.0
chbdy,1013,100,line,212,213,,,space,500,500,,,0.0,1.0,0.0
chbdy,1014,100,line,213,214,,,space,500,500,,,0.0,1.0,0.0
chbdy,1015,100,line,214,215,,,space,500,500,,,0.0,1.0,0.0
chbdy,1016,100,line,215,216,,,space,500,500,,,0.0,1.0,0.0
chbdy,1017,100,line,216,181,,,space,500,500,,,0.0,1.0,0.0
phbdy,100,200,0.001,0.9,0.9
mat4,200,1.3433
spoint,500
spc,1,500,1,578.67
$
$ Direct radiation load from a distant source: load case 1
qvect,1,355.0,0.0,-1.0,0.0,1001,thru,1017
$
$ view ids
$view,1,yes,yes,1,1,0.0
$
chbdy,2001,300,line,20,21,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2002,300,line,21,22,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2003,300,line,22,23,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2004,300,line,23,24,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2005,300,line,24,25,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2006,300,line,25,26,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2007,300,line,26,27,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2008,300,line,27,28,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2009,300,line,28,29,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2010,300,line,29,30,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2011,300,line,30,31,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2012,300,line,31,32,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2013,300,line,32,33,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2014,300,line,33,34,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2015,300,line,34,35,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2016,300,line,35,36,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2017,300,line,36,1,,,space,500,500,,,0.0,-1.0,0.0
phbdy,300,400,0.001,0.9,0.9
mat4,400,1.3433
$
temp,2,1,578.67,3,578.67,5,578.67
temp,2,7,578.67,9,578.67,10,578.67
temp,2,11,578.67,12,578.67,14,578.67
temp,2,15,578.67,18,578.67,20,578.67
temp,2,21,578.67,22,578.67,23,578.67
temp,2,24,578.67,25,578.67,26,578.67
```

TABLE 3-26. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 5 (Continued)

```
temp,2,27,578.67,28,578.67,29,578.67
temp,2,30,578.67,31,578.67,32,578.67
temp,2,33,578.67,34,578.67,35,578.67
temp,2,36,578.67,37,578.67,41,578.67
temp,2,44,578.67,45,578.67,47,578.67
temp,2,48,578.67,50,578.67,51,578.67
temp,2,52,578.67,53,578.67,54,578.67
temp,2,55,578.67,56,578.67,58,578.67
temp,2,59,578.67,62,578.67,67,578.67
temp,2,69,578.67,71,578.67,73,578.67
temp,2,75,578.67,76,578.67,77,578.67
temp,2,78,578.67,79,578.67,80,578.67
temp,2,83,578.67,85,578.67,87,578.67
temp,2,88,578.67,98,578.67,101,578.67
temp,2,104,578.67,105,578.67,107,578.67
temp,2,108,578.67,109,578.67,112,578.67
temp,2,115,578.67,116,578.67,118,578.67
temp,2,120,578.67,121,578.67,122,578.67
temp,2,123,578.67,124,578.67,125,578.67
temp,2,128,578.67,129,578.67,130,578.67
temp,2,133,578.67,135,578.67,137,578.67
temp,2,138,578.67,145,578.67,146,578.67
temp,2,147,578.67,150,578.67,152,578.67
temp,2,160,578.67,161,578.67,164,578.67
temp,2,165,578.67,172,578.67,174,578.67
temp,2,177,578.67,178,578.67,180,578.67
temp,2,181,578.67,182,578.67,183,578.67
temp,2,184,578.67,188,578.67,193,578.67
temp,2,195,578.67,196,578.67,197,578.67
temp,2,198,578.67,199,578.67,200,578.67
temp,2,201,578.67,202,578.67,203,578.67
temp,2,204,578.67,205,578.67,206,578.67
temp,2,207,578.67,208,578.67,209,578.67
temp,2,210,578.67,211,578.67,212,578.67
temp,2,213,578.67,214,578.67,215,578.67
temp,2,216,578.67,219,578.67,220,578.67
temp,2,221,578.67,222,578.67,223,578.67
temp,2,226,578.67,227,578.67,228,578.67
temp,2,229,578.67,231,578.67,232,578.67
temp,2,235,578.67,241,578.67,243,578.67
temp,2,244,578.67,245,578.67,246,578.67
temp,2,248,578.67,249,578.67,250,578.67
temp,2,253,578.67,254,578.67,257,578.67
temp,2,258,578.67,259,578.67,260,578.67
temp,2,264,578.67,267,578.67,268,578.67
temp,2,269,578.67,270,578.67,273,578.67
temp,2,274,578.67,277,578.67,282,578.67
temp,2,283,578.67,292,578.67,293,578.67
temp,2,295,578.67,297,578.67,298,578.67
temp,2,299,578.67,300,578.67,301,578.67
temp,2,302,578.67,303,578.67,306,578.67
temp,2,307,578.67,308,578.67,313,578.67
temp,2,314,578.67,316,578.67,317,578.67
temp,2,318,578.67,323,578.67,324,578.67
temp,2,500,578.67
$
```

TABLE 3-26. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 5 (Continued)

```
GRID            1       0      0.      0.      0.      0
GRID            3       0      1.1.667E-3      0.      0
GRID            5       0      3.1.667E-3      0.      0
GRID            7       0      5.1.667E-3      0.      0
GRID            9       0      7.1.667E-3      0.      0
GRID           10       0      8.1.667E-3      0.      0
GRID           11       0      9.1.667E-3      0.      0
GRID           12       0     10.1.667E-3      0.      0
GRID           14       0     12.1.667E-3      0.      0
GRID           15       0     13.1.667E-3      0.      0
GRID           18       0     16.1.667E-3      0.      0
GRID           20       0     17.      0.      0.      0
GRID           21       0     16.      0.      0.      0
GRID           22       0     15.      0.      0.      0
GRID           23       0     14.      0.      0.      0
GRID           24       0     13.      0.      0.      0
GRID           25       0     12.      0.      0.      0
GRID           26       0     11.      0.      0.      0
GRID           27       0     10.      0.      0.      0
GRID           28       0      9.      0.      0.      0
GRID           29       0      8.      0.      0.      0
GRID           30       0      7.      0.      0.      0
GRID           31       0      6.      0.      0.      0
GRID           32       0      5.      0.      0.      0
GRID           33       0      4.      0.      0.      0
GRID           34       0      3.      0.      0.      0
GRID           35       0      2.      0.      0.      0
GRID           36       0      1.      0.      0.      0
GRID           37       0      0.1.667E-3      0.      0
GRID           41       0      3.0.032917      0.      0
GRID           44       0      6.0.032917      0.      0
GRID           45       0      7.0.032917      0.      0
GRID           47       0      9.0.032917      0.      0
GRID           48       0     10.0.032917      0.      0
GRID           50       0     12.0.032917      0.      0
GRID           51       0     13.0.032917      0.      0
GRID           52       0     14.0.032917      0.      0
GRID           53       0     15.0.032917      0.      0
GRID           54       0     16.0.032917      0.      0
GRID           55       0     17.0.032917      0.      0
GRID           56       0     17.1.667E-3      0.      0
GRID           58       0     15.1.667E-3      0.      0
GRID           59       0     14.1.667E-3      0.      0
GRID           62       0     11.1.667E-3      0.      0
GRID           67       0      6.1.667E-3      0.      0
GRID           69       0      4.1.667E-3      0.      0
GRID           71       0      2.1.667E-3      0.      0
GRID           73       0      0.0.032917      0.      0
GRID           75       0      1.0.034583      0.      0
GRID           76       0      2.0.034583      0.      0
GRID           77       0      3.0.034583      0.      0
GRID           78       0      4.0.034583      0.      0
GRID           79       0      5.0.034583      0.      0
GRID           80       0      6.0.034583      0.      0
GRID           83       0      9.0.034583      0.      0
GRID           85       0     11.0.034583      0.      0
GRID           87       0     13.0.034583      0.      0
```

TABLE 3-26. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 5 (Continued)

```
GRID            88       0     14.0.034583      0.       0
GRID            98       0     11.0.032917      0.       0
GRID           101       0      8.0.032917      0.       0
GRID           104       0      5.0.032917      0.       0
GRID           105       0      4.0.032917      0.       0
GRID           107       0      2.0.032917      0.       0
GRID           108       0      1.0.032917      0.       0
GRID           109       0      0.0.034583      0.       0
GRID           112       0      2. 0.06375      0.       0
GRID           115       0      5. 0.06375      0.       0
GRID           116       0      6. 0.06375      0.       0
GRID           118       0      8. 0.06375      0.       0
GRID           120       0     10. 0.06375      0.       0
GRID           121       0     11. 0.06375      0.       0
GRID           122       0     12. 0.06375      0.       0
GRID           123       0     13. 0.06375      0.       0
GRID           124       0     14. 0.06375      0.       0
GRID           125       0     15. 0.06375      0.       0
GRID           128       0     17.0.034583      0.       0
GRID           129       0     16.0.034583      0.       0
GRID           130       0     15.0.034583      0.       0
GRID           133       0     12.0.034583      0.       0
GRID           135       0     10.0.034583      0.       0
GRID           137       0      8.0.034583      0.       0
GRID           138       0      7.0.034583      0.       0
GRID           145       0      0. 0.06375      0.       0
GRID           146       0      0. 0.95542      0.       0
GRID           147       0      1. 0.95542      0.       0
GRID           150       0      4. 0.95542      0.       0
GRID           152       0      6. 0.95542      0.       0
GRID           160       0     14. 0.95542      0.       0
GRID           161       0     15. 0.95542      0.       0
GRID           164       0     17. 0.06375      0.       0
GRID           165       0     16. 0.06375      0.       0
GRID           172       0      9. 0.06375      0.       0
GRID           174       0      7. 0.06375      0.       0
GRID           177       0      4. 0.06375      0.       0
GRID           178       0      3. 0.06375      0.       0
GRID           180       0      1. 0.06375      0.       0
GRID           181       0      0. 1.01917      0.       0
GRID           182       0      0.  1.0175      0.       0
GRID           183       0      1.  1.0175      0.       0
GRID           184       0      2.  1.0175      0.       0
GRID           188       0      6.  1.0175      0.       0
GRID           193       0     11.  1.0175      0.       0
GRID           195       0     13.  1.0175      0.       0
GRID           196       0     14.  1.0175      0.       0
GRID           197       0     15.  1.0175      0.       0
GRID           198       0     16.  1.0175      0.       0
GRID           199       0     17.  1.0175      0.       0
GRID           200       0     17. 1.01917      0.       0
GRID           201       0     16. 1.01917      0.       0
GRID           202       0     15. 1.01917      0.       0
GRID           203       0     14. 1.01917      0.       0
GRID           204       0     13. 1.01917      0.       0
GRID           205       0     12. 1.01917      0.       0
GRID           206       0     11. 1.01917      0.       0
```

TABLE 3-26. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 5 (Continued)

```
GRID           207       0      10. 1.01917       0.        0
GRID           208       0       9. 1.01917       0.        0
GRID           209       0       8. 1.01917       0.        0
GRID           210       0       7. 1.01917       0.        0
GRID           211       0       6. 1.01917       0.        0
GRID           212       0       5. 1.01917       0.        0
GRID           213       0       4. 1.01917       0.        0
GRID           214       0       3. 1.01917       0.        0
GRID           215       0       2. 1.01917       0.        0
GRID           216       0       1. 1.01917       0.        0
GRID           219       0       1. 0.98625       0.        0
GRID           220       0       2. 0.98625       0.        0
GRID           221       0       3. 0.98625       0.        0
GRID           222       0       4. 0.98625       0.        0
GRID           223       0       5. 0.98625       0.        0
GRID           226       0       8. 0.98625       0.        0
GRID           227       0       9. 0.98625       0.        0
GRID           228       0      10. 0.98625       0.        0
GRID           229       0      11. 0.98625       0.        0
GRID           231       0      13. 0.98625       0.        0
GRID           232       0      14. 0.98625       0.        0
GRID           235       0      17. 0.98625       0.        0
GRID           241       0      12.  1.0175       0.        0
GRID           243       0      10.  1.0175       0.        0
GRID           244       0       9.  1.0175       0.        0
GRID           245       0       8.  1.0175       0.        0
GRID           246       0       7.  1.0175       0.        0
GRID           248       0       5.  1.0175       0.        0
GRID           249       0       4.  1.0175       0.        0
GRID           250       0       3.  1.0175       0.        0
GRID           253       0       0. 0.98625       0.        0
GRID           254       0       0. 0.98458       0.        0
GRID           257       0       3. 0.98458       0.        0
GRID           258       0       4. 0.98458       0.        0
GRID           259       0       5. 0.98458       0.        0
GRID           260       0       6. 0.98458       0.        0
GRID           264       0      10. 0.98458       0.        0
GRID           267       0      13. 0.98458       0.        0
GRID           268       0      14. 0.98458       0.        0
GRID           269       0      15. 0.98458       0.        0
GRID           270       0      16. 0.98458       0.        0
GRID           273       0      16. 0.98625       0.        0
GRID           274       0      15. 0.98625       0.        0
GRID           277       0      12. 0.98625       0.        0
GRID           282       0       7. 0.98625       0.        0
GRID           283       0       6. 0.98625       0.        0
GRID           292       0       2. 0.95542       0.        0
GRID           293       0       3. 0.95542       0.        0
GRID           295       0       5. 0.95542       0.        0
GRID           297       0       7. 0.95542       0.        0
GRID           298       0       8. 0.95542       0.        0
GRID           299       0       9. 0.95542       0.        0
GRID           300       0      10. 0.95542       0.        0
GRID           301       0      11. 0.95542       0.        0
GRID           302       0      12. 0.95542       0.        0
GRID           303       0      13. 0.95542       0.        0
GRID           306       0      16. 0.95542       0.        0
```

TABLE 3-26. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 5 (Continued)

```
GRID          307       0      17. 0.95542       0.       0
GRID          308       0      17. 0.98458       0.       0
GRID          313       0      12. 0.98458       0.       0
GRID          314       0      11. 0.98458       0.       0
GRID          316       0       9. 0.98458       0.       0
GRID          317       0       8. 0.98458       0.       0
GRID          318       0       7. 0.98458       0.       0
GRID          323       0       2. 0.98458       0.       0
GRID          324       0       1. 0.98458       0.       0
CQUAD4          1       9        1       37        3      36
CQUAD4          2       9       36        3       71      35
CQUAD4          3       9       35       71        5      34
CQUAD4          4       9       34        5       69      33
CQUAD4          5       9       33       69        7      32
CQUAD4          6       9       32        7       67      31
CQUAD4          7       9       31       67        9      30
CQUAD4          8       9       30        9       10      29
CQUAD4          9       9       29       10       11      28
CQUAD4         10       9       28       11       12      27
CQUAD4         11       9       27       12       62      26
CQUAD4         12       9       26       62       14      25
CQUAD4         13       9       25       14       15      24
CQUAD4         14       9       24       15       59      23
CQUAD4         15       9       23       59       58      22
CQUAD4         16       9       22       58       18      21
CQUAD4         17       9       21       18       56      20
CQUAD4         18       8       37       73      108       3
CQUAD4         19       8        3      108      107      71
CQUAD4         20       8       71      107       41       5
CQUAD4         21       8        5       41      105      69
CQUAD4         22       8       69      105      104       7
CQUAD4         23       8        7      104       44      67
CQUAD4         24       8       67       44       45       9
CQUAD4         25       8        9       45      101      10
CQUAD4         26       8       10      101       47      11
CQUAD4         27       8       11       47       48      12
CQUAD4         28       8       12       48       98      62
CQUAD4         29       8       62       98       50      14
CQUAD4         30       8       14       50       51      15
CQUAD4         31       8       15       51       52      59
CQUAD4         32       8       59       52       53      58
CQUAD4         33       8       58       53       54      18
CQUAD4         34       8       18       54       55      56
CQUAD4         35       7       73      109       75     108
CQUAD4         36       7      108       75       76     107
CQUAD4         37       7      107       76       77      41
CQUAD4         38       7       41       77       78     105
CQUAD4         39       7      105       78       79     104
CQUAD4         40       7      104       79       80      44
CQUAD4         41       7       44       80      138      45
CQUAD4         42       7       45      138      137     101
CQUAD4         43       7      101      137       83      47
CQUAD4         44       7       47       83      135      48
CQUAD4         45       7       48      135       85      98
CQUAD4         46       7       98       85      133      50
CQUAD4         47       7       50      133       87      51
CQUAD4         48       7       51       87       88      52
```

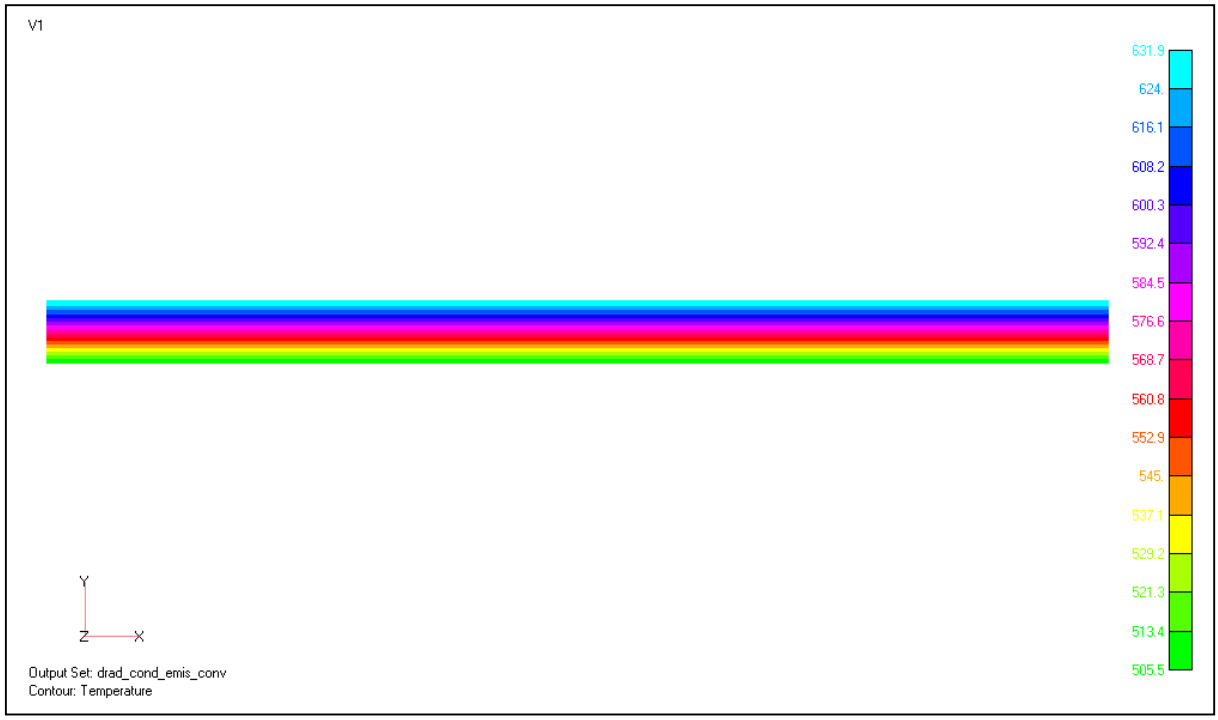
TABLE 3-26. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 5 (Continued)

```
CQUAD4      49       7      52       88      130       53
CQUAD4      50       7      53      130      129       54
CQUAD4      51       7      54      129      128       55
CQUAD4      52       6     109      145      180       75
CQUAD4      53       6      75      180      112       76
CQUAD4      54       6      76      112      178       77
CQUAD4      55       6      77      178      177       78
CQUAD4      56       6      78      177      115       79
CQUAD4      57       6      79      115      116       80
CQUAD4      58       6      80      116      174      138
CQUAD4      59       6     138      174      118      137
CQUAD4      60       6     137      118      172       83
CQUAD4      61       6      83      172      120      135
CQUAD4      62       6     135      120      121       85
CQUAD4      63       6      85      121      122      133
CQUAD4      64       6     133      122      123       87
CQUAD4      65       6      87      123      124       88
CQUAD4      66       6      88      124      125      130
CQUAD4      67       6     130      125      165      129
CQUAD4      68       6     129      165      164      128
CQUAD4      69       5     145      146      147      180
CQUAD4      70       5     180      147      292      112
CQUAD4      71       5     112      292      293      178
CQUAD4      72       5     178      293      150      177
CQUAD4      73       5     177      150      295      115
CQUAD4      74       5     115      295      152      116
CQUAD4      75       5     116      152      297      174
CQUAD4      76       5     174      297      298      118
CQUAD4      77       5     118      298      299      172
CQUAD4      78       5     172      299      300      120
CQUAD4      79       5     120      300      301      121
CQUAD4      80       5     121      301      302      122
CQUAD4      81       5     122      302      303      123
CQUAD4      82       5     123      303      160      124
CQUAD4      83       5     124      160      161      125
CQUAD4      84       5     125      161      306      165
CQUAD4      85       5     165      306      307      164
CQUAD4      86       1     182      181      216      183
CQUAD4      87       1     183      216      215      184
CQUAD4      88       1     184      215      214      250
CQUAD4      89       1     250      214      213      249
CQUAD4      90       1     249      213      212      248
CQUAD4      91       1     248      212      211      188
CQUAD4      92       1     188      211      210      246
CQUAD4      93       1     246      210      209      245
CQUAD4      94       1     245      209      208      244
CQUAD4      95       1     244      208      207      243
CQUAD4      96       1     243      207      206      193
CQUAD4      97       1     193      206      205      241
CQUAD4      98       1     241      205      204      195
CQUAD4      99       1     195      204      203      196
CQUAD4     100       1     196      203      202      197
CQUAD4     101       1     197      202      201      198
CQUAD4     102       1     198      201      200      199
CQUAD4     103       2     253      182      183      219
CQUAD4     104       2     219      183      184      220
CQUAD4     105       8     220      184      250      221
```

TABLE 3-26. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 5 (Continued)

```
CQUAD4      106       2      221      250      249      222
CQUAD4      107       2      222      249      248      223
CQUAD4      108       2      223      248      188      283
CQUAD4      109       2      283      188      246      282
CQUAD4      110       2      282      246      245      226
CQUAD4      111       2      226      245      244      227
CQUAD4      112       2      227      244      243      228
CQUAD4      113       2      228      243      193      229
CQUAD4      114       2      229      193      241      277
CQUAD4      115       2      277      241      195      231
CQUAD4      116       2      231      195      196      232
CQUAD4      117       2      232      196      197      274
CQUAD4      118       2      274      197      198      273
CQUAD4      119       2      273      198      199      235
CQUAD4      120       3      254      253      219      324
CQUAD4      121       3      324      219      220      323
CQUAD4      122       3      323      220      221      257
CQUAD4      123       3      257      221      222      258
CQUAD4      124       3      258      222      223      259
CQUAD4      125       3      259      223      283      260
CQUAD4      126       3      260      283      282      318
CQUAD4      127       3      318      282      226      317
CQUAD4      128       3      317      226      227      316
CQUAD4      129       3      316      227      228      264
CQUAD4      130       3      264      228      229      314
CQUAD4      131       3      314      229      277      313
CQUAD4      132       3      313      277      231      267
CQUAD4      133       3      267      231      232      268
CQUAD4      134       3      268      232      274      269
CQUAD4      135       3      269      274      273      270
CQUAD4      136       3      270      273      235      308
CQUAD4      137       4      146      254      324      147
CQUAD4      138       4      147      324      323      292
CQUAD4      139       4      292      323      257      293
CQUAD4      140       4      293      257      258      150
CQUAD4      141       4      150      258      259      295
CQUAD4      142       4      295      259      260      152
CQUAD4      143       4      152      260      318      297
CQUAD4      144       4      297      318      317      298
CQUAD4      145       4      298      317      316      299
CQUAD4      146       4      299      316      264      300
CQUAD4      147       4      300      264      314      301
CQUAD4      148       4      301      314      313      302
CQUAD4      149       4      302      313      267      303
CQUAD4      150       4      303      267      268      160
CQUAD4      151       4      160      268      269      161
CQUAD4      152       4      161      269      270      306
CQUAD4      153       4      306      270      308      307
ENDDATA
```

The results of the one-half FEM wing model analysis are presented in figure 3-5 in the form of a contour plot. The contours appear to be indicative of the temperature profile of the THERMOD analysis. The top surface, which was subjected to direct solar radiation, is certainly much hotter than the bottom surface. The temperatures are significantly lower than those in figure 3-4 of sample problem 4 because in sample problem 5 the wing surfaces were modeled to emit infrared radiation energy.



Note that the temperatures are in absolute terms (°R).

FIGURE 3-5. CONTOUR PLOT OF THE FEM OUTPUT OF SAMPLE PROBLEM 5

The truncated FEM output file is shown in table 3-27. The nodes, from top to bottom of the wing, located at mid-span of the model, are indicated by nodes 209, 245, 226, 317, 298, 118, 137, 101, 10, and 29. The temperatures of these nodes were extracted from this file and are reproduced in table 3-28. Mid-span was chosen because it was sufficiently far away from any edge effects that might be present. Note that the temperatures in table 3-28 were reduced from absolute temperatures (°R) to °F.

When compared, the temperatures of tables 3-25 and 3-28 show excellent agreement, validating the radiation, conduction and convection, capabilities of the THERMOD program, including infrared emission.

TABLE 3-27. TRUNCATED FEM OUTPUT FILE OF SAMPLE PROBLEM 5

```
1      DIRECT_RADIATION_CONDUCTION_EMISSION_CONVECTION (T=0.001FT)      AUGUST  17, 2000    UAI/NASTRAN VERSION 20.1          PAGE
18
      10.7 IN GAP FILLED BY AIR; K=0.016BTU/HR/FT/DEGF
0

                                                T E M P E R A T U R E   V E C T O R

      POINT ID.   TYPE      ID   VALUE     ID+1 VALUE     ID+2 VALUE     ID+3 VALUE     ID+4 VALUE     ID+5 VALUE
             1    TEMP     5.055055E+02
             3    TEMP     5.055174E+02
             5    TEMP     5.055174E+02
             7    TEMP     5.055174E+02
             9    TEMP     5.055174E+02   5.055174E+02   5.055174E+02   5.055174E+02
            14    TEMP     5.055174E+02   5.055174E+02
            18    TEMP     5.055174E+02
            20    TEMP     5.055055E+02   5.055055E+02   5.055055E+02   5.055055E+02   5.055055E+02   5.055055E+02
            26    TEMP     5.055055E+02   5.055055E+02   5.055055E+02   5.055055E+02   5.055055E+02   5.055055E+02
            32    TEMP     5.055055E+02   5.055055E+02   5.055055E+02   5.055055E+02   5.055055E+02   5.055174E+02
            41    TEMP     5.087106E+02
            44    TEMP     5.087106E+02   5.087106E+02
            47    TEMP     5.087106E+02   5.087106E+02
            50    TEMP     5.087106E+02   5.087106E+02   5.087106E+02   5.087106E+02   5.087106E+02   5.087106E+02
            56    TEMP     5.055174E+02
            58    TEMP     5.055174E+02   5.055174E+02
            62    TEMP     5.055174E+02
            67    TEMP     5.055174E+02
            69    TEMP     5.055174E+02
            71    TEMP     5.055174E+02
            73    TEMP     5.087106E+02
            75    TEMP     5.087225E+02   5.087225E+02   5.087225E+02   5.087225E+02   5.087225E+02   5.087225E+02
            83    TEMP     5.087225E+02
            85    TEMP     5.087225E+02
            87    TEMP     5.087225E+02   5.087225E+02
            98    TEMP     5.087106E+02
           101    TEMP     5.087106E+02
           104    TEMP     5.087106E+02   5.087106E+02
           107    TEMP     5.087106E+02   5.087106E+02   5.087225E+02
           112    TEMP     5.089311E+02
           115    TEMP     5.089311E+02   5.089311E+02
           118    TEMP     5.089311E+02
           120    TEMP     5.089311E+02   5.089311E+02   5.089311E+02   5.089311E+02   5.089311E+02   5.089311E+02
           128    TEMP     5.087225E+02   5.087225E+02   5.087225E+02
           133    TEMP     5.087225E+02
           135    TEMP     5.087225E+02
           137    TEMP     5.087225E+02   5.087225E+02
           145    TEMP     5.089311E+02   6.285157E+02   6.285157E+02
           150    TEMP     6.285157E+02
           152    TEMP     6.285157E+02
           160    TEMP     6.285157E+02   6.285157E+02
           164    TEMP     5.089311E+02   5.089311E+02
           172    TEMP     5.089311E+02
           174    TEMP     5.089311E+02
           177    TEMP     5.089311E+02   5.089311E+02
           180    TEMP     5.089311E+02   6.319413E+02   6.319294E+02   6.319294E+02   6.319294E+02
           188    TEMP     6.319294E+02
           193    TEMP     6.319294E+02
           195    TEMP     6.319294E+02   6.319294E+02   6.319294E+02   6.319294E+02   6.319294E+02   6.319413E+02
           201    TEMP     6.319413E+02   6.319413E+02   6.319413E+02   6.319413E+02   6.319413E+02   6.319413E+02
1      DIRECT_RADIATION_CONDUCTION_EMISSION_CONVECTION (T=0.001FT)      AUGUST  17, 2000    UAI/NASTRAN VERSION 20.1          PAGE
19
      10.7 IN GAP FILLED BY AIR; K=0.016BTU/HR/FT/DEGF
0

                                                T E M P E R A T U R E   V E C T O R

      POINT ID.   TYPE      ID   VALUE     ID+1 VALUE     ID+2 VALUE     ID+3 VALUE     ID+4 VALUE     ID+5 VALUE
           207    TEMP     6.319413E+02   6.319413E+02   6.319413E+02   6.319413E+02   6.319413E+02   6.319413E+02
           213    TEMP     6.319413E+02   6.319413E+02   6.319413E+02   6.319413E+02
           219    TEMP     6.287362E+02   6.287362E+02   6.287362E+02   6.287362E+02   6.287362E+02
           226    TEMP     6.287362E+02   6.287362E+02   6.287362E+02   6.287362E+02
           231    TEMP     6.287362E+02   6.287362E+02
           235    TEMP     6.287362E+02
           241    TEMP     6.319294E+02
           243    TEMP     6.319294E+02   6.319294E+02   6.319294E+02   6.319294E+02
           248    TEMP     6.319294E+02   6.319294E+02   6.319294E+02
           253    TEMP     6.287362E+02   6.287242E+02
           257    TEMP     6.287242E+02   6.287242E+02   6.287242E+02   6.287242E+02
           264    TEMP     6.287242E+02
           267    TEMP     6.287242E+02   6.287242E+02   6.287242E+02   6.287242E+02
           273    TEMP     6.287362E+02   6.287362E+02
           277    TEMP     6.287362E+02
           282    TEMP     6.287362E+02   6.287362E+02
           292    TEMP     6.285157E+02   6.285157E+02
           295    TEMP     6.285157E+02
           297    TEMP     6.285157E+02   6.285157E+02   6.285157E+02   6.285157E+02   6.285157E+02   6.285157E+02
           303    TEMP     6.285157E+02
           306    TEMP     6.285157E+02   6.285157E+02   6.287242E+02
           313    TEMP     6.287242E+02   6.287242E+02
           316    TEMP     6.287242E+02   6.287242E+02   6.287242E+02
           323    TEMP     6.287242E+02   6.287242E+02
           500    TEMP     5.786700E+02
```

TABLE 3-28. FINITE ELEMENT METHOD-SIMULATED TEMPERATURES (°F) OF THE RIGHT WING OF SAMPLE PROBLEM 5

T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
172.3	172.3	169.1	169.1	168.9	49.3	49.1	49.0	45.9	45.8

3.6 SAMPLE PROBLEM 6.

In sample problem 5, the effects of infrared emission, in addition to the combined effects of conduction, convection, and direct solar radiation, were studied. The effects of infrared emission were carried out by removing the emission restriction on the wing surfaces of sample problem 4, by changing it from 0.0 to 0.9. The only external source of heat originated from direct solar radiation. Sample problem 6 incorporated the effects of external infrared radiation from the sky, in addition to the direct solar radiation. As in sample problems 1 through 5, THERMOD was set up to solve a complete aircraft problem, while the FEM method was confined to the wing model.

To ensure consistency with the FEM wing model, the wing in the THERMOD model was isolated from infrared radiation effects from the fuselage and tarmac surfaces by assigning emissivity values of 0.0. Unlike sample problem 5, the sky radiation was assigned an absolute temperature of 459.67°R, so as to incorporate the infrared radiation from the sky. The conduction and convection heat transfer modes were left intact, as in sample problem 5.

As in sample problem 5, the wings were further isolated from the tarmac effects by arbitrarily placing the wing at a height of 100.0 ft from the tarmac. In addition, the infrared reflection effects from the fuselage surface were reduced by maintaining a cabin height of 0.1 ft.

As in sample problem 5, the fillet effect was removed from the wing top by assigning a 0.0 value in the second field of input data set 6. See the THERMOD User's Reference Manual for further details on the input requirements for fillet effects. The THERMOD input file, input.dat, is illustrated in table 3-29.

TABLE 3-29. THERMOD INPUT FILE (input.dat) OF SAMPLE PROBLEM 6

```
198e-6,0.704
1, 0.020,125,0.300,0.30
2, 0.375,4.4,0.021,0.24
3, 0.020,125,0.300,0.30
4, 0.350,125,0.300,0.30
5, 10.70,0.067,0.016,0.24
6, 0.350,125,0.300,0.30
7, 0.020,125,0.300,0.30
8, 0.375,4.4,0.021,0.24
9, 0.020,125,0.300,0.30
10,0.030,125,0.300,0.30
11,0.375,4.4,0.021,0.24
12,0.020,125,0.300,0.30
```

TABLE 3-29. THERMOD INPUT FILE (input.dat) OF SAMPLE PROBLEM 6 (Continued)

```
13,0.250,10.,0.020,0.24
14,48.00,0.067,0.016,0.24
15,0.020,125,0.300,0.30
16,0.375,4.4,0.021,0.24
17,0.020,125,0.300,0.30
18,0.250,10.,0.020,0.24
19,30.00,0.067,0.016,0.24
20,5.000,10.,0.020,0.24
21,0.020,125,0.300,0.30
22,0.375,4.4,0.021,0.24
23,0.020,125,0.300,0.30
24,2.500,0.067,0.016,0.24
25,0.020,125,0.300,0.30
26,0.375,4.4,0.021,0.24
27,0.020,125,0.300,0.30
28,0.250,130,0.800,0.20
3.5,34.0,100.0,5.5,22.0,11.0,0.1,4.0,30,24,28
0.70,1.0,0.0,2.0,150,0.80,0.22
0.3,0.9,0.3,0.9,0.3,0.9,0.1,0.9
3,0.0
0.9,0.9,0.0,0.0
1.0,0.0,0.9,0.9,1.0,0.0,1.0,0.0
9
0,10,10,0,0,75,110,110,190,190
5,120,5,60,20,5,120,60,60
7
60 570.67 459.67 14 330 10 10 0.36
75 573.67 459.67 14 355 10 10 0.31
90 578.67 459.67 14 355 10 12 0.33
75 581.67 459.67 14 330 10 10 0.31
60 582.67 459.67 14 291 10 10 0.36
45 583.67 459.67 14 231 10 10 0.44
30 582.67 459.67 14 160 10 10 0.57
1,0.02,180,10
10,1.0,1.0
10,10,10,10,10,10,10,10,10,10,10,10,10,10,10,
10,10,10,10,10,10,10,10,10,10,10,10,10,10,10,
10,10,10,10,10,10,10,10,10,10,10,10,10,10,10,
10,10,10,10,10,10,10,10,10,10,10,10,10,10,10,
10,10,10,10,10,10,10
```

Temperatures from the THERMOD run is shown in table 3-30, from which the steady-state temperatures T1, T2…..T10 (top to bottom of wing) for time period 3 were extracted and tabulated in table 3-31.

TABLE 3-30. THERMOD OUTPUT FILE (summary.dat) FOR SAMPLE PROBLEM 6

```
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
THERMOD:  A THERMAL PROGRAM FOR AIRCRAFTS
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$



 SUMMARY OF STEADY-STATE AND TRANSIENT ANALYSIS



 (Temperatures are shown for all time periods)


 TEMPERATURES AT THE END OF STEADY STATE ANALYSIS

        TEMPERATURES IN DEGREES FAHRENHEIT
         1     2     3     4     5     6     7

  1 171.1 189.7 195.5 186.1 166.2 137.9 108.3
  2 171.1 189.7 195.5 186.1 166.2 137.9 108.3
  3 169.0 187.2 192.8 183.8 164.3 136.8 107.9
  4 168.9 187.1 192.8 183.8 164.3 136.8 107.9
  5 168.8 187.0 192.7 183.6 164.2 136.7 107.9
  6  88.8  91.1  94.1  95.4  95.2  94.8  93.3
  7  88.7  91.0  93.9  95.2  95.1  94.8  93.3
  8  88.7  90.9  93.9  95.2  95.1  94.7  93.2
  9  86.5  88.4  91.2  92.9  93.3  93.6  92.9
 10  86.5  88.4  91.2  92.8  93.3  93.6  92.9
 11 171.1 189.7 195.5 186.1 166.2 137.9 108.3
 12 171.1 189.7 195.5 186.1 166.2 137.9 108.3
 13 168.9 187.2 192.8 183.8 164.3 136.8 107.9
 14 168.9 187.1 192.8 183.8 164.3 136.8 107.9
 15 168.8 187.0 192.7 183.6 164.2 136.7 107.9
 16  88.8  91.1  94.1  95.4  95.2  94.8  93.3
 17  88.7  91.0  93.9  95.2  95.1  94.8  93.3
 18  88.7  90.9  93.9  95.2  95.1  94.7  93.2
 19  86.5  88.4  91.2  92.9  93.3  93.6  92.9
 20  86.5  88.4  91.2  92.8  93.3  93.6  92.9
 21 276.7 310.4 322.3 304.0 268.2 219.2 169.9
 22 276.5 310.3 322.1 303.8 268.1 219.1 169.9
 23 242.5 264.0 274.0 259.4 236.0 200.8 161.5
 24 242.4 263.8 273.8 259.2 235.8 200.7 161.5
 25 218.6 231.4 240.1 228.1 213.4 187.9 155.7
 26 185.0 192.9 200.7 191.5 182.5 165.1 141.4
 27 143.9 149.0 155.3 152.9 149.4 142.2 131.2
 28 143.9 149.0 155.3 152.9 149.4 142.2 131.2
 29 140.9 145.9 152.0 150.1 147.1 140.6 130.4
 30 140.9 145.9 152.0 150.1 147.1 140.6 130.4
```

TABLE 3-30. THERMOD OUTPUT FILE (summary.dat) FOR SAMPLE PROBLEM 6 (Continued)

```
  31 128.1 132.2 137.8 138.0 136.7 133.5 127.2
  32 128.1 132.2 137.8 138.0 136.7 133.5 127.2
  33 128.1 132.2 137.8 138.0 136.7 133.5 127.2
  34 128.1 132.2 137.8 138.0 136.7 133.5 127.2
  35 115.2 118.5 123.6 125.9 126.4 126.3 124.0
  36 115.2 118.5 123.6 125.9 126.4 126.3 124.0
  37 112.3 115.3 120.4 123.2 124.0 124.7 123.3
  38 112.2 115.3 120.4 123.2 124.0 124.7 123.3
  39 218.4 180.1 132.7 182.8 216.8 225.1 206.3
  40 218.4 180.2 132.9 182.9 216.7 225.0 206.2
  41 202.0 186.0 165.4 186.7 200.0 196.5 176.2
  42 202.0 186.0 165.5 186.8 200.0 196.4 176.1
  43 190.5 190.1 188.2 189.5 188.3 176.4 155.1
  44 181.2 184.4 188.2 184.1 180.0 168.0 149.3
  45 158.2 161.3 165.5 163.7 161.3 153.5 140.6
  46 158.0 161.2 165.4 163.6 161.2 153.5 140.6
  47 125.1 128.2 132.9 134.5 134.5 132.8 128.3
  48 124.9 128.0 132.7 134.3 134.3 132.7 128.2
  49 123.9 128.0 133.1 130.2 127.0 120.3 110.7
  50 126.1 130.5 135.7 132.6 129.1 121.8 111.6
  51 188.8 207.4 215.7 208.8 191.6 168.5 144.8
  52 183.9 201.5 209.6 203.3 187.3 165.7 143.4
  53 188.8 207.4 215.7 208.8 191.6 168.5 144.8

Maximum Structural Temperature for Period   1 = 276.67 Occurring
at Location  21
Maximum Structural Temperature for Period   2 = 310.45 Occurring
at Location  21
Maximum Structural Temperature for Period   3 = 322.29 Occurring
at Location  21
Maximum Structural Temperature for Period   4 = 304.01 Occurring
at Location  21
Maximum Structural Temperature for Period   5 = 268.19 Occurring
at Location  21
Maximum Structural Temperature for Period   6 = 225.14 Occurring
at Location  39
Maximum Structural Temperature for Period   7 = 206.35 Occurring
at Location  39

Maximum Structural Temperature Over All     7 Periods =322.29
Occurring at Location  21 at Period   3
```

TABLE 3-30. THERMOD OUTPUT FILE (summary.dat) FOR SAMPLE PROBLEM 6 (Continued)

```
TEMPERATURES AT THE END OF TRANSIENT ANALYSIS

       TEMPERATURES IN DEGREES FAHRENHEIT
         1     2     3     4     5     6     7

  1 117.0 121.7 126.8 128.5 127.3 125.4 121.6
  2 118.4 123.4 128.6 130.0 128.3 125.7 121.2
  3 164.7 181.8 187.5 179.2 161.2 135.7 109.0
  4 166.1 183.7 189.3 180.7 162.3 136.0 108.7
  5 167.4 185.3 191.0 182.1 163.1 136.2 108.4
  6  89.4  91.7  94.7  96.0  95.9  95.4  93.9
  7  89.8  92.1  95.1  96.5  96.4  96.1  94.6
  8  90.4  92.7  95.8  97.2  97.1  96.8  95.3
  9 108.2 111.1 115.8 118.6 119.6 120.5 119.5
 10 108.8 111.6 116.4 119.3 120.2 121.2 120.2
 11 117.0 121.7 126.8 128.5 127.3 125.4 121.6
 12 118.4 123.4 128.6 130.0 128.3 125.7 121.2
 13 164.7 181.8 187.5 179.2 161.2 135.7 109.0
 14 166.1 183.6 189.3 180.7 162.3 136.0 108.7
 15 167.4 185.3 191.0 182.1 163.1 136.2 108.4
 16  89.4  91.7  94.7  96.0  95.9  95.4  93.9
 17  89.8  92.1  95.1  96.5  96.4  96.1  94.6
 18  90.4  92.7  95.8  97.2  97.1  96.8  95.3
 19 108.2 111.1 115.8 118.6 119.6 120.5 119.5
 20 108.8 111.6 116.4 119.3 120.2 121.2 120.2
 21 125.0 130.7 136.2 137.4 135.3 132.0 126.9
 22 127.1 132.9 138.5 139.5 137.0 133.2 127.5
 23 189.3 201.7 208.5 201.7 189.3 169.4 145.5
 24 191.0 203.5 210.4 203.4 190.7 170.4 146.0
 25 188.7 198.6 205.0 197.8 187.4 168.9 145.2
 26 167.6 174.4 180.2 175.2 168.6 155.4 137.2
 27 144.1 149.2 155.5 153.0 149.5 142.3 131.1
 28 143.2 148.3 154.5 152.3 148.9 142.0 131.1
 29 140.9 145.9 152.0 150.2 147.1 140.6 130.5
 30 140.9 145.8 151.9 150.1 147.0 140.6 130.4
 31 127.8 131.9 137.5 137.8 136.6 133.5 127.2
 32 127.8 131.9 137.5 137.8 136.6 133.5 127.2
 33 127.8 131.9 137.5 137.8 136.6 133.5 127.2
 34 127.8 131.9 137.5 137.8 136.6 133.5 127.2
 35 114.7 117.9 123.1 125.6 126.1 126.3 124.0
 36 114.6 117.8 123.0 125.5 126.1 126.3 124.0
 37 111.2 114.2 119.2 122.2 123.2 124.1 123.1
 38 111.1 114.1 119.1 122.1 123.1 124.1 123.0
 39 116.3 117.5 120.0 125.2 127.6 128.9 126.9
 40 117.9 118.9 121.2 126.4 128.9 130.0 127.7
 41 163.4 159.9 154.8 162.9 166.6 161.7 148.3
```

TABLE 3-30. THERMOD OUTPUT FILE (summary.dat) FOR SAMPLE PROBLEM 6 (Continued)

```
  42 164.8 161.4 156.2 164.2 167.7 162.5 148.8
  43 166.2 168.2 169.0 170.1 168.3 159.2 143.7
  44 162.8 166.0 169.0 168.0 165.3 156.4 142.0
  45 152.2 154.1 156.2 157.5 156.6 150.4 139.0
  46 150.9 152.7 154.8 156.3 155.6 149.6 138.6
  47 117.0 118.3 121.2 125.9 128.1 129.1 127.0
  48 115.9 117.2 120.0 124.9 127.2 128.4 126.6
  49 113.1 116.3 121.1 123.1 123.3 122.7 120.0
  50 115.2 118.6 123.5 125.0 124.9 123.6 120.3
  51 306.1 348.1 361.3 339.6 295.0 235.5 177.6
  52 288.9 327.5 340.0 320.5 279.9 225.7 172.8
  53 306.1 348.1 361.3 339.6 295.0 235.5 177.6

Maximum Structural Temperature for Period   1 = 191.02 Occurring
at Location  24
Maximum Structural Temperature for Period   2 = 203.55 Occurring
at Location  24
Maximum Structural Temperature for Period   3 = 210.37 Occurring
at Location  24
Maximum Structural Temperature for Period   4 = 203.36 Occurring
at Location  24
Maximum Structural Temperature for Period   5 = 190.72 Occurring
at Location  24
Maximum Structural Temperature for Period   6 = 170.41 Occurring
at Location  24
Maximum Structural Temperature for Period   7 = 148.79 Occurring
at Location  42

Maximum Structural Temperature Over All     7 Periods =210.37
Occurring at Location  24 at Period   3
```

TABLE 3-31. THERMOD-SIMULATED TEMPERATURES (°F) OF THE RIGHT WING OF SAMPLE PROBLEM 6

T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
195.5	195.5	192.8	192.8	192.7	94.1	93.9	93.9	91.2	91.2

As in the previous sample problems, a one-half wing structure was modeled using the UAI/NASTRAN FEM program. Instead of just two types of loads that were applied as in sample problem 5, three types of loads were applied to the model in sample problem 6. These loads, based on period 3 of the THERMOD input file, were direct solar radiation of 355 Btu/hr/ft^2, convection with a film coefficient of h = 1.3433 (Btu/hr)/(ft^2°F), and infrared sky radiation, based on a sky temperature of 0°F (459.67°R). The film coefficient was calculated internally by the THERMOD program and was based on the theory of airflow on a flat surface and a wind speed of 14 ft/sec. The solar radiation load was applied perpendicular to the top surface only, while both the top and bottom surfaces were subjected to the infrared sky radiation. Both the top and bottom surfaces were subjected to the convection loads. The ambient

temperature was maintained at 119°F (578.67°R). As in sample problem 5, the wings were assigned a nonzero emissivity value of 0.9, allowing the wings to emit and absorb infrared radiation. The effect of infrared radiation of the tarmac was neglected.

The FEM input file is shown in table 3-32. The ambient temperature of 119°F was imposed through the SPC case control card. This ambient temperature boundary condition was scalar in nature and was implemented through the SPOINT bulk data. The boundary elements, CHBDY, through which solar radiation and convection effects were applied, were modeled using the LINE boundary shape type, connecting the boundary nodes along the wing top and bottom. The SPACE designation in the CHBDY boundary element indicates that this element emits infrared radiation to a black body, in which case, no VIEW bulk data was required. Property cards PHBDY and the material cards MAT4, define absorptivity, emissivity, film coefficient, and conductivity values. Note that as in problem 5, the wing was assigned an emissivity of 0.9, as indicated in the PHBDY card. Load case 10 combines all three load cases: solar radiation on the top surface (indicated by QVECT) and the infrared sky radiation on the top and bottom surfaces (indicated by QBDY1). Because of the involvement of infrared radiation, through emission, this sample problem was rendered nonlinear. This required the Stefan-Boltzman constant, σ, and an initial set of temperatures, which were implemented through the PARAM and TEMPERATURE statements, respectively.

TABLE 3-32. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 6

```
ID D:\Natha,MSC/N
APP HEAT
SOL 3
TIME 10000
CEND
  TITLE = dradiation_infrd_conduction_emission_convection (t=0.001ft)
  SUBTITLE = 10.7 in gap filled by air; k=0.016BTU/hr/ft/degF
   load = 10
   SPC = 1
   temperature(estimate)=2
   THERMAL= ALL
   FLUX = ALL
   SPCF = ALL
BEGIN BULK
$ ***************************************************************************
$   Written by : MSC/NASTRAN for Windows
$   Version    : 6.00
$   Translator : UAI/NASTRAN
$   From Model : D:\Thermod_Validation\FEM\conduction_only.MOD
$   Date       : Mon Mar 06 11:27:09 2000
$ ***************************************************************************
$
PARAM,K6ROT,100.
PARAM,MAXRATIO,1.E+8
param,sigma,1.714e-9
param,tabs,0.0
param,maxit,10
CORD2C            1         0        0.        0.        0.        0.        0.
1.+MSC/NC1
```

TABLE 3-32. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 6 (Continued)

```
+MSC/NC1      1.      0.      1.
CORD2S           2         0        0.        0.        0.        0.        0.
1.+MSC/NC2
+MSC/NC2      1.      0.      1.
$
$ MSC/NASTRAN for Windows Property 1 : 0.02 in glass_outer_layer
PSHELL         1       1   0.001       1               1              0.
$ MSC/NASTRAN for Windows Property 2 : 3/8 in foam
PSHELL         2       2   0.001       2               2              0.
$ MSC/NASTRAN for Windows Property 3 : 0.02 in inner glass
PSHELL         3       1   0.001       1               1              0.
$ MSC/NASTRAN for Windows Property 4 : 0.350 in cap
PSHELL         4       1   0.001       1               1              0.
$ MSC/NASTRAN for Windows Property 5 : 10.70 in air space
PSHELL         5       3   0.001       3               3              0.
$ MSC/NASTRAN for Windows Property 6 : 0.350 in cap
PSHELL         6       1   0.001       1               1              0.
$ MSC/NASTRAN for Windows Property 7 : 0.02 in inner glass
PSHELL         7       1   0.001       1               1              0.
$ MSC/NASTRAN for Windows Property 8 : 3/8 in foam
PSHELL         8       2   0.001       2               2              0.
$ MSC/NASTRAN for Windows Property 9 : 0.02 in glass_outer_layer
PSHELL         9       1   0.001       1               1              0.
$ MSC/NASTRAN for Windows Material 1 : glass
MAT4           1     0.3       1.
$ MSC/NASTRAN for Windows Material 2 : foam
MAT4           2   0.021       1.
$ MSC/NASTRAN for Windows Material 3 : air
MAT4           3   0.016       1.
$
chbdy,1001,100,line,200,201,,,space,500,500,,,0.0,1.0,0.0
chbdy,1002,100,line,201,202,,,space,500,500,,,0.0,1.0,0.0
chbdy,1003,100,line,202,203,,,space,500,500,,,0.0,1.0,0.0
chbdy,1004,100,line,203,204,,,space,500,500,,,0.0,1.0,0.0
chbdy,1005,100,line,204,205,,,space,500,500,,,0.0,1.0,0.0
chbdy,1006,100,line,205,206,,,space,500,500,,,0.0,1.0,0.0
chbdy,1007,100,line,206,207,,,space,500,500,,,0.0,1.0,0.0
chbdy,1008,100,line,207,208,,,space,500,500,,,0.0,1.0,0.0
chbdy,1009,100,line,208,209,,,space,500,500,,,0.0,1.0,0.0
chbdy,1010,100,line,209,210,,,space,500,500,,,0.0,1.0,0.0
chbdy,1011,100,line,210,211,,,space,500,500,,,0.0,1.0,0.0
chbdy,1012,100,line,211,212,,,space,500,500,,,0.0,1.0,0.0
chbdy,1013,100,line,212,213,,,space,500,500,,,0.0,1.0,0.0
chbdy,1014,100,line,213,214,,,space,500,500,,,0.0,1.0,0.0
chbdy,1015,100,line,214,215,,,space,500,500,,,0.0,1.0,0.0
chbdy,1016,100,line,215,216,,,space,500,500,,,0.0,1.0,0.0
chbdy,1017,100,line,216,181,,,space,500,500,,,0.0,1.0,0.0
phbdy,100,200,0.001,0.9,0.9
mat4,200,1.3433
spoint,500
spc,1,500,1,578.67
$
$ Direct radiation load from a distant source: load case 1:
qvect,1,355.0,0.0,-1.0,0.0,1001,thru,1017
$
$ Infrared radiation from the sky: load case 2 (applied to the top)
$ and load case 3 (applied to the bottom)
```

TABLE 3-32. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 6 (Continued)

```
$ Q0=sigma*(T^4)=1.714e-9*(459.67)^4
$ =76.5236BTU/hr/ft^2: assuming sky temp.=0degF=459.67 degR.
Qbdy1,2,76.5236,1001,thru,1017
qbdy1,3,76.5236,2001,thru,2017
$ combine the above three load cases 1, 2 and 3 into load case 10:
load,10,1.0,1.0,1,1.0,2,1.0,3
$
chbdy,2001,300,line,20,21,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2002,300,line,21,22,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2003,300,line,22,23,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2004,300,line,23,24,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2005,300,line,24,25,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2006,300,line,25,26,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2007,300,line,26,27,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2008,300,line,27,28,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2009,300,line,28,29,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2010,300,line,29,30,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2011,300,line,30,31,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2012,300,line,31,32,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2013,300,line,32,33,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2014,300,line,33,34,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2015,300,line,34,35,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2016,300,line,35,36,,,space,500,500,,,0.0,-1.0,0.0
chbdy,2017,300,line,36,1,,,space,500,500,,,0.0,-1.0,0.0
phbdy,300,400,0.001,0.9,0.9
mat4,400,1.3433
$
temp,2,1,578.67,3,578.67,5,578.67
temp,2,7,578.67,9,578.67,10,578.67
temp,2,11,578.67,12,578.67,14,578.67
temp,2,15,578.67,18,578.67,20,578.67
temp,2,21,578.67,22,578.67,23,578.67
temp,2,24,578.67,25,578.67,26,578.67
temp,2,27,578.67,28,578.67,29,578.67
temp,2,30,578.67,31,578.67,32,578.67
temp,2,33,578.67,34,578.67,35,578.67
temp,2,36,578.67,37,578.67,41,578.67
temp,2,44,578.67,45,578.67,47,578.67
temp,2,48,578.67,50,578.67,51,578.67
temp,2,52,578.67,53,578.67,54,578.67
temp,2,55,578.67,56,578.67,58,578.67
temp,2,59,578.67,62,578.67,67,578.67
temp,2,69,578.67,71,578.67,73,578.67
temp,2,75,578.67,76,578.67,77,578.67
temp,2,78,578.67,79,578.67,80,578.67
temp,2,83,578.67,85,578.67,87,578.67
temp,2,88,578.67,98,578.67,101,578.67
temp,2,104,578.67,105,578.67,107,578.67
temp,2,108,578.67,109,578.67,112,578.67
temp,2,115,578.67,116,578.67,118,578.67
temp,2,120,578.67,121,578.67,122,578.67
temp,2,123,578.67,124,578.67,125,578.67
temp,2,128,578.67,129,578.67,130,578.67
temp,2,133,578.67,135,578.67,137,578.67
temp,2,138,578.67,145,578.67,146,578.67
temp,2,147,578.67,150,578.67,152,578.67
temp,2,160,578.67,161,578.67,164,578.67
```

TABLE 3-32. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 6 (Continued)

```
temp,2,165,578.67,172,578.67,174,578.67
temp,2,177,578.67,178,578.67,180,578.67
temp,2,181,578.67,182,578.67,183,578.67
temp,2,184,578.67,188,578.67,193,578.67
temp,2,195,578.67,196,578.67,197,578.67
temp,2,198,578.67,199,578.67,200,578.67
temp,2,201,578.67,202,578.67,203,578.67
temp,2,204,578.67,205,578.67,206,578.67
temp,2,207,578.67,208,578.67,209,578.67
temp,2,210,578.67,211,578.67,212,578.67
temp,2,213,578.67,214,578.67,215,578.67
temp,2,216,578.67,219,578.67,220,578.67
temp,2,221,578.67,222,578.67,223,578.67
temp,2,226,578.67,227,578.67,228,578.67
temp,2,229,578.67,231,578.67,232,578.67
temp,2,235,578.67,241,578.67,243,578.67
temp,2,244,578.67,245,578.67,246,578.67
temp,2,248,578.67,249,578.67,250,578.67
temp,2,253,578.67,254,578.67,257,578.67
temp,2,258,578.67,259,578.67,260,578.67
temp,2,264,578.67,267,578.67,268,578.67
temp,2,269,578.67,270,578.67,273,578.67
temp,2,274,578.67,277,578.67,282,578.67
temp,2,283,578.67,292,578.67,293,578.67
temp,2,295,578.67,297,578.67,298,578.67
temp,2,299,578.67,300,578.67,301,578.67
temp,2,302,578.67,303,578.67,306,578.67
temp,2,307,578.67,308,578.67,313,578.67
temp,2,314,578.67,316,578.67,317,578.67
temp,2,318,578.67,323,578.67,324,578.67
temp,2,500,578.67
$
GRID            1       0      0.      0.      0.       0
GRID            3       0      1.1.667E-3      0.       0
GRID            5       0      3.1.667E-3      0.       0
GRID            7       0      5.1.667E-3      0.       0
GRID            9       0      7.1.667E-3      0.       0
GRID           10       0      8.1.667E-3      0.       0
GRID           11       0      9.1.667E-3      0.       0
GRID           12       0     10.1.667E-3      0.       0
GRID           14       0     12.1.667E-3      0.       0
GRID           15       0     13.1.667E-3      0.       0
GRID           18       0     16.1.667E-3      0.       0
GRID           20       0     17.      0.      0.       0
GRID           21       0     16.      0.      0.       0
GRID           22       0     15.      0.      0.       0
GRID           23       0     14.      0.      0.       0
GRID           24       0     13.      0.      0.       0
GRID           25       0     12.      0.      0.       0
GRID           26       0     11.      0.      0.       0
GRID           27       0     10.      0.      0.       0
GRID           28       0      9.      0.      0.       0
GRID           29       0      8.      0.      0.       0
GRID           30       0      7.      0.      0.       0
GRID           31       0      6.      0.      0.       0
GRID           32       0      5.      0.      0.       0
GRID           33       0      4.      0.      0.       0
```

TABLE 3-32. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 6 (Continued)

```
GRID           34       0       3.      0.      0.       0
GRID           35       0       2.      0.      0.       0
GRID           36       0       1.      0.      0.       0
GRID           37       0       0.1.667E-3      0.       0
GRID           41       0       3.0.032917      0.       0
GRID           44       0       6.0.032917      0.       0
GRID           45       0       7.0.032917      0.       0
GRID           47       0       9.0.032917      0.       0
GRID           48       0      10.0.032917      0.       0
GRID           50       0      12.0.032917      0.       0
GRID           51       0      13.0.032917      0.       0
GRID           52       0      14.0.032917      0.       0
GRID           53       0      15.0.032917      0.       0
GRID           54       0      16.0.032917      0.       0
GRID           55       0      17.0.032917      0.       0
GRID           56       0      17.1.667E-3      0.       0
GRID           58       0      15.1.667E-3      0.       0
GRID           59       0      14.1.667E-3      0.       0
GRID           62       0      11.1.667E-3      0.       0
GRID           67       0       6.1.667E-3      0.       0
GRID           69       0       4.1.667E-3      0.       0
GRID           71       0       2.1.667E-3      0.       0
GRID           73       0       0.0.032917      0.       0
GRID           75       0       1.0.034583      0.       0
GRID           76       0       2.0.034583      0.       0
GRID           77       0       3.0.034583      0.       0
GRID           78       0       4.0.034583      0.       0
GRID           79       0       5.0.034583      0.       0
GRID           80       0       6.0.034583      0.       0
GRID           83       0       9.0.034583      0.       0
GRID           85       0      11.0.034583      0.       0
GRID           87       0      13.0.034583      0.       0
GRID           88       0      14.0.034583      0.       0
GRID           98       0      11.0.032917      0.       0
GRID          101       0       8.0.032917      0.       0
GRID          104       0       5.0.032917      0.       0
GRID          105       0       4.0.032917      0.       0
GRID          107       0       2.0.032917      0.       0
GRID          108       0       1.0.032917      0.       0
GRID          109       0       0.0.034583      0.       0
GRID          112       0       2. 0.06375      0.       0
GRID          115       0       5. 0.06375      0.       0
GRID          116       0       6. 0.06375      0.       0
GRID          118       0       8. 0.06375      0.       0
GRID          120       0      10. 0.06375      0.       0
GRID          121       0      11. 0.06375      0.       0
GRID          122       0      12. 0.06375      0.       0
GRID          123       0      13. 0.06375      0.       0
GRID          124       0      14. 0.06375      0.       0
GRID          125       0      15. 0.06375      0.       0
GRID          128       0      17.0.034583      0.       0
GRID          129       0      16.0.034583      0.       0
GRID          130       0      15.0.034583      0.       0
GRID          133       0      12.0.034583      0.       0
GRID          135       0      10.0.034583      0.       0
GRID          137       0       8.0.034583      0.       0
GRID          138       0       7.0.034583      0.       0
```

TABLE 3-32. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 6 (Continued)

```
GRID          145       0      0. 0.06375      0.        0
GRID          146       0      0. 0.95542      0.        0
GRID          147       0      1. 0.95542      0.        0
GRID          150       0      4. 0.95542      0.        0
GRID          152       0      6. 0.95542      0.        0
GRID          160       0     14. 0.95542      0.        0
GRID          161       0     15. 0.95542      0.        0
GRID          164       0     17. 0.06375      0.        0
GRID          165       0     16. 0.06375      0.        0
GRID          172       0      9. 0.06375      0.        0
GRID          174       0      7. 0.06375      0.        0
GRID          177       0      4. 0.06375      0.        0
GRID          178       0      3. 0.06375      0.        0
GRID          180       0      1. 0.06375      0.        0
GRID          181       0      0. 1.01917      0.        0
GRID          182       0      0.  1.0175      0.        0
GRID          183       0      1.  1.0175      0.        0
GRID          184       0      2.  1.0175      0.        0
GRID          188       0      6.  1.0175      0.        0
GRID          193       0     11.  1.0175      0.        0
GRID          195       0     13.  1.0175      0.        0
GRID          196       0     14.  1.0175      0.        0
GRID          197       0     15.  1.0175      0.        0
GRID          198       0     16.  1.0175      0.        0
GRID          199       0     17.  1.0175      0.        0
GRID          200       0     17. 1.01917      0.        0
GRID          201       0     16. 1.01917      0.        0
GRID          202       0     15. 1.01917      0.        0
GRID          203       0     14. 1.01917      0.        0
GRID          204       0     13. 1.01917      0.        0
GRID          205       0     12. 1.01917      0.        0
GRID          206       0     11. 1.01917      0.        0
GRID          207       0     10. 1.01917      0.        0
GRID          208       0      9. 1.01917      0.        0
GRID          209       0      8. 1.01917      0.        0
GRID          210       0      7. 1.01917      0.        0
GRID          211       0      6. 1.01917      0.        0
GRID          212       0      5. 1.01917      0.        0
GRID          213       0      4. 1.01917      0.        0
GRID          214       0      3. 1.01917      0.        0
GRID          215       0      2. 1.01917      0.        0
GRID          216       0      1. 1.01917      0.        0
GRID          219       0      1. 0.98625      0.        0
GRID          220       0      2. 0.98625      0.        0
GRID          221       0      3. 0.98625      0.        0
GRID          222       0      4. 0.98625      0.        0
GRID          223       0      5. 0.98625      0.        0
GRID          226       0      8. 0.98625      0.        0
GRID          227       0      9. 0.98625      0.        0
GRID          228       0     10. 0.98625      0.        0
GRID          229       0     11. 0.98625      0.        0
GRID          231       0     13. 0.98625      0.        0
GRID          232       0     14. 0.98625      0.        0
GRID          235       0     17. 0.98625      0.        0
GRID          241       0     12.  1.0175      0.        0
GRID          243       0     10.  1.0175      0.        0
GRID          244       0      9.  1.0175      0.        0
```

TABLE 3-32. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 6 (Continued)

```
GRID           245       0       8.  1.0175       0.        0
GRID           246       0       7.  1.0175       0.        0
GRID           248       0       5.  1.0175       0.        0
GRID           249       0       4.  1.0175       0.        0
GRID           250       0       3.  1.0175       0.        0
GRID           253       0       0. 0.98625       0.        0
GRID           254       0       0. 0.98458       0.        0
GRID           257       0       3. 0.98458       0.        0
GRID           258       0       4. 0.98458       0.        0
GRID           259       0       5. 0.98458       0.        0
GRID           260       0       6. 0.98458       0.        0
GRID           264       0      10. 0.98458       0.        0
GRID           267       0      13. 0.98458       0.        0
GRID           268       0      14. 0.98458       0.        0
GRID           269       0      15. 0.98458       0.        0
GRID           270       0      16. 0.98458       0.        0
GRID           273       0      16. 0.98625       0.        0
GRID           274       0      15. 0.98625       0.        0
GRID           277       0      12. 0.98625       0.        0
GRID           282       0       7. 0.98625       0.        0
GRID           283       0       6. 0.98625       0.        0
GRID           292       0       2. 0.95542       0.        0
GRID           293       0       3. 0.95542       0.        0
GRID           295       0       5. 0.95542       0.        0
GRID           297       0       7. 0.95542       0.        0
GRID           298       0       8. 0.95542       0.        0
GRID           299       0       9. 0.95542       0.        0
GRID           300       0      10. 0.95542       0.        0
GRID           301       0      11. 0.95542       0.        0
GRID           302       0      12. 0.95542       0.        0
GRID           303       0      13. 0.95542       0.        0
GRID           306       0      16. 0.95542       0.        0
GRID           307       0      17. 0.95542       0.        0
GRID           308       0      17. 0.98458       0.        0
GRID           313       0      12. 0.98458       0.        0
GRID           314       0      11. 0.98458       0.        0
GRID           316       0       9. 0.98458       0.        0
GRID           317       0       8. 0.98458       0.        0
GRID           318       0       7. 0.98458       0.        0
GRID           323       0       2. 0.98458       0.        0
GRID           324       0       1. 0.98458       0.        0
CQUAD4           1       9        1       37        3       36
CQUAD4           2       9       36        3       71       35
CQUAD4           3       9       35       71        5       34
CQUAD4           4       9       34        5       69       33
CQUAD4           5       9       33       69        7       32
CQUAD4           6       9       32        7       67       31
CQUAD4           7       9       31       67        9       30
CQUAD4           8       9       30        9       10       29
CQUAD4           9       9       29       10       11       28
CQUAD4          10       9       28       11       12       27
CQUAD4          11       9       27       12       62       26
CQUAD4          12       9       26       62       14       25
CQUAD4          13       9       25       14       15       24
CQUAD4          14       9       24       15       59       23
CQUAD4          15       9       23       59       58       22
CQUAD4          16       9       22       58       18       21
```

TABLE 3-32. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 6 (Continued)

```
CQUAD4         17         9         21         18         56         20
CQUAD4         18         8         37         73        108          3
CQUAD4         19         8          3        108        107         71
CQUAD4         20         8         71        107         41          5
CQUAD4         21         8          5         41        105         69
CQUAD4         22         8         69        105        104          7
CQUAD4         23         8          7        104         44         67
CQUAD4         24         8         67         44         45          9
CQUAD4         25         8          9         45        101         10
CQUAD4         26         8         10        101         47         11
CQUAD4         27         8         11         47         48         12
CQUAD4         28         8         12         48         98         62
CQUAD4         29         8         62         98         50         14
CQUAD4         30         8         14         50         51         15
CQUAD4         31         8         15         51         52         59
CQUAD4         32         8         59         52         53         58
CQUAD4         33         8         58         53         54         18
CQUAD4         34         8         18         54         55         56
CQUAD4         35         7         73        109         75        108
CQUAD4         36         7        108         75         76        107
CQUAD4         37         7        107         76         77         41
CQUAD4         38         7         41         77         78        105
CQUAD4         39         7        105         78         79        104
CQUAD4         40         7        104         79         80         44
CQUAD4         41         7         44         80        138         45
CQUAD4         42         7         45        138        137        101
CQUAD4         43         7        101        137         83         47
CQUAD4         44         7         47         83        135         48
CQUAD4         45         7         48        135         85         98
CQUAD4         46         7         98         85        133         50
CQUAD4         47         7         50        133         87         51
CQUAD4         48         7         51         87         88         52
CQUAD4         49         7         52         88        130         53
CQUAD4         50         7         53        130        129         54
CQUAD4         51         7         54        129        128         55
CQUAD4         52         6        109        145        180         75
CQUAD4         53         6         75        180        112         76
CQUAD4         54         6         76        112        178         77
CQUAD4         55         6         77        178        177         78
CQUAD4         56         6         78        177        115         79
CQUAD4         57         6         79        115        116         80
CQUAD4         58         6         80        116        174        138
CQUAD4         59         6        138        174        118        137
CQUAD4         60         6        137        118        172         83
CQUAD4         61         6         83        172        120        135
CQUAD4         62         6        135        120        121         85
CQUAD4         63         6         85        121        122        133
CQUAD4         64         6        133        122        123         87
CQUAD4         65         6         87        123        124         88
CQUAD4         66         6         88        124        125        130
CQUAD4         67         6        130        125        165        129
CQUAD4         68         6        129        165        164        128
CQUAD4         69         5        145        146        147        180
CQUAD4         70         5        180        147        292        112
CQUAD4         71         5        112        292        293        178
CQUAD4         72         5        178        293        150        177
CQUAD4         73         5        177        150        295        115
```

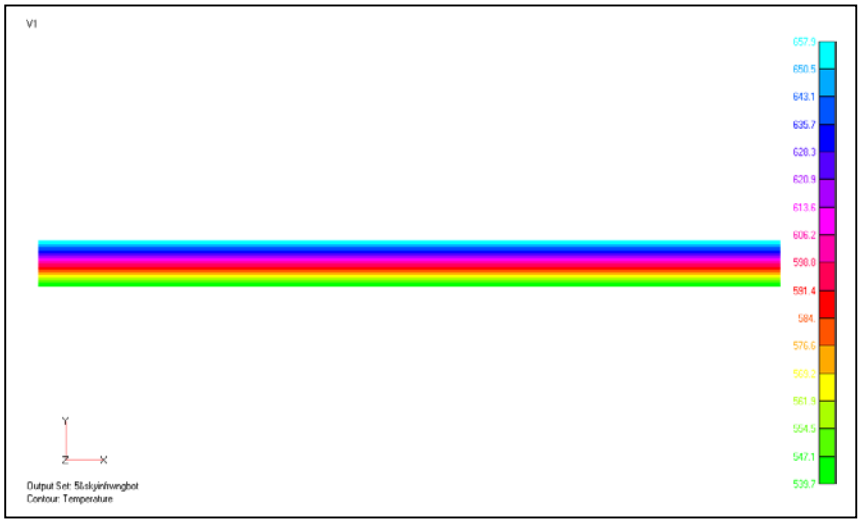
TABLE 3-32. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 6 (Continued)

```
CQUAD4      74       5      115      295      152      116
CQUAD4      75       5      116      152      297      174
CQUAD4      76       5      174      297      298      118
CQUAD4      77       5      118      298      299      172
CQUAD4      78       5      172      299      300      120
CQUAD4      79       5      120      300      301      121
CQUAD4      80       5      121      301      302      122
CQUAD4      81       5      122      302      303      123
CQUAD4      82       5      123      303      160      124
CQUAD4      83       5      124      160      161      125
CQUAD4      84       5      125      161      306      165
CQUAD4      85       5      165      306      307      164
CQUAD4      86       1      182      181      216      183
CQUAD4      87       1      183      216      215      184
CQUAD4      88       1      184      215      214      250
CQUAD4      89       1      250      214      213      249
CQUAD4      90       1      249      213      212      248
CQUAD4      91       1      248      212      211      188
CQUAD4      92       1      188      211      210      246
CQUAD4      93       1      246      210      209      245
CQUAD4      94       1      245      209      208      244
CQUAD4      95       1      244      208      207      243
CQUAD4      96       1      243      207      206      193
CQUAD4      97       1      193      206      205      241
CQUAD4      98       1      241      205      204      195
CQUAD4      99       1      195      204      203      196
CQUAD4     100       1      196      203      202      197
CQUAD4     101       1      197      202      201      198
CQUAD4     102       1      198      201      200      199
CQUAD4     103       2      253      182      183      219
CQUAD4     104       2      219      183      184      220
CQUAD4     105       8      220      184      250      221
CQUAD4     106       2      221      250      249      222
CQUAD4     107       2      222      249      248      223
CQUAD4     108       2      223      248      188      283
CQUAD4     109       2      283      188      246      282
CQUAD4     110       2      282      246      245      226
CQUAD4     111       2      226      245      244      227
CQUAD4     112       2      227      244      243      228
CQUAD4     113       2      228      243      193      229
CQUAD4     114       2      229      193      241      277
CQUAD4     115       2      277      241      195      231
CQUAD4     116       2      231      195      196      232
CQUAD4     117       2      232      196      197      274
CQUAD4     118       2      274      197      198      273
CQUAD4     119       2      273      198      199      235
CQUAD4     120       3      254      253      219      324
CQUAD4     121       3      324      219      220      323
CQUAD4     122       3      323      220      221      257
CQUAD4     123       3      257      221      222      258
CQUAD4     124       3      258      222      223      259
CQUAD4     125       3      259      223      283      260
CQUAD4     126       3      260      283      282      318
CQUAD4     127       3      318      282      226      317
CQUAD4     128       3      317      226      227      316
CQUAD4     129       3      316      227      228      264
CQUAD4     130       3      264      228      229      314
```

TABLE 3-32. FINITE ELEMENT METHOD INPUT FILE OF SAMPLE PROBLEM 6 (Continued)

```
CQUAD4    131       3       314     229     277     313
CQUAD4    132       3       313     277     231     267
CQUAD4    133       3       267     231     232     268
CQUAD4    134       3       268     232     274     269
CQUAD4    135       3       269     274     273     270
CQUAD4    136       3       270     273     235     308
CQUAD4    137       4       146     254     324     147
CQUAD4    138       4       147     324     323     292
CQUAD4    139       4       292     323     257     293
CQUAD4    140       4       293     257     258     150
CQUAD4    141       4       150     258     259     295
CQUAD4    142       4       295     259     260     152
CQUAD4    143       4       152     260     318     297
CQUAD4    144       4       297     318     317     298
CQUAD4    145       4       298     317     316     299
CQUAD4    146       4       299     316     264     300
CQUAD4    147       4       300     264     314     301
CQUAD4    148       4       301     314     313     302
CQUAD4    149       4       302     313     267     303
CQUAD4    150       4       303     267     268     160
CQUAD4    151       4       160     268     269     161
CQUAD4    152       4       161     269     270     306
CQUAD4    153       4       306     270     308     307
ENDDATA
```

The results of the one-half FEM wing model analysis are presented in figure 3-6 in the form of a contour plot. The contours appear to be indicative of the temperature profile of the THERMOD analysis. The top surface, which was subjected to both direct solar radiation and infrared sky radiation, is certainly much hotter than the bottom surface, which was subjected to the infrared sky radiation only. The temperatures are higher than those found in figure 3-5 of sample problem 5 because of the inclusion of both the direct solar radiation and infrared sky radiation.



Note that the temperatures are in absolute terms (°R).

FIGURE 3-6. CONTOUR PLOT OF THE FEM OUTPUT OF SAMPLE PROBLEM 6

The truncated FEM output file is shown in table 3-33. The nodes, from top to bottom of the wing, located at mid-span of the model are indicated by nodes 209, 245, 226, 317, 298, 118, 137, 101, 10, and 29. The temperatures of these nodes were extracted from this file and are reproduced in table 3-34. Mid-span was chosen because it was sufficiently far away from any edge effects that might be present. Note that the temperatures in table 3-34 were reduced from absolute temperatures (°R) to °F.

TABLE 3-33. TRUNCATED FEM OUTPUT FILE OF SAMPLE PROBLEM 6

```
1      DRADIATION_INFRD_CONDUCTION_EMISSION_CONVECTION (T=0.001FT)      AUGUST   21, 2000    UAI/NASTRAN VERSION 20.1         PAGE
18
      10.7 IN GAP FILLED BY AIR; K=0.016BTU/HR/FT/DEGF
0

                                          T E M P E R A T U R E   V E C T O R

      POINT ID.   TYPE      ID   VALUE     ID+1 VALUE     ID+2 VALUE     ID+3 VALUE     ID+4 VALUE     ID+5 VALUE
             1    TEMP     5.397126E+02
             3    TEMP     5.397238E+02
             5    TEMP     5.397238E+02
             7    TEMP     5.397238E+02
             9    TEMP     5.397238E+02   5.397238E+02   5.397238E+02   5.397238E+02
            14    TEMP     5.397238E+02   5.397238E+02
            18    TEMP     5.397238E+02
            20    TEMP     5.397126E+02   5.397126E+02   5.397126E+02   5.397126E+02   5.397126E+02   5.397126E+02
            26    TEMP     5.397126E+02   5.397126E+02   5.397126E+02   5.397126E+02   5.397126E+02   5.397126E+02
            32    TEMP     5.397126E+02   5.397126E+02   5.397126E+02   5.397126E+02   5.397126E+02   5.397238E+02
            41    TEMP     5.427075E+02
            44    TEMP     5.427075E+02   5.427075E+02
            47    TEMP     5.427075E+02   5.427075E+02
            50    TEMP     5.427075E+02   5.427075E+02   5.427075E+02   5.427075E+02   5.427075E+02   5.427075E+02
            56    TEMP     5.397238E+02
            58    TEMP     5.397238E+02   5.397238E+02
            62    TEMP     5.397238E+02
            67    TEMP     5.397238E+02
            69    TEMP     5.397238E+02
            71    TEMP     5.397238E+02
            73    TEMP     5.427075E+02
            75    TEMP     5.427186E+02   5.427186E+02   5.427186E+02   5.427186E+02   5.427186E+02   5.427186E+02
            83    TEMP     5.427186E+02
            85    TEMP     5.427186E+02
            87    TEMP     5.427186E+02   5.427186E+02
            98    TEMP     5.427075E+02
           101    TEMP     5.427075E+02
           104    TEMP     5.427075E+02   5.427075E+02
           107    TEMP     5.427075E+02   5.427075E+02   5.427186E+02
           112    TEMP     5.429136E+02
           115    TEMP     5.429136E+02   5.429136E+02
           118    TEMP     5.429136E+02
           120    TEMP     5.429136E+02   5.429136E+02   5.429136E+02   5.429136E+02   5.429136E+02   5.429136E+02
           128    TEMP     5.427186E+02   5.427186E+02   5.427186E+02
           133    TEMP     5.427186E+02
           135    TEMP     5.427186E+02
           137    TEMP     5.427186E+02   5.427186E+02
           145    TEMP     5.429136E+02   6.546570E+02   6.546570E+02
           150    TEMP     6.546570E+02
           152    TEMP     6.546570E+02
           160    TEMP     6.546570E+02   6.546570E+02
           164    TEMP     5.429136E+02   5.429136E+02
           172    TEMP     5.429136E+02
           174    TEMP     5.429136E+02
           177    TEMP     5.429136E+02   5.429136E+02
           180    TEMP     5.429136E+02   6.578580E+02   6.578469E+02   6.578469E+02   6.578469E+02
           188    TEMP     6.578469E+02
           193    TEMP     6.578469E+02
           195    TEMP     6.578469E+02   6.578469E+02   6.578469E+02   6.578469E+02   6.578469E+02   6.578580E+02
           201    TEMP     6.578580E+02   6.578580E+02   6.578580E+02   6.578580E+02   6.578580E+02   6.578580E+02
1      DRADIATION_INFRD_CONDUCTION_EMISSION_CONVECTION (T=0.001FT)      AUGUST   21, 2000    UAI/NASTRAN VERSION 20.1         PAGE
19
      10.7 IN GAP FILLED BY AIR; K=0.016BTU/HR/FT/DEGF
0

                                          T E M P E R A T U R E   V E C T O R

      POINT ID.   TYPE      ID   VALUE     ID+1 VALUE     ID+2 VALUE     ID+3 VALUE     ID+4 VALUE     ID+5 VALUE
           207    TEMP     6.578580E+02   6.578580E+02   6.578580E+02   6.578580E+02   6.578580E+02   6.578580E+02
           213    TEMP     6.578580E+02   6.578580E+02   6.578580E+02   6.578580E+02
           219    TEMP     6.548631E+02   6.548631E+02   6.548631E+02   6.548631E+02   6.548631E+02
           226    TEMP     6.548631E+02   6.548631E+02   6.548631E+02   6.548631E+02
           231    TEMP     6.548631E+02   6.548631E+02
           235    TEMP     6.548631E+02
           241    TEMP     6.578469E+02
           243    TEMP     6.578469E+02   6.578469E+02   6.578469E+02   6.578469E+02
           248    TEMP     6.578469E+02   6.578469E+02   6.578469E+02
           253    TEMP     6.548631E+02   6.548519E+02
           257    TEMP     6.548519E+02   6.548519E+02   6.548519E+02   6.548519E+02
           264    TEMP     6.548519E+02
           267    TEMP     6.548519E+02   6.548519E+02   6.548519E+02   6.548519E+02
           273    TEMP     6.548631E+02   6.548631E+02
```

TABLE 3-33. TRUNCATED FEM OUTPUT FILE OF SAMPLE PROBLEM 6 (Continued)

```
       277    TEMP     6.548631E+02
       282    TEMP     6.548631E+02   6.548631E+02
       292    TEMP     6.546570E+02   6.546570E+02
       295    TEMP     6.546570E+02
       297    TEMP     6.546570E+02   6.546570E+02   6.546570E+02   6.546570E+02   6.546570E+02   6.546570E+02
       303    TEMP     6.546570E+02
       306    TEMP     6.546570E+02   6.546570E+02   6.548519E+02
       313    TEMP     6.548519E+02   6.548519E+02
       316    TEMP     6.548519E+02   6.548519E+02   6.548519E+02
       323    TEMP     6.548519E+02   6.548519E+02
       500    TEMP     5.786700E+02
```

When compared, the temperatures of tables 3-31 and 3-34 show good agreement at the wing top. However, there is a significant difference in the bottom wing temperatures. This is due to the fact that the wing bottom in the FEM model was subjected to the sky radiation only, while the wing bottom in the THERMOD model was subjected to both the sky radiation and the tarmac radiation. In addition, the THERMOD program used control volumes and view factors in modeling the radiation effects, while the sample FEM model radiated heat to space, whereby the temperature-increasing effects of multiple reflections within an enclosure was neglected. These are the reasons why the wing bottom temperatures of the FEM model are lower than the THERMOD model, as comparison of tables 3-31 and 3-34 shows. In any case, sample problem 6 validates the radiation, conduction, and convection capabilities of THERMOD program, including infrared emission and absorption.

TABLE 3-34. FINITE ELEMENT METHOD-SIMULATED TEMPERATURES (°F) OF THE RIGHT WING OF SAMPLE PROBLEM 6

T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
198.2	198.2	195.2	195.2	195.0	83.2	83.0	83.0	80.0	80.0

4. SAMPLE PROBLEM.

This section presents a complete thermal solution for an aircraft. The objective was to determine the MOL temperature of the aircraft painted with a particular paint scheme and subjected to a given thermal environment. The solution involved both the steady-state and the transient analysis procedures. The transient analysis will be dependent on the type of flight profile information provided. Hypothetical values were used for all required thermal input data.

4.1 INPUT DATA.

THERMOD requires one input file, input.dat. Once invoked (by double-clicking THERMOD), THERMOD automatically reads in the input.dat file and reads out two output files. These output files are summary.dat and transient.dat. The summary.dat file summarizes the temperature results and prints the maximum operating temperatures for steady state and transient state. The transient.dat file prints the transient temperatures with respect to time.

A complete description of the input file, input variables, their definitions, and formats is located in the THERMOD User's Manual [2]. Refer to figures 1-1 through 1-4 for a graphical description of the problem.

Numerical values for the geometric and thermal properties for the hypothetical problem are presented in the following.

The environmental data for the sample problem is based on table 4-1. An analysis was performed for each hour noted in the table. This is important because the maximum ambient temperature could lag the maximum solar radiation, as indicated in the table. To account for infrared sky radiation, an effective sky temperature of 0°F was assumed. This temperature can vary from about -50°F under a cold, clear sky to +50°F under warm, cloudy conditions [6]. Because a desert environment is likely to be simulated during an extremely hot day, it is reasonable to assume a cold, clear sky that would allow maximum solar radiation to penetrate through the atmosphere. Thus, an effective sky temperature of 0°F was assumed.

TABLE 4-1. TEMPERATURE AND ASSOCIATED RADIATION DATA

Hour	Angle* (degrees)	Ambient Temperature (°F)	Wind (ft/sec)	Solar Radiation (Btu/hr/ft^2)
1100	60	106	10	300
1200	75	109	11	325
1300	90	114	14	325
1400	75	117	13	300
1500	60	120	12	261
1600	45	119	12	201
1700	30	118	10	130

*Angle refers to the sun's incident angle at different times. To determine the infrared radiation from the sky, an effective sky temperature of 0°F was assumed.

The dimensional schematics of the model are given in figure 1-2. The dimensions and thermal property values of various elements of the hypothetical problem are given in tables 4-2 through 4-10.

TABLE 4-2. THICKNESS OF THERMAL ELEMENTS OF THE WING

Thermal Element	Thickness (in)
Outer skin	0.03
Foam	0.375
Inner skin	0.02
Spar cap	0.30
Air space	12.0
Spar cap	0.30
Inner skin	0.02
Foam	0.375
Outer skin	0.03

Use figure 1-2 (Detail a: Wing) in conjunction with this table.

TABLE 4-3. THICKNESS OF THERMAL ELEMENTS OF THE FUSELAGE SIDE

Thermal Element	Thickness (in)
Outer skin	0.03
Foam	0.375
Inner skin	0.02
Insulatory material C	0.25

Use figure 1-2 (Detail b: Fuselage side) in conjunction with this table.

TABLE 4-4. THICKNESS OF THE THERMAL ELEMENTS OF THE FLOOR

Thermal Element	Thickness (in)
Insulatory material B	5.0
Outer skin	0.03
Foam	0.375
Inner skin	0.02
Floor space	3.0
Inner skin	0.02
Foam	0.375
Outer skin	0.03

Use figure 1-2 (Detail c: Floor) in conjunction with this table. The insulatory material B is a symbolic representation of the seat, the carpet, the middle console, and other possible items, all combined and treated as one material. This assumption is necessary for THERMOD models conduction in one dimension only (through-thickness). In addition, THERMOD considers all discretized elements as being isothermal, characterized by uniform radiosity, irradiation, and material properties. The thickness of insulatory material B is regarded as the weighted average (in terms of surface area) of the items just described.

TABLE 4-5. THICKNESS OF THE THERMAL ELEMENTS OF THE ROOF

Thermal Element	Thickness (in)
Outer skin	0.03
Foam	0.375
Inner skin	0.02
Insulatory material A	0.25

Use figure 1-2 (Detail d: Roof) in conjunction with this table.

TABLE 4-6. OVERALL DIMENSIONS OF THE THERMAL MODEL

Dimension	Length (ft)
L_{wing}	35.0
W_{wing}	3.5
H_{wing}	2.8
L_{cabin}	11.0
W_{cabin}	4.0
H_{cabin}	2.5
L_{flg}	22.0
L_{ledge}	5.5

Greenhouse effect within the cabin is modeled with the following dimensions: W_{cabin} = 4.0 ft; H_{cabin} = 2.5 ft; L_{cabin} = 11.0 ft.

TABLE 4-7. ABSORPTIVITY AND EMISSIVITY PROPERTIES OF THE EXTERIOR SURFACES OF THE WING AND FUSELAGE

Thermal Element	Absorptivity	Emissivity
Wing	0.45	0.80
Fuselage sides	0.65	0.90
Fuselage top	0.50	0.85
Fuselage bottom	0.60	0.85

TABLE 4-8. THERMAL PROPERTIES OF VARIOUS SOLID MATERIALS

Thermal Element	Density (lb/ft^3)	Conductivity (Btu/hr/ft/°F)	Specific Heat Capacity (Btu/lb/°F)
Divinycell HT70 foam [13]	4.4	0.021	0.24
E-Glass Composite [14]	125	0.30	0.30
Fuselage Interior Material (A, B, C as in figure 1-1)	10	0.020	0.24
Plexiglas [6]	130	0.80	0.20
Tarmac [6]	150	0.80	0.22

Note: The numbers in brackets refer to the references from which the corresponding data were obtained.

TABLE 4-9. THERMAL PROPERTIES OF AIR

Thermal Element	Density (lb/ft^3)	Conductivity (Btu/hr/ft/°F)	Specific Heat Capacity (Btu/lb/°F)	Kinematic Viscosity (ft^2/sec)	Prandtl Number
Air [6]	0.067	0.016	0.24	198e-6	0.704

Note: The number in brackets refer to the references from which the corresponding data were obtained. Air properties are based on a temperature of 150°F.

TABLE 4-10. MISCELLANEOUS PROPERTIES

Item	Values
Tarmac surface: asphalt [6]	Absorptivity = 0.9; emissivity = 0.9
Tarmac depth	2.0 ft of concrete
Insulatory material A and C [15]	Absorptivity = 0.5; emissivity = 0.9
Insulatory material B [15]	Absorptivity = 0.6; emissivity = 0.9
Plexiglas [6 and 16]	Absorptivity = 0.2; emissivity = 0.9; transmissivity = 0.70; thickness = 0.25 in.
Cabin scatter factor	Sides = 0.9; floor = 0.9
Exterior scatter factor [6]	Wing = 0.9; fuselage = 0.9

Note: The numbers in brackets refer to the references from which the corresponding data were obtained.

Note that the E-glass values in table 4-8 are based on typical 7781 epoxy-based glass composite [14]. Materials A and C could represent some typical composite panels made of felt core, sandwiched between layers of glass cloth. The insulatory material B is a symbolic representation of the seat, carpet, and other possible items, all combined and treated as one material. This assumption is necessary for THERMOD models conduction in one dimension only (through-thickness). In addition, THERMOD considers all discretized elements as being isothermal, characterized by uniform radiosity, irradiation, and material properties. The thermal properties of insulatory materials A, B, and C are simply assumed as shown.

The thermal values used for Plexiglas in table 4-8 are typical values for this material [6]. The tarmac base material is conservatively assumed to be concrete, allowing for substantial conduction of heat from the unsheltered tarmac region to the sheltered tarmac region underneath the wing. The tarmac, however, is assumed to be paved with an asphalt surface, thereby, absorbing the most heat from the sun (solar absorptivity = 0.9; see table 4-10) and emitting the most infrared radiation (emissivity = 0.9; see table 4-10) than would a typical concrete-paved tarmac.

In table 4-10, a tarmac depth of 2.0 ft was assumed: judged thick enough to conduct substantial heat from the unsheltered tarmac to the sheltered tarmac underneath the wing. The absorptivity of the insulatory materials A, B, and C may vary from 0.1 to 0.7 [15], depending on the texture and its composition. Their emissivities are generally high [15], therefore, a value of 0.9 was

assumed for all of them. Depending on the thickness and tint of the Plexiglas, its transmissivity may vary. FAA Title 14 Code of Federal Regulation 23.775 (d) stipulates that the transmissivity of the windshield and side windows must not be less than 0.70 when the pilot is seated in the normal flight position. Based on this stipulation, a transmissivity value of 0.70 was assumed. A Plexiglas thickness of 0.25 in. was assumed in the analysis.

The scatter factor for the cabin and exterior (wings and fuselage) surfaces are as shown in table 4-10. The scatter factor is defined as the fraction of the reflected solar radiation that is diffuse; the rest is specular (focus). Generally, the cabin does not have highly polished surfaces, therefore, a 0.9 scatter factor is justified. The exterior surface is, generally, not highly polished and non-mirror-like. Reference 6 states that for most engineering applications, a dull surface may be assumed. A scatter factor of 0.9, which produces a dull surface, is assumed for the exterior surface. This means 10% of the reflected solar radiation is specular.

Cooling takes place when the door is opened and the full convective forces that have always been present outside (due to wind, see table 4-1) is assumed to be applied within the cabin until an ambient cabin temperature of 140°F is reached. This ambient temperature is calculated by taking the weighted average surface temperatures of T25, T26, T43, T44, and T50 at each time step of the transient phase. When the ambient temperature reaches 140°F, the door is closed, and the aircraft begins taxiing as indicated in figure 1-4.

Based on the above information, THERMOD determines the steady-state temperature of the model. The results are then used as a starting base in a second phase of analysis, in which cooling is introduced. This phase of the analysis is called the transient analysis. To undertake this analysis, the flight profile information of figure 1-3 is used. The flight profile provides information on relative wind velocity, which is then used to determine the instantaneous convective coefficient. The higher the coefficient the sooner the temperature reaches a steady-state during the transient cooling phase. At the end of the transient analysis (at the point of application of the limit or gust load), the 44 structural temperatures, are compared to each other, and the maximum of these structural temperatures is then used as the MOL temperature for a given paint scheme. It should be emphasized that THERMOD was developed in this manner so that no special remedial measures need to be taken to address temperatures in heat-soaked deep locations. These and all other temperatures are addressed as individual unknowns within a system of nonlinear equations, and the maximum of these unknowns (structural temperatures) is reported as the MOL temperature for a given paint scheme.

4.2 INPUT FILE.

The input file, input.dat, for the sample problem is presented in table 4-11. A total of 15 sets of data are required to complete the model description. Most of these data sets were developed based on the information provided above. Some information, not described above, was also included in these sets, which can be found in the THERMOD User's Manual [2].

TABLE 4-11. INPUT FILE (input.dat) FOR THE SAMPLE PROBLEM

```
198e-6,0.704
1, 0.030,125,0.300,0.30
2, 0.375,4.4,0.021,0.24
3, 0.020,125,0.300,0.30
4, 0.300,125,0.300,0.30
5, 12.0,0.067,0.016,0.24
6, 0.300,125,0.300,0.30
7, 0.020,125,0.300,0.30
8, 0.375,4.4,0.021,0.24
9, 0.030,125,0.300,0.30
10,0.030,125,0.300,0.30
11,0.375,4.4,0.021,0.24
12,0.020,125,0.300,0.30
13,0.250,10.,0.020,0.24
14,48.00,0.067,0.016,0.24
15,0.030,125,0.300,0.30
16,0.375,4.4,0.021,0.24
17,0.020,125,0.300,0.30
18,0.250,10.,0.020,0.24
19,30.00,0.067,0.016,0.24
20,5.000,10.,0.020,0.24
21,0.030,125,0.300,0.30
22,0.375,4.4,0.021,0.24
23,0.020,125,0.300,0.30
24,3.00,0.067,0.016,0.24
25,0.020,125,0.300,0.30
26,0.375,4.4,0.021,0.24
27,0.030,125,0.300,0.30
28,0.250,130,0.800,0.20
3.5,35.0,2.8,5.5,22.0,11.0,2.5,4.0,30,24,28
0.70,0.9,0.9,2.0,150,0.80,0.22
0.5,0.9,0.6,0.9,0.5,0.9,0.2,0.9
3,100
0.9,0.9,0.9,0.9
0.65,0.90,0.45,0.80,0.50,0.85,0.60,0.85
9
0,10,10,0,0,75,110,110,190,190
5,120,5,60,20,5,120,60,60
7
60 565.67 459.67 10 300 10 10 0.36
75 568.67 459.67 11 325 10 10 0.31
90 573.67 459.67 14 325 10 12 0.33
75 576.67 459.67 13 300 10 10 0.31
60 579.67 459.67 12 261 10 10 0.36
45 578.67 459.67 12 201 10 10 0.44
30 577.67 459.67 10 130 10 10 0.57
1,0.02,140,100
10,1.0,1.0
```

TABLE 4-11. INPUT FILE (input.dat) FOR THE SAMPLE PROBLEM (Continued)

```
10,10,10,10,10,10,10,10,10,10,10,10,10,10,10,
10,10,10,10,10,10,10,10,10,10,10,10,10,10,10,
10,10,10,10,10,10,10,10,10,10,10,10,10,10,10,
10,10,10,10,10,10,10,10,10,10,10,10,10,10,10,
10,10,10,10,10,10,10
```

4.3 OUTPUT FILES.

Two output files were generated: summary.dat and transient.dat. The summary.dat file summarizes the temperature results and prints the MOL temperature for steady state and transient state, as shown in table 4-12. The MOL temperature at the end of the steady-sate analysis was 174.1°F. The MOL temperature at the end of the transient analysis was 151.0°F. Thus, the transient analysis has reduced the maximum soaked temperature by 23.1°F. The final MOL temperature for this aircraft was 151.0°F.

The transient.dat file prints the transient temperatures with respect to time, as shown in table 4-13. The variations of all 53 temperatures with respect to time are presented.

TABLE 4-12. SAMPLE PROBLEM OUTPUT DATA FILE (summary.dat)

```
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
THERMOD:  A THERMAL PROGRAM FOR AIRCRAFTS
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$



 SUMMARY OF STEADY-STATE AND TRANSIENT ANALYSIS



 (Temperatures are shown for all time periods)


 TEMPERATURES AT THE END OF STEADY STATE ANALYSIS

        TEMPERATURES IN DEGREES FAHRENHEIT
         1     2     3     4     5     6     7

   1 138.1 149.1 150.4 146.9 137.1 119.1 100.3
   2 138.1 149.1 150.4 146.9 137.1 119.1 100.3
   3 137.5 148.4 149.7 146.3 136.6 118.9 100.4
   4 137.5 148.4 149.7 146.3 136.6 118.9 100.4
   5 137.5 148.4 149.7 146.3 136.6 118.9 100.4
   6 112.1 117.9 120.3 120.6 118.4 111.4 103.8
   7 112.0 117.9 120.3 120.5 118.4 111.4 103.8
   8 112.0 117.9 120.3 120.5 118.3 111.4 103.8
   9 111.4 117.2 119.6 119.9 117.9 111.2 103.9
```

TABLE 4-12. SAMPLE PROBLEM OUTPUT DATA FILE (summary.dat) (Continued)

```
  10 111.4 117.2 119.6 119.9 117.9 111.2 103.9
  11 134.1 145.9 148.3 144.1 133.8 116.2  98.1
  12 134.1 145.9 148.3 144.1 133.8 116.2  98.1
  13 133.6 145.2 147.7 143.5 133.5 116.1  98.2
  14 133.6 145.2 147.7 143.5 133.5 116.1  98.2
  15 133.6 145.2 147.6 143.5 133.4 116.1  98.2
  16 111.9 117.8 120.3 120.5 118.3 111.3 103.7
  17 111.9 117.8 120.2 120.5 118.3 111.3 103.7
  18 111.9 117.8 120.2 120.5 118.3 111.3 103.7
  19 111.4 117.1 119.6 119.9 117.9 111.2 103.9
  20 111.4 117.1 119.6 119.9 117.9 111.2 103.9
  21 135.8 145.0 144.3 141.2 132.7 115.4  92.8
  22 135.9 145.1 144.4 141.3 132.8 115.6  92.8
  23 166.2 169.4 165.9 164.3 160.0 143.1 109.0
  24 166.3 169.5 166.0 164.4 160.1 143.2 109.1
  25 187.5 186.5 181.0 180.5 179.1 162.5 120.4
  26 195.0 193.5 188.7 187.4 186.5 170.6 125.1
  27 148.4 150.7 149.8 149.4 147.9 137.0 110.9
  28 148.4 150.7 149.8 149.3 147.9 137.0 110.9
  29 145.1 147.6 147.0 146.6 145.1 134.6 109.9
  30 145.1 147.6 147.0 146.6 145.1 134.6 109.9
  31 127.6 131.5 132.4 132.3 130.6 122.0 104.5
  32 127.6 131.5 132.4 132.3 130.6 122.0 104.5
  33 127.6 131.5 132.4 132.3 130.6 122.0 104.5
  34 127.6 131.5 132.4 132.3 130.6 122.0 104.5
  35 110.1 115.5 117.8 118.1 116.2 109.4  99.2
  36 110.1 115.5 117.8 118.1 116.2 109.4  99.2
  37 106.8 112.4 115.0 115.4 113.4 107.0  98.2
  38 106.8 112.4 115.0 115.3 113.4 107.0  98.2
  39 159.2 147.2 126.8 143.9 153.5 147.2 130.2
  40 159.3 147.3 127.0 144.0 153.6 147.3 130.2
  41 174.0 166.3 152.3 161.8 167.1 157.2 129.8
  42 174.1 166.4 152.4 161.8 167.2 157.2 129.8
  43 184.4 179.7 170.2 174.3 176.7 164.2 129.6
  44 187.2 180.7 170.1 175.4 179.5 169.1 135.0
  45 160.5 158.6 152.2 155.4 156.8 146.9 121.3
  46 160.4 158.5 152.1 155.3 156.6 146.8 121.2
  47 122.3 126.9 126.4 126.7 124.1 115.0 101.6
  48 122.1 126.7 126.3 126.6 123.9 114.9 101.4
  49 149.8 150.9 146.4 147.1 146.2 134.9 113.9
  50 151.7 152.6 148.0 148.7 147.8 136.3 114.4
  51 109.7 116.7 118.1 117.3 113.0 102.9  90.6
  52 104.2 111.0 112.9 112.1 108.0  98.6  86.5
  53 109.7 116.7 118.1 117.3 113.0 102.9  90.6

Maximum Structural Temperature for Period   1 = 174.10 Occurring
at Location  42
```

TABLE 4-12. SAMPLE PROBLEM OUTPUT DATA FILE (summary.dat) (Continued)

```
Maximum Structural Temperature for Period   2 = 169.52 Occurring
at Location  24
Maximum Structural Temperature for Period   3 = 165.98 Occurring
at Location  24
Maximum Structural Temperature for Period   4 = 164.41 Occurring
at Location  24
Maximum Structural Temperature for Period   5 = 167.20 Occurring
at Location  42
Maximum Structural Temperature for Period   6 = 157.23 Occurring
at Location  42
Maximum Structural Temperature for Period   7 = 130.19 Occurring
at Location  39

Maximum Structural Temperature Over All     7 Periods =174.10
Occurring at Location  42 at Period   1


 TEMPERATURES AT THE END OF TRANSIENT ANALYSIS

        TEMPERATURES IN DEGREES FAHRENHEIT
          1     2     3     4     5     6     7

   1 108.5 112.3 117.2 119.5 121.4 118.9 116.5
   2 109.3 113.3 118.1 120.3 121.8 118.9 116.0
   3 135.1 145.5 147.0 144.1 135.3 118.9 101.7
   4 135.9 146.4 147.9 144.8 135.7 118.9 101.2
   5 136.5 147.2 148.6 145.4 136.0 118.9 100.9
   6 112.1 117.9 120.3 120.6 118.4 111.4 104.4
   7 111.9 117.8 120.2 120.5 118.4 111.6 104.6
   8 111.8 117.6 120.1 120.5 118.5 111.8 104.9
   9 107.4 110.9 115.6 118.2 120.4 118.4 116.5
  10 107.3 110.7 115.5 118.1 120.4 118.6 116.9
  11 108.4 112.2 117.2 119.5 121.3 118.8 116.4
  12 109.2 113.2 118.1 120.2 121.6 118.7 115.9
  13 131.7 142.5 145.2 141.7 132.4 116.2  99.7
  14 132.4 143.4 146.0 142.4 132.7 116.1  99.2
  15 132.9 144.1 146.6 142.9 132.9 116.1  98.8
  16 111.9 117.8 120.3 120.5 118.3 111.3 104.3
  17 111.8 117.7 120.2 120.4 118.3 111.5 104.5
  18 111.7 117.5 120.0 120.4 118.4 111.7 104.9
  19 107.4 110.9 115.6 118.2 120.4 118.4 116.5
  20 107.3 110.7 115.5 118.1 120.4 118.6 116.9
  21 108.6 112.6 117.5 119.5 121.0 118.3 115.3
  22 109.5 113.4 118.2 120.2 121.5 118.7 115.3
  23 135.3 138.6 140.9 139.5 136.8 132.6 114.4
  24 136.4 139.7 141.8 140.4 137.6 133.3 114.5
  25 148.7 150.0 150.5 149.3 147.4 143.0 119.3
  26 153.3 154.1 154.9 153.5 152.3 147.9 122.5
```

TABLE 4-12. SAMPLE PROBLEM OUTPUT DATA FILE (summary.dat) (Continued)

```
  27 148.8 151.0 150.1 149.6 148.2 137.2 110.9
  28 147.8 150.1 149.3 148.8 147.4 136.6 110.8
  29 145.1 147.7 147.1 146.7 145.2 134.6 110.0
  30 145.1 147.6 147.0 146.6 145.1 134.6 110.0
  31 128.1 131.7 132.9 133.3 132.4 124.5 108.4
  32 128.1 131.7 132.9 133.3 132.4 124.5 108.4
  33 128.1 131.7 132.9 133.3 132.4 124.5 108.4
  34 128.1 131.7 132.9 133.3 132.4 124.5 108.4
  35 111.1 115.8 118.9 120.0 119.6 114.4 106.8
  36 111.0 115.6 118.8 120.0 119.6 114.5 107.0
  37 107.1 110.6 115.3 117.8 119.9 117.8 115.7
  38 107.0 110.5 115.2 117.7 119.9 118.0 116.0
  39 109.1 111.4 114.9 118.6 121.7 120.2 117.9
  40 110.0 112.2 115.5 119.2 122.3 120.8 118.1
  41 137.3 136.0 133.9 137.5 139.3 137.7 123.5
  42 138.3 136.9 134.7 138.2 140.0 138.3 123.7
  43 144.9 144.1 142.7 144.6 145.6 143.0 124.5
  44 147.5 145.2 142.7 145.7 148.0 146.6 128.2
  45 136.2 135.6 134.5 137.1 138.6 137.5 123.2
  46 135.1 134.6 133.8 136.4 137.9 136.8 122.9
  47 109.9 112.1 115.5 119.2 122.2 120.7 118.0
  48 109.0 111.4 114.9 118.6 121.7 120.2 117.8
  49 112.2 115.2 119.2 121.4 123.3 121.1 117.0
  50 114.3 117.3 121.0 123.0 124.7 122.3 117.2
  51 166.3 183.2 182.1 174.9 157.7 128.5  98.0
  52 155.1 170.7 170.4 163.9 148.2 121.6  93.1
  53 166.3 183.2 182.1 174.9 157.7 128.5  98.0

Maximum Structural Temperature for Period   1 = 148.77 Occurring
at Location  27
Maximum Structural Temperature for Period   2 = 151.00 Occurring
at Location  27
Maximum Structural Temperature for Period   3 = 150.07 Occurring
at Location  27
Maximum Structural Temperature for Period   4 = 149.62 Occurring
at Location  27
Maximum Structural Temperature for Period   5 = 148.17 Occurring
at Location  27
Maximum Structural Temperature for Period   6 = 138.33 Occurring
at Location  42
Maximum Structural Temperature for Period   7 = 123.67 Occurring
at Location  42

Maximum Structural Temperature Over All     7 Periods =151.00
Occurring at Location  27 at Period   2
```

The MOL temperature at the end of the steady-sate analysis was 174.1°F. The MOL temperature at the end of the transient analysis was 151.0°F. Thus, the final MOL temperature for this aircraft was 151.0°F.

TABLE 4-13. SAMPLE PROBLEM OUTPUT DATA FILE (transient.dat)

```
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
THERMOD:  A THERMAL PROGRAM FOR AIRCRAFTS
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$


 TRANSIENT TEMPERATURES FOR PERIOD:           1

 COOLING WHILE DOOR IS OPENED:

 time(sec)      1     2     3     4     .     .     .    51    52    53
    0.0000   138.1 138.1 137.5 137.5    .     .     .  109.7 104.2 109.7
    2.0000   138.1 138.1 137.5 137.5    .     .     .  109.7 104.2 109.7
    4.0000   138.1 138.1 137.6 137.5    .     .     .  109.7 104.2 109.7
    6.0000   138.1 138.1 137.6 137.5    .     .     .  109.7 104.2 109.7
    8.0000   138.1 138.1 137.6 137.5    .     .     .  109.7 104.2 109.7
   10.0000   138.1 138.1 137.6 137.5    .     .     .  109.7 104.2 109.7
       .        .     .     .     .     .     .     .     .     .     .
       .        .     .     .     .     .     .     .     .     .     .
       .        .     .     .     .     .     .     .     .     .     .
  386.0000   138.1 138.1 137.6 137.5    .     .     .  109.7 104.2 109.7
  388.0000   138.1 138.1 137.6 137.5    .     .     .  109.7 104.2 109.7
  390.0000   138.1 138.1 137.6 137.5    .     .     .  109.7 104.2 109.7

 COOLING DURING AIRCRAFT MANEUVERS:

 time(sec)      1     2     3     4     .     .     .    51    52    53
  392.0000   138.1 138.1 137.6 137.5    .     .     .  119.1 112.6 119.0
  394.0000   138.0 138.1 137.6 137.5    .     .     .  145.5 136.3 145.5
  396.0000   137.9 138.0 137.6 137.5    .     .     .  157.2 146.8 157.2
  398.0000   137.8 137.9 137.6 137.5    .     .     .  162.3 151.4 162.3
  400.0000   137.6 137.8 137.6 137.5    .     .     .  164.6 153.5 164.6
       .        .     .     .     .     .     .     .     .     .     .
       .        .     .     .     .     .     .     .     .     .     .
       .        .     .     .     .     .     .     .     .     .     .
  840.0000   108.5 109.3 135.2 135.9    .     .     .  166.3 155.1 166.3
  842.0000   108.5 109.3 135.1 135.9    .     .     .  166.3 155.1 166.3
  844.0000   108.5 109.3 135.1 135.9    .     .     .  166.3 155.1 166.3
  846.0000   108.5 109.3 135.1 135.9    .     .     .  166.3 155.1 166.3


 TRANSIENT TEMPERATURES FOR PERIOD:           2

 COOLING WHILE DOOR IS OPENED:

 time(sec)      1     2     3     4     .     .     .    51    52    53
       .        .     .     .     .     .     .     .     .     .     .
       .        .     .     .     .     .     .     .     .     .     .
       .        .     .     .     .     .     .     .     .     .     .

 COOLING DURING AIRCRAFT MANEUVERS:

 time(sec)      1     2     3     4     .     .     .    51    52    53
       .        .     .     .     .     .     .     .     .     .     .
       .        .     .     .     .     .     .     .     .     .     .
       .        .     .     .     .     .     .     .     .     .     .
```

TABLE 4-13. SAMPLE PROBLEM OUTPUT DATA FILE (transient.dat) (Continued)

```
TRANSIENT TEMPERATURES FOR PERIOD:           3

COOLING WHILE DOOR IS OPENED:

time(sec)      1     2     3     4     .     .     .   51    52    53
      .        .     .     .     .     .     .     .     .     .     .
      .        .     .     .     .     .     .     .     .     .     .
      .        .     .     .     .     .     .     .     .     .     .

COOLING DURING AIRCRAFT MANEUVERS:

time(sec)      1     2     3     4     .     .     .   51    52    53
      .        .     .     .     .     .     .     .     .     .     .
      .        .     .     .     .     .     .     .     .     .     .
      .        .     .     .     .     .     .     .     .     .     .

TRANSIENT TEMPERATURES FOR PERIOD:           4

COOLING WHILE DOOR IS OPENED:

time(sec)      1     2     3     4     .     .     .   51    52    53
   0.0000   146.9 146.9 146.3 146.3    .     .     .  117.3 112.1 117.3
   2.0000   146.9 146.9 146.3 146.3    .     .     .  117.3 112.1 117.3
   4.0000   146.9 146.9 146.3 146.3    .     .     .  117.3 112.1 117.3
   6.0000   146.9 146.9 146.3 146.3    .     .     .  117.3 112.1 117.3
   8.0000   146.9 146.9 146.3 146.3    .     .     .  117.3 112.1 117.3
  10.0000   146.9 146.9 146.3 146.3    .     .     .  117.3 112.1 117.3
      .        .     .     .     .     .     .     .     .     .     .
      .        .     .     .     .     .     .     .     .     .     .
      .        .     .     .     .     .     .     .     .     .     .

 336.0000   146.9 146.9 146.3 146.3    .     .     .  117.3 112.1 117.3
 338.0000   146.9 146.9 146.3 146.3    .     .     .  117.3 112.1 117.3
 340.0000   146.9 146.9 146.3 146.3    .     .     .  117.3 112.1 117.3
 342.0000   146.9 146.9 146.3 146.3    .     .     .  117.3 112.1 117.3
 344.0000   146.9 146.9 146.3 146.3    .     .     .  117.3 112.1 117.3

COOLING DURING AIRCRAFT MANEUVERS:

 time(sec)      1     2     3     4     .     .     .   51    52    53
 346.0000   146.9 146.9 146.3 146.3    .     .     .  143.5 135.7 143.5
 348.0000   146.8 146.8 146.3 146.3    .     .     .  161.1 151.4 161.1
 350.0000   146.6 146.7 146.3 146.3    .     .     .  168.8 158.4 168.8
 352.0000   146.5 146.6 146.3 146.3    .     .     .  172.2 161.5 172.2
 354.0000   146.4 146.5 146.3 146.3    .     .     .  173.7 162.8 173.7
      .        .     .     .     .     .     .     .     .     .     .
      .        .     .     .     .     .     .     .     .     .     .
      .        .     .     .     .     .     .     .     .     .     .
 790.0000   119.5 120.3 144.2 144.9 145.5 120.6 120.5 174.9 163.9 174.9
 792.0000   119.5 120.3 144.1 144.9 145.5 120.6 120.5 174.9 163.9 174.9
 794.0000   119.5 120.3 144.1 144.9 145.4 120.6 120.5 174.9 163.9 174.9
 796.0000   119.5 120.3 144.1 144.8 145.4 120.6 120.5 174.9 163.9 174.9
 798.0000   119.5 120.3 144.1 144.8 145.4 120.6 120.5 174.9 163.9 174.9
```

TABLE 4-13. SAMPLE PROBLEM OUTPUT DATA FILE (transient.dat) (Continued)

```
 TRANSIENT TEMPERATURES FOR PERIOD:           5

 COOLING WHILE DOOR IS OPENED:

 time(sec)      1     2     3     4     .     .     .   51    52    53
       .        .     .     .     .     .     .     .     .     .     .
       .        .     .     .     .     .     .     .     .     .     .
       .        .     .     .     .     .     .     .     .     .     .

 COOLING DURING AIRCRAFT MANEUVERS:

 time(sec)      1     2     3     4     .     .     .   51    52    53
       .        .     .     .     .     .     .     .     .     .     .
       .        .     .     .     .     .     .     .     .     .     .
       .        .     .     .     .     .     .     .     .     .     .


 TRANSIENT TEMPERATURES FOR PERIOD:           6

 COOLING WHILE DOOR IS OPENED:

 time(sec)      1     2     3     4     .     .     .   51    52    53
       .        .     .     .     .     .     .     .     .     .     .
       .        .     .     .     .     .     .     .     .     .     .
       .        .     .     .     .     .     .     .     .     .     .

 COOLING DURING AIRCRAFT MANEUVERS:

 time(sec)      1     2     3     4     .     .     .   51    52    53
       .        .     .     .     .     .     .     .     .     .     .
       .        .     .     .     .     .     .     .     .     .     .
       .        .     .     .     .     .     .     .     .     .     .


TRANSIENT TEMPERATURES FOR PERIOD:           7

 COOLING WHILE DOOR IS OPENED:

 time(sec)      1     2     3     4     .     .     .   51    52    53
       .        .     .     .     .     .     .     .     .     .     .
       .        .     .     .     .     .     .     .     .     .     .
       .        .     .     .     .     .     .     .     .     .     .

 COOLING DURING AIRCRAFT MANEUVERS:

 time(sec)      1     2     3     4     .     .     .   51    52    53
       .        .     .     .     .     .     .     .     .     .     .
       .        .     .     .     .     .     .     .     .     .     .
       .        .     .     .     .     .     .     .     .     .     .
```

Note: This file was truncated. Transient data was written for each time period for all 53 temperatures. Interior cooling took place when the door was opened. Once cabin ambient temperature of 140°F was reached, the door was closed, and the aircraft was subjected to further cooling while maneuvering according to the input flight profile.

5. SUMMARY.

A thermal analysis was performed on a hypothetical aircraft. The wing was painted with a paint color containing the following thermal properties: absorptivity = 0.45 and emissivity = 0.80. The fuselage was painted as follows: (1) sides: absorptivity = 0.65 and emissivity = 0.90, (2) top: absorptivity = 0.50 and emissivity = 0.85, and (3) bottom: absorptivity = 0.60 and emissivity = 0.85.

Table 4-12 shows all 53 steady-state temperatures for different times of the day. For example, at 1100 hours (time period 1), temperature T1 is 138.1°F, and at 1300 hours (time period 2), it is 149.1°F. The hottest structural temperature is T42 (174.1°F), occurring at 1100 hours (time period 1). If only steady-state results were used in the Federal Aviation Administration certification, the maximum operating limit (MOL) temperature for this aircraft should at least be 175°F. However, THERMOD was modeled to consider transient analysis, and as a result, the benefits associated with this cooling phase should be considered.

Table 4-12 also shows the results of the transient analysis. The transient analysis was performed using the flight profile of figure 1-4 and the steady-state temperatures of table 4-12 as the starting base. In general, the transient temperatures of table 4-12 are lower than steady-state temperatures. The hottest transient structural temperature is T27 (151.0°F), occurring at 1200 hours (time period 2). This temperature is practically the same as its steady-state counterpart (T27 = 150.7°F). This is due to the fact that T27 was located underneath the 5-inch-thick insulatory material (material B, representing the seats, carpet, and other related items), which acts as an effective barrier to thermal changes above it. Note that in contrast, surfaces that are exposed to convective forces (such as those surfaces represented by T1, T11, T25, T26, T39, T43, T44, and T49) undergo rapid cooling.

A few important observations from tables 4-12 and 4-13 should be noted.

1. A total of 53 temperatures were simulated, out of which 44 temperatures were considered structural and 9 were nonstructural. The structural temperatures were T1-T24, T27-T38, T39-T42, and T45-T48. The nonstructural temperatures were

    a. insulatory material temperatures (T25, T26, T43, and T44);
    b. Plexiglas temperatures (T49 and T50); and
    c. tarmac temperatures (T51, T52, and T53).

2. Transient temperature results were simulated based on the flight profile information in figure 1-4.

3. To obtain conservative results, THERMOD assumed the ground to possess thermal characteristics similar to that of the tarmac throughout the entire flight profile, even while the plane was in the air.

4. In some cases, the transient temperatures of table 4-12 are higher than the corresponding steady-state temperatures, even though the transient phase is thought to have a cooling effect on the plane. Generally, during the transient phase, the aircraft is expected to cool

down due to convective heat transfer from the air flowing over (it until equilibrium is achieved).

For the purpose of computing the transient phase temperatures, THERMOD does not take airplane altitude into account, but instead, compensates by changing the air flow temperature over the airplane to equal the ambient temperatures prescribed for that flight profile. The convective heat transfer coefficients vary according to the time and speed set for each flight segment by the user. The user also sets the ambient conditions when they specify the "time of the day", "sun inclination angle", "relative wind speed" and "solar radiation" etc. This means, that the airplane would in fact never leave the ground, but its flight profile such as shown in figure 1-4 would be simulated by changing the ambient conditions and the convective coefficients for each specified flight segment.

Thus, in some cases, when the user has set the time of the day as early morning or late evenings, and depending on the user's other 'weather condition' inputs, it's sometimes possible that the airplane's exterior is cooler (due to relatively cooler steady state temperatures) than the relatively warmer surroundings (which are warmer due to the user specified inputs of solar radiation, sun angle etc.). And thus, for calculating transient phase temperatures, when THERMOD moves this relatively warmer air over the airplane, it raises the temperature on the airplane's exterior.

5. The tarmac temperatures (T51, T52, and T53) show significant increase during the transient phase. In the steady-state phase, these temperatures were lower because they represent regions that were directly under the wing, which provided some measure of shade from direct sunlight. However, because the plane is in motion, as in the transient phase, these temperatures were essentially the exposed tarmac temperatures.

6. For a given paint scheme, THERMOD simulated the temperatures at each time period. The 44 structural temperatures in the transient phase were compared with each other over seven time periods (1100, 1200, 1300, 1400, 1500, 1600, and 1700 hours), and the maximum structural temperature obtained from this comparison was used as the MOL temperature. This MOL temperature may be located at the surface (depending on how dark the paint is), inside the cabin, within the floor space, or elsewhere. It is the maximum structural temperature experienced anywhere in the aircraft.

From this project, it was observed that this hypothetical aircraft with paint absorptivity and emissivity values as noted above had a MOL temperature of 174.1°F at the end of the steady-sate analysis. The MOL temperature at the end of the transient analysis was 151.0°F. Thus, the transient analysis reduced the maximum soaked temperature by 23.1°F. The final MOL temperature for this aircraft was 151.0°F. This temperature occurred on the floor surface underneath the insulatory material (material B of figure 1-1) covering the floor.

6. REFERENCES.

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APPENDIX A—THERMOD CODE

THERMOD is a FORTRAN-based program developed using the DIGITAL VISUAL FORTRAN 6.0 compiler, an IBM-compatible Pentium II PC, and Windows 98. THERMOD is noninteractive and runs on either the DOS or Windows platform. A computer with 64 MB or more of RAM and with at least 500 MB of hard disk space is recommended. A typical analysis may take from as little as 30 seconds to a few hours, depending on the whether the explicit forward finite difference method (EFFDM) or the implicit backward finite difference method (IBFDM), respectively, is selected. It also depends on the time step used in the transient analysis.

THERMOD requires one input file, input.dat. Once invoked (by double-clicking THERMOD), THERMOD automatically reads in the input.dat file and reads out two output files, which are summary.dat and transient.dat. The summary.dat file summarizes the temperature results and prints the maximum operating temperatures for steady state and transient state. The transient.dat file prints the transient temperatures with respect to time. Details on these files and instructions on how to use THERMOD can be found in THERMOD User's Manual [A-1].

THERMOD simulates the service temperatures of an aircraft by setting up and solving a set of 67 equations in a nonlinear system of equations to produce 53 steady-state temperatures and 14 steady-state radiosity. The solution is performed using the Newton-Raphson iteration technique [A-2]. This is followed by a transient analysis, based on either the EFFDM or the IBFDM. Figure A-1 shows a flowchart of THERMOD. The following paragraphs give a brief description of THERMOD, and section A.1 lists the definitions of the routines. Section A.2 presents the THERMOD code in its entity.

MAIN is the main controlling program that calls subroutine READIN. READIN reads in the input file containing the relevant information to run THERMOD. MAIN next calls the SOLUTION subroutine, which controls both the steady-state and transient analyses. SOLUTION performs this function by calling 11 subroutines as shown in figure A-1. THERMOD was programmed to simulate the temperatures of an aircraft for a particular paint scheme chosen. The subroutines VIEWFACT, HCONVECT, QREFCAB, TARMMOD, INFRQSKY, and SBFILLET are called by SOLUTION only once. SOLUTION also calls subroutines QREFFW, QREFTW, NEWTRAPH, and TRANSIEN.

The steady-state analysis phase is controlled by the NEWTRAPH subroutine, which calls THERMODL, LUDCMP, and LUBKSB subroutines. The THERMODL subroutine forms the 67 equations needed in THERMODL. This is the heart of the steady-state analysis. THERMODL also calls JACOBIAN to formulate the Jacobians needed in the Newton-Raphson Iteration solution procedure [A-2]. Having formulated the equations using the THERMODL and JACOBIAN subroutines, NEWTRAPH next calls the LUDCMP subroutine, which decomposes the Jacobian matrix. This is followed by another call by NEWTRAPH to LUBKSB where backsubstitution is performed to find the solution for the unknowns.

The transient analysis phase is controlled either by the TRNSIEN1 or TRNSIEN2 subroutines, where the EFFDM method is controlled by TRNSIEN1 and the IBFDM method is controlled by TRNSIEN2. TRNSIEN1 calls LHSWNG1, RHSWNG1, FUSLGR1, FUSLGRF1, TARMAC1,

UPRADIO, and HCOOLCON subroutines. These subroutines together with LUDCMP and LUBKSB complete the EFFDM transient analysis. The inclusion of the UPRADIO subroutine, which updates the radiosity for each time increment, is necessary because without it, numerical overflow or other numerical difficulties will result. TRNSIEN2 calls LHSWNG2, RHSWNG2, FUSLGR2, FUSLGRF2, TARMAC2, UPRADIO, and HCOOLCON and NEWRAPH2 subroutines. The UPDRADIO calls LUDCMP and LUBKSB to update the radiosity. The NEWRAPH2 subroutine calls LHSWNG2, RHSWNG2, FUSLGR2, FUSLGRF2, TARMAC2, LUDCMP, and LUBKSB to complete the IBFDM finite difference analysis.

A.1 DEFINITION OF SUBROUTINES.

MAIN	The main controlling program.
READIN	Reads in the input data.
SOLUTION	Controls both the steady-state and transient analyses.
VIEWFACT	The controlling routine for determining view factors for aligned parallel rectangles and for perpendicular rectangles with a common edge.
VIEWFC	Determines the view factors for aligned parallel rectangles, and is the controlling routine for determining the view factors for perpendicular rectangles with a common edge.
VFACFIJ	Determines the view factors for perpendicular rectangles with a common edge.
HCONVECT	Determines the steady-state convective coefficients for the fuselage, wing, and tarmac.
QREFCAB	Determines the intercepted solar radiation in the cabin, and is the controlling outline for determining the diffuse solar radiation that is absorbed in the cabin by treating the cabin as a partial cavity.
DIFFSOLA	Determines the diffuse solar radiation that is absorbed in a six-sided rectangular enclosure by treating it as a partial cavity in which multiple reflections and absorptions are considered.
TARMMODL	Determines the infrared emission from the tarmac as well as the tarmac temperature.
INFRQSKY	Determines the infrared emission from the sky.
SBFILLET	Determines the view factors of fillets by assuming them to be a quadrant.
QREFFW	Determines the intercepted solar radiation at the fuselage-wing junction, and is the controlling routine for determining the diffuse solar radiation that is absorbed at this junction by treating the junction as a partial cavity.

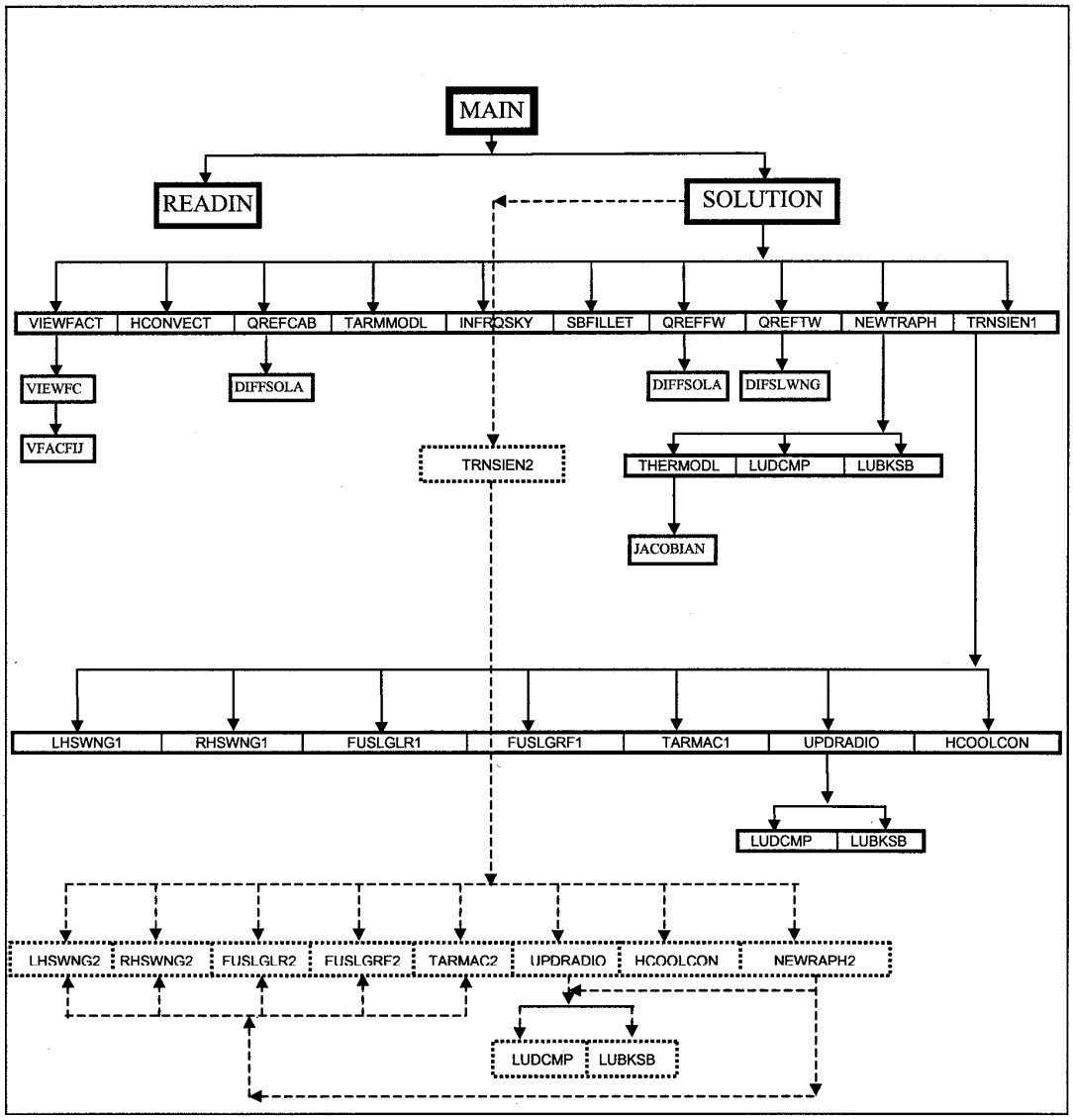
QREFTW	Determines the intercepted solar radiation at the tarmac-wing bottom region, and is the controlling routine for determining the diffuse solar radiation that is absorbed in this region by treating the region as a partial cavity.
DIFSLWNG	Determines the diffuse solar radiation that is absorbed at the tarmac-wing bottom region by representing the region as a six-sided rectangular enclosure and by treating it as a partial cavity in which multiple reflections and absorptions are considered. The region is divided into three smaller rectangular boxes, representing the LHS, RHS, and the MIDDLE of the wing.
NEWTRAPH	The controlling routine for the steady-state analysis based on the Newton-Raphson iteration technique.
THERMODL	Formulates the 67 heat transfer equations.
LUDCMP	Decomposes a matrix by the LU decomposition technique.
LUBKSB	Determines the solution of the unknown by backward substitution.
JACOBIAN	Determines the Jacobian for the 67 equations as a requirement of the Newton-Raphson iteration technique.
TRNSIEN1	The controlling routine for the EFFDM transient analysis.
LHSWNG1	Performs EFFDM transient analysis of the left wing (the wing exposed to the solar radiation).
RHSWNG1	Performs EFFDM transient analysis of the right wing (the wing that is under the shade of the fuselage).
FUSLGLR1	Performs EFFDM transient analysis of the fuselage from left to right.
FUSLGRF1	Performs EFFDM transient analysis of the fuselage from top to bottom (including the Plexiglas cover).
TARMAC1	Performs EFFDM transient analysis of the tarmac.
UPRADIO	Updates radiosity (all 14) at each time increment of the transient analysis.
HCOOLCON	Determines the convective coefficient at each time increment for the fuselage surface and the wing surface based on a given flight profile.
TRNSIEN2	The controlling routine for the IBFDM transient analysis.
LHSWNG2	Performs IBFDM transient analysis of the left wing (the wing exposed to the solar radiation).
RHSWNG2	Performs IBFDM transient analysis of the right wing (the wing that is under the shade of the fuselage).

FUSLGLR2 Performs IBFDM transient analysis of the fuselage from left to right.

FUSLGRF2 Performs IBFDM transient analysis of the fuselage from top to bottom (including the Plexiglas cover).

TARMAC2 Performs IBFDM transient analysis of the tarmac.

NEWRAPH2 The controlling subroutine for the nonlinear solution of the IBFDM transient problem. The nonlinear solution is provided by the Newton-Raphson iteration technique.



Solid lines represent the original THERMOD program. The dotted lines represent additions to the original THERMOD program.

FIGURE A-1. FLOWCHART OF THE THERMOD MODEL

A-2. THERMOD PROGRAM CODE.

```
program main
c This is the main controlling program.
c This program determines the service temperatures of an aircraft.
c There are 67 equations with 67 unknowns to be solved in a non-linear
c system of equations.
c
c Program developed by Nathan Govindarajoo, PhD., PE., Consulting Engineer.
c Program belongs to FAA and AGATE.
c
      write(6,*)'$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$'
      write(6,*)'WELCOME TO THERMOD: A THERMAL PROGRAM FOR AIRCRAFTS'
      write(6,*)'$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$'
           write(6,*)' '
           write(6,*)'INPUT DATA BEING READ'
      call readin
      write(6,*)'INPUT DATA SUCCESSFULLY READ'
           write(6,*)' '
           write(6,*)'SOLUTION IN PROGRESS'
      call solution
      write(6,*)' '
           write(6,*)'THERMOD SUCCESSFULLY COMPLETED'
      end
c
      subroutine readin
c purpose: reads in the data
c calls: none
c called from: main
      common/c1/n,ntrial,tolt,tolfn
      common/c2/t(200),fn(200),jacob(200,200)
      common/c3/th(100),k(100)
      common/c4/widthwng,lengtwng,hwng,locwng,lplane,lfuselg,hfuselg,
     &          wfuselg
      common/c5/trnsm,absorbta,emista,tarmd,densta,conducta,shcta
      common/c6/absorbf,emisf,absorbw,emisw,absorbfl,emisfl,absorbfi,
     &emisfi,absorbpg,emispg,absorftp,emisrftp,absorfbt,emisrfbt,
     &absorbfb,emisfb
      common/c7/nperiods,envtdata(100,20)
      common/c8/icode,nconstrn,idtemp(100),tempcons(100)
      common/c9/scatffl,scatffi,scatfw,scatff
      common/c10/aircondc,thdiffus,visckine,prandtl
      common/c11/icodef11,percent,nparts
      common/c12/a1,a2,a3,a4,a5,a6(100),a7(100)
      common/c13/nintervl,vel(100),timeintv(100)
      common/c14/thicknes(100),density(100),conductv(100),sheatcap(100)
      common/c15/ibegabsf,iendabsf,ibegemsf,iendemsf,ibegabsw,iendabsw,
     &          ibegemsw,iendemsw
      common/c16/ifindiff,deltime,amcabtmp,intvprnt
      common/store1/absorbff,emisff,absorbww,emisww,absrftpp,emirftpp,
     &          absrbfbb,emisfbb
```

```
      real k,lengtwng,locwng,lplane,lfuselg
      parameter(small=0.00001,smallth=0.0001,glassk=1.0)
      open(unit=8,file='input.dat',status='old')
c
c Variables:
c absorbf=absorbtivity of exterior fuselage side
c emisf=emissivity of exterior fuselage side
c absorbfl=absorbtivity of floor of cabin (fuselage interior)
c emisfl=emissivity of floor of cabin (fuselage interior)
c absorbfi=absorbtivity of side of cabin (fuselage interior)
c emisfi=emissivity of side of cabin (fuselage interior)
c absorbpg=absorbtivity of plexiglass
c emispg=emissivity of plexiglass
c absorftp=absorbtivity of the top of roof top of fuselage exterior
c emisrftp=emissivity of the top of roof top of fuselage exterior
c absorfbt=absorbtivity of the bottom of roof top in fuselage interior
c emisrfbt=emissivity of the bottom of roof top in fuselage interior
c absorbfb=absorptivity of the bottom of fuselage exterior (ie above tarmac)
c emisfb=emissivity of the bottom of fuselage exterior (ie above tarmac)
c n=number of equations=67
c ifindiff=inidicator for the type of finite difference method in transient analysis:
c         =1 means explicit finite difference method
c         =2 means implicit finite difference method
c ntrial=maximum number of iterations allowed in the non-linear solution
c tolt=temperature tolerance in the solution
c tolfn=function tolerance in the solution
c t()=temperature (deg F or Rankine)
c fn()=equations/or functions
c jacob(,)=Jacobian
c th()=element thickness (ft)
c k()=element conductivity ((BTU/hr/ft/deg F)
c widthwng=wing width (ft)
c lengtwng=total wing length (tip-to-tip) (ft)
c hwng=wing height from ground (ft)
c locwng=leading edge wing location from the fuselage front (ft)
c lplane=entire plane length (ft)
c lfuselg=fuselage length (ft)
c hfuselg=height of fuselage (ft)
c wfuselg=width of fuselage (ft)
c trnsm=transmissivity of plexiglass
c absorbta=tarmac absorbtivity
c emista=tarmac emissivity
c tarmd=tarmac depth (overall) (ft)
c densta=tarmac density (overall) (lb/ft^3)
c conducta=tarmac conductivity (overall) (BTU/hr/ft/deg F)
c shcta=tarmac specific heat capacity (overall) (BTU/lbm/deg F)
c nperiods=number of time intervals (say from the morning till the evening)
c envtdata(,1)=sun's incident angle (degrees)
c envtdata(,2)=ambient temperature (Rankine)
c envtdata(,3)=effective sky temperature (Rankine)
c envtdata(,4)=wind speed (ft/s)
```

```
c envtdata(,5)=total (both direct and diffused) solar radiation (BTU/hr/sq.ft)
c envtdata(,6)=area (sq. ft) of plexiglass perpendicular to the sun, & seen
c              by the sun
c envtdata(,7)=area (sq. ft) of plexiglass horizontal to the sun, & seen
c              by the sun
c envtdata(,8)=fraction of sun that gets into the fuselage (in terms of
c               the projected area)
c icode=1, means, only one analysis is done knowing the paint scheme
c icode=2, means, analysis is done for all paint schemes, satisfying
c          some temperature requirements
c nconstrn=number of temperatures that must be satisfied above
c idtemp()=which temperature
c tempcons()=the value of the temperature requirement to be satisfied
c scatffl=fraction of the light reflected from the floor
c           that is diffused
c scatffi=fraction of the light reflected from the interior fuselage side
c           that is diffused
c scatfw=fraction of the light reflected from the wing that is diffused
c scatff=fraction of the light reflected from the exterior fuselage side
c           that is diffused
c aircondc=conductivity of air (BTU/hr/ft/deg F)
c thdiffus=air thermal diffusivity (ft^2/sec)
c visckine=air kinematic viscosity (ft^2/sec)
c prandtl=Prandtl number
c icodef11=1: the fillet is completely painted with paint that is the same as
c            that used on the wing
c icodef11=2: the fillet is completely painted with paint that is the same as
c            that used on the fuselage
c icodef11=3: the fuselage/wing paint boundary falls on the fillet; need
c            to assign the percentage of the fillet occupied by the wing paint
c percent=percentage when icodef11=3
c nparts=determines absorptivity and emissivity increments (1/nparts)
c a1=total area (sq. ft) of the plexiglass
c a2=total area (sq. ft) of the fuselage top half
c a3=a1/(a1+a2)*lfuselg*wfuselg
c a4=a2/(a1+a2)*lfuselg*wfuselg
c a5()=area (sq. ft) of plexiglass that intercepts diffuse reflected solar
c    rays from the tarmac
c a6()=same as envtdata(,6)
c a7()=same as envtdata(,7)
c nintervl=number of intervals in the flight profile used in cooling phase
c vel()=speed of aircraft during cooling phase (mph)
c timeintv()=time interval during each portion of the flight profile (sec)
c thicknes()=element thickness (in)
c density()=element density(lb/ft^3)
c conductv()=element thermal conductivity (BTU/hr/ft/deg F)
c sheatcap()=element specific heat capacity (BTU/lbm/deg F)
c ibegabsf=fuselage absorbtivity pointer on the beginning location of
c           the paint matrix
c iendabsf=fuselage absorbtivity pointer on the ending location of
c           the paint matrix
```

```
c ibegemsf=fuselage emissivity pointer on the beginning location of
c           the paint matrix
c iendemsf=fuselage emissivity pointer on the ending location of
c           the paint matrix
c ibegabsw=wing absorbtivity pointer on the beginning location of
c           the paint matrix
c iendabsw=wing absorbtivity pointer on the ending location of
c           the paint matrix
c ibegemsw=wing emissivity pointer on the beginning location of
c           the paint matrix
c iendemsw=wing emissivity pointer on the ending location of
c           the paint matrix
c deltime=time increment in the transient phase (sec)
c amcabtmp=ambient cabin temperature that is tolerable before egressing
c           and taxing (deg F)
c intvprnt=print interval in the transient phase
c
      read(8,*)visckine,prandtl
      do 10 i=1,28
c j is number of the element: it is just a dummy; not used anywhere
          read(8,*)j,thicknes(i),density(i),conductv(i),sheatcap(i)
 10   thicknes(i)=thicknes(i)/12.
      read(8,*)widthwng,lengtwng,hwng,locwng,lplane,lfuselg,hfuselg,
     &     wfuselg,a1,a2,a5
      read(8,*)trnsm,absorbta,emista,tarmd,densta,conducta,shcta
      read(8,*)absorbfl,emisfl,absorbfi,emisfi,absorfbt,emisrfbt,
     &          absorbpg,emispg
      if(absorbfl.eq.1.0)absorbfl=1.-small
      if(absorbfl.eq.0.0)absorbfl=small
      if(emisfl.eq.1.0)emisfl=1.-small
      if(emisfl.eq.0.0)emisfl=small
      if(absorbfi.eq.1.0)absorbfi=1.-small
      if(absorbfi.eq.0.0)absorbfi=small
      if(emisfi.eq.1.0)emisfi=1.-small
      if(emisfi.eq.0.0)emisfi=small
      if(absorfbt.eq.1.0)absorfbt=1.-small
      if(absorfbt.eq.0.0)absorfbt=small
      if(emisrfbt.eq.1.0)emisrfbt=1.-small
      if(emisrfbt.eq.0.0)emisrfbt=small
      if(absorbpg.eq.1.0)absorbpg=1.-small
      if(absorbpg.eq.0.0)absorbpg=small
      if(emispg.eq.1.0)emispg=1.-small
      if(emispg.eq.0.0)emispg=small
      read(8,*)icodef11,percent
      read(8,*)scatffl,scatffi,scatfw,scatff
c     read(8,*)icode
          icode=1
      if(icode.eq.1)then
          read(8,*)absorbf,emisf,absorbw,emisw,absorftp,emisrftp,
     &               absorbfb,emisfb
          if(absorbf.eq.1.0)absorbf=1.-small
```

```
          if(absorbf.eq.0.0)absorbf=small
          if(emisf.eq.1.0)emisf=1.-small
          if(emisf.eq.0.0)emisf=small
          if(absorbw.eq.1.0)absorbw=1.-small
          if(absorbw.eq.0.0)absorbw=small
          if(emisw.eq.1.0)emisw=1.-small
          if(emisw.eq.0.0)emisw=small
          if(absorftp.eq.1.0)absorftp=1.-small
          if(absorftp.eq.0.0)absorftp=small
          if(emisrftp.eq.1.0)emisrftp=1.-small
          if(emisrftp.eq.0.0)emisrftp=small
          if(absorbfb.eq.1.0)absorbfb=1.-small
          if(absorbfb.eq.0.0)absorbfb=small
          if(emisfb.eq.1.0)emisfb=1.-small
          if(emisfb.eq.0.0)emisfb=small
      elseif(icode.eq.2)then
          read(8,*)nparts
          read(8,*)ibegabsf,iendabsf
          read(8,*)ibegemsf,iendemsf
          read(8,*)ibegabsw,iendabsw
          read(8,*)ibegemsw,iendemsw
          read(8,*)nconstrn
          read(8,*)(idtemp(i),tempcons(i),i=1,nconstrn)
      endif
      read(8,*)nintervl
      read(8,*)(vel(i),i=1,nintervl+1)
      read(8,*)(timeintv(i),i=1,nintervl)
      read(8,*)nperiods
      do 20 i=1,nperiods
 20   read(8,*)(envtdata(i,j),j=1,8)
      n=67
      read(8,*)ifindiff,deltime,amcabtmp,intvprnt
      amcabtmp=amcabtmp+459.67
      read(8,*)ntrial,tolt,tolfn
c initial trial for the aircraft temperatures and radiosities
      read(8,*)(t(i),i=1,n)
c because some of these properties will be destroyed depending on
c icode, they will be stored for later retrieval
      absorbff=absorbf
      emisff=emisf
      absorbww=absorbw
      emisww=emisw
      absrftpp=absorftp
      emirftpp=emisrftp
      absrbfbb=absorbfb
      emisfbb=emisfb
c
c reference some of the values as follows:
c
c air conductivity & thermal diffusivity within the cabin
c conductv(14) same as conductv(19)
```

```
      aircondc=conductv(19)
      thdiffus=conductv(19)/(density(19)*sheatcap(19))*(1./3600)
c bec. the model was developed piece-meal, need to reorder things
c as follows (for internal representation):
c first thickness:
     th(1)=thicknes(1)
     th(2)=thicknes(2)
     th(3)=thicknes(3)
     th(4)=thicknes(4)
     th(29)=thicknes(5)
     th(30)=thicknes(6)
     th(5)=thicknes(7)
     th(6)=thicknes(8)
     th(7)=thicknes(9)
     th(8)=thicknes(10)
     th(9)=thicknes(11)
     th(10)=thicknes(12)
     th(23)=thicknes(13)
     th(11)=thicknes(14)
     th(27)=thicknes(15)
     th(26)=thicknes(16)
     th(25)=thicknes(17)
     th(28)=thicknes(18)
     th(24)=thicknes(19)
     th(21)=thicknes(20)
     th(20)=thicknes(21)
     th(19)=thicknes(22)
     th(18)=thicknes(23)
     th(31)=thicknes(24)
     th(14)=thicknes(25)
     th(13)=thicknes(26)
     th(12)=thicknes(27)
     th(22)=thicknes(28)
c spar inside the cabin is assumed not to be in direct contact with the
c floor or belly-pan.  its temperature is taken to be the average of the
c floor bottom and top of belly-pan.  because of this, and the fact that
c floor bottom temp. is usually higher than the belly-pan top, no bulk
c or turbulent air motion exists.  also radiation effects
c will be assumed to be negligible; therefore, temperatures:
c t(31), t(32), t(33) and t(32) will all be assumed to be the same.
c ie equal to the average of the floor bottom and top of belly-pan.
c therefore the floor space (space between the floor bottom and belly-pan
c top is assumed=th(31), and all others (th(17); th(16); th(32); and
c th(15) is assumed very small;= smallth. numerically ok.
     th(17)=smallth
     th(16)=smallth
     th(32)=smallth
     th(15)=smallth
c now conductivity:
     k(1)=conductv(1)
     k(2)=conductv(2)
```

```
      k(3)=conductv(3)
      k(4)=conductv(4)
      k(29)=conductv(5)
      k(30)=conductv(6)
      k(5)=conductv(7)
      k(6)=conductv(8)
      k(7)=conductv(9)
      k(8)=conductv(10)
      k(9)=conductv(11)
      k(10)=conductv(12)
      k(23)=conductv(13)
      k(11)=conductv(14)
      k(27)=conductv(15)
      k(26)=conductv(16)
      k(25)=conductv(17)
      k(28)=conductv(18)
      k(24)=conductv(19)
      k(21)=conductv(20)
      k(20)=conductv(21)
      k(19)=conductv(22)
      k(18)=conductv(23)
      k(31)=conductv(24)
      k(14)=conductv(25)
      k(13)=conductv(26)
      k(12)=conductv(27)
      k(22)=conductv(28)
c because of the statements made above, k(17); k(16); k(32) and
c k(15) are taken as somewhat higher than glass (1.0); too high, say 1500
c will cause numerical overflow during the solution process:
c this and the above thicknesses (smallth) will make k()/th() very large:
c thereby making the resistance th()/k()        negligible, which is what we want.
      k(17)=glassk
      k(16)=glassk
      k(32)=glassk
      k(15)=glassk
      close(8)
      return
      end
c
      subroutine solution
c purpose: controls the solution of the problem
c calls: viewfact,hconvect,qrefcab,tarmmodl,infrqsky,sbfillet,qreffw,
c          qreftw,newtraph,transien,
c called from: main
      common/c1/n,ntrial,tolt,tolfn
      common/c2/t(200),fn(200),jacob(200,200)
      common/c4/widthwng,lengtwng,hwng,locwng,lplane,lfuselg,hfuselg,
     &          wfuselg
      common/c5/trnsm,absorbta,emista,tarmd,densta,conducta,shcta
      common/c6/absorbf,emisf,absorbw,emisw,absorbfl,emisfl,absorbfi,
     &emisfi,absorbpg,emispg,absorftp,emisrftp,absorfbt,emisrfbt,
```

```
     &absorbfb,emisfb
      common/c7/nperiods,envtdata(100,20)
      common/c8/icode,nconstrn,idtemp(100),tempcons(100)
      common/c11/icodef11,percent,nparts
      common/c12/a1,a2,a3,a4,a5,a6(100),a7(100)
      common/c15/ibegabsf,iendabsf,ibegemsf,iendemsf,ibegabsw,iendabsw,
     &                ibegemsw,iendemsw
      common/c16/ifindiff,deltime,amcabtmp,intvprnt
      common/convect/hf(100),hw(100),ht(100)
      common/tarmacqt/qqtarm(100),tttarm(100)
      common/qskyinfr/qqsky(100)
      common/fillet/f11w,f11f
      common/result/temp(200),temptrn(200)
      dimension tinitial(100)
      dimension tempall(100,100),itemp1(2,100),tempall1(100),
     &location(100),tempp(100),tempp1(100)
           dimension itemp1tr(2,100),temptr(100,100),temptr1(100),
     &locattr(100)
      character*1 indicat(150,150)/22500*'N'/
      character*1 indicat1(150,150)/22500*'N'/
      parameter(small=0.00001)
      parameter(tarmleng=100.0)
      real lfuselg,lplane
      open(unit=9,file='summary.dat',status='unknown')
      open(unit=10,file='transient.dat',status='unknown')
c     open(unit=12,file='outconv',status='unknown')
c     open(unit=13,file='odiffsol',status='unknown')
c      open(unit=14,file='out2.dat',status='unknown')
c      open(unit=15,file='out3.dat',status='unknown')
c     open(unit=16,file='transin3.out',status='unknown')
c     open(unit=17,file='transin4.out',status='unknown')
c Variables:
c hf=fuselage convective coefficient
c hw=wing convective coefficient
c ht=tarmac convective coefficient
c qqtarm=tarmac emission
c tttarm=tarmac temperature
c qqsky=sky emission
c f11w=fillet view factor (for wing)
c f11f=fillet view factor (for fuselage)
c tinitial=initial guessed temperatures
c indicat=indicator for the paint matrix
c tarmleng=tarmac length for finding hw
c
c store the initial guessed temperatures
c
      do 80 i=1,n
 80   tinitial(i)=t(i)
c
c store the various areas relating the fuselage roof and
c the plexiglass:
```

```
c
      a3=a1/(a1+a2)*lfuselg*wfuselg
      a4=a2/(a1+a2)*lfuselg*wfuselg
      do 85 j=1,nperiods
           a6(j)=envtdata(j,6)
 85        a7(j)=envtdata(j,7)
c
c find view factors
      call viewfact
c find convection coefficients (hf) for the fuselage (4 sides) &
c for the left wing (hw) (top & bottom) and the
c right wing (hw) (top & bottom).
c hf for all four fuselage sides are the same
c hw for all the wing sides are the same
c
c find hf for the fuselage:
      call hconvect(lplane,hf)
c find hw for the wings
      call hconvect(widthwng,hw)
c now find ht for the tarmac
      call hconvect(tarmleng,ht)
c find reflected solar rays (qrefl) within the cabin
      call qrefcab
c find tarmac temperature and qtarm (tarmac radiation)
      call tarmmodl(absorbta,emista,qqtarm,tttarm)
c find the infrared sky radiation
      call infrqsky(qqsky)
c find the modification factors for absorbtivity & emissivity due to fillets
      call sbfillet(icodef11,percent,f11w,f11f)
      if(icode.eq.2)del=1./nparts
c
c for the option chosen determine the temperatures; or paint scheme for
c a given set of temperatures chosen
c
c icode=1: just one run with temperature output for a given
c set of paint scheme:
c
      write(10,*)'$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$'
      write(10,*)'THERMOD:  A THERMAL PROGRAM FOR AIRCRAFTS'
           write(10,*)'$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$'
           if(icode.eq.1)then
             itotitr=0
             absinfrf=emisf*(1./(1.-f11f*(1.-emisf)))
             eemisf=emisf*(1.-f11f)/(1.-f11f*(1.-emisf))
             rff=absinfrf/eemisf
             call qreffw(absorbf,absorbw)
             call qreftw(absorbw)
             absinfrw=emisw*(1./(1.-f11w*(1.-emisw)))
             eemisw=emisw*(1.-f11w)/(1.-f11w*(1.-emisw))
             rfw=absinfrw/eemisw
c                    write(6,*)'absorbf,emisf,absorbw,emisw'
```

```
c                write(6,*)absorbf,emisf,absorbw,emisw
            do 10 i=1,nperiods
            write(6,*)' '
                write(6,*)'STEADY STATE ANALYSIS BEGUN FOR PERIOD',i
                itotitr=itotitr+1
                do 90 itemp=1,n
 90             t(itemp)=tinitial(itemp)
                theta=envtdata(i,1)
                ta=envtdata(i,2)
                qsky=qqsky(i)
                qdir=envtdata(i,5)
                hhf=hf(i)
                hhw=hw(i)
                hht=ht(i)
                qtarm=qqtarm(i)
                ttarm=tttarm(i)
c find airplane temperature
                call newtraph(i,kkk,theta,ta,qsky,hhf,hhw,hht,qdir,
     &          qtarm,ttarm,absorbf,emisf,absorbw,emisw,
     &          eemisf,eemisw,rff,rfw)
 95             format(1x,i1,1x,i4,70(1x,f4.0))
        write(6,*)'STEADY STATE ANALYSIS COMPLETED FOR PERIOD',i
c               write(6,95)i,kkk,(temp(j),j=1,n)
                itemp1(1,i)=i
c               itemp1(2,i)=kkk
                do 97 j=1,n
 97             tempall(j,i)=temp(j)
                write(6,*)'TRANSIENT ANALYSIS BEGUN FOR PERIOD',i
                if(ifindiff.eq.1)call trnsien1(itotitr,i,theta,ta,qsky,
     &          hhf,hhw,hht,qdir,qtarm,ttarm,absorbf,emisf,absorbw,
     &          emisw,eemisf,eemisw,rff,rfw)
                if(ifindiff.eq.2)call trnsien2(itotitr,i,theta,ta,qsky,
     &          hhf,hhw,hht,qdir,qtarm,ttarm,absorbf,emisf,absorbw,
     &          emisw,eemisf,eemisw,rff,rfw)
        write(6,*)'TRANSIENT ANALYSIS COMPLETED FOR PERIOD',i
            itemp1tr(1,i)=i
            do 197 j=1,n
 197     temptr(j,i)=temptrn(j)
 10         continue
c find the maximum temperatures
        write(9,*)'$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$'
        write(9,*)'THERMOD:  A THERMAL PROGRAM FOR AIRCRAFTS'
            write(9,*)'$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$'
            write(9,*)' '
        write(9,*)' '
        write(9,*)' '
                write(9,*)'SUMMARY OF STEADY-STATE AND TRANSIENT ANALYSIS'
            write(9,*)' '
            write(9,*)' '
            write(9,*)' '
c               write(9,*)'absorbf,emisf,absorbw,emisw'
```

```
c                 write(9,*)absorbf,emisf,absorbw,emisw
                  tempall2=0.0
              temptr2=0.0
                  do 120 i=1,nperiods
                    tempall1(i)=0.0
               temptr1(i)=0.0
c Temperatures T25, T26, T43, T44 (all insulatory surfaces); T51, T52 and
c T53 (tarmac surfaces); and T49 and T50 (plexiglass material) are
c considered non-structural.
                    do 125 j=1,48
                      if(j.ne.25.and.j.ne.26.and.j.ne.43.and.j.ne.44)then
                        if(tempall(j,i).gt.tempall1(i))then
                            tempall1(i)=tempall(j,i)
                            location(i)=j
                        endif
                      endif
                      if(j.ne.25.and.j.ne.26.and.j.ne.43.and.j.ne.44)then
                        if(temptr(j,i).gt.temptr1(i))then
                            temptr1(i)=temptr(j,i)
                            locattr(i)=j
                        endif
                      endif
 125                continue
                    if(tempall1(i).gt.tempall2)then
                      tempall2=tempall1(i)
                      locfinal=location(i)
                      iperiodf=i
                    endif
                    if(temptr1(i).gt.temptr2)then
                      temptr2=temptr1(i)
                      locfintr=locattr(i)
                      iperiotr=i
                    endif
 120              continue
c print the temperatures
c                 do 100 j=1,2
c 100             write(9,101)(itemp1(j,i),i=1,nperiods)
c steady-state output
        write(9,*)'(Temperatures are shown for all time periods)'
            write(9,*)' '
            write(9,*)' '
                  write(9,*)'TEMPERATURES AT THE END OF STEADY STATE ANALYSIS'
            write(9,*)' '
        write(9,250)
 250     format(8x,'TEMPERATURES IN DEGREES FAHRENHEIT')
        write(9,101)(itemp1(1,i),i=1,nperiods)
 101              format(4x,100(1x,i5))
        write(9,*)' '
                  do 99 j=1,53
 99               write(9,98)j,(tempall(j,i),i=1,nperiods)
 98               format(1x,i3,100(1x,f5.1))
```

```
        write(9,*)''
                do 130 i=1,nperiods
c               write(6,*)'maximum structural temperature for period',i,'=',
c    &           tempall1(i),' occurring at location',location(i)
                write(9,135)i,tempall1(i),location(i)
 135     format('Maximum Structural Temperature for Period',1x,i3,1x,
    &   '=',1x,f6.2,1x,'Occurring at Location',1x,i3)
 130            continue
c               write(6,*)'maximum structural temperature over all periods=',
c    &           tempall2,' occurring at location ',locfinal,' and at ',
c    &           'period ',iperiodf
        write(9,*)' '
            write(9,136)nperiods,tempall2,locfinal,iperiodf
 136     format('Maximum Structural Temperature Over All',1x,i3,
    &   1x,'Periods',1x,'=',f6.2,1x,'Occurring at Location',1x,i3,
    &   1x,'at Period',1x,i3)
c transient analysis output
            write(9,*)' '
            write(9,*)' '
                write(9,*)'TEMPERATURES AT THE END OF TRANSIENT ANALYSIS'
            write(9,*)' '
        write(9,250)
        write(9,101)(itemp1tr(1,i),i=1,nperiods)
        write(9,*)' '
                do 299 j=1,53
 299            write(9,98)j,(temptr(j,i),i=1,nperiods)
        write(9,*)''
                do 1130 i=1,nperiods
c               write(6,*)'maximum structural temperature for period',i,'=',
c    &           temptr1(i),' occurring at location',locattr(i)
                write(9,137)i,temptr1(i),locattr(i)
 137     format('Maximum Structural Temperature for Period',1x,i3,1x,
    &   '=',1x,f6.2,1x,'Occurring at Location',1x,i3)
 1130           continue
c               write(6,*)'maximum structural temperature over all',nperiods,
c           'periods=',
c    &           temptr2,' occurring at location ',locfintr,' and at ',
c    &           'period ',iperiotr
        write(9,*)' '
            write(9,138)nperiods,temptr2,locfintr,iperiotr
 138     format('Maximum Structural Temperature Over All',1x,i3,
    &   1x,'Periods',1x,'=',f6.2,1x,'Occurring at Location',1x,i3,
    &   1x,'at Period',1x,i3)
c
c
c
c icode=2: this is the "mother" of all iterations.  for a given paint
c on the fuselage, this option iterates for all paint combination on the
c wing.  this process is repeated for the next fuselage paint.          note
c that the fuselage paint are the same for the sides, top and bottom.
c this is how it has been programmed. can be modified if requested.
```

```
c this option outputs a matrix of paint schemes that are permissible for
c the entire plane without violating a set of temperature
c requirements requested by the user.
c
     elseif(icode.eq.2)then
          itotitr=0
          do 440 iabsorbf=ibegabsf,iendabsf
          absorbf=(iabsorbf-1)*del
          if(iabsorbf.eq.1)absorbf=small
          if(iabsorbf.eq.nparts+1)absorbf=1.-small
          absorftp=absorbf
          absorbfb=absorbf
          do 460 iemisf=ibegemsf,iendemsf
          isumm=(iabsorbf-1)*(nparts+1)+iemisf
          emisf=(iemisf-1)*del
          if(iemisf.eq.1)emisf=small
          if(iemisf.eq.nparts+1)emisf=1.-small
          emisrftp=emisf
          emisfb=emisf
          absinfrf=emisf*(1./(1.-f11f*(1.-emisf)))
          eemisf=emisf*(1.-f11f)/(1.-f11f*(1.-emisf))
          rff=absinfrf/eemisf
          do 470 iabsorbw=ibegabsw,iendabsw
            absorbw=(iabsorbw-1)*del
            if(iabsorbw.eq.1)absorbw=small
            if(iabsorbw.eq.nparts+1)absorbw=1.-small
            call qreffw(absorbf,absorbw)
            call qreftw(absorbw)
            do 450 iemisw=ibegemsw,iendemsw
              isum=(iabsorbw-1)*(nparts+1)+iemisw
              emisw=(iemisw-1)*del
              if(iemisw.eq.1)emisw=small
              if(iemisw.eq.nparts+1)emisw=1.-small
              absinfrw=emisw*(1./(1.-f11w*(1.-emisw)))
              eemisw=emisw*(1.-f11w)/(1.-f11w*(1.-emisw))
              rfw=absinfrw/eemisw
              itot=0
              itot1=0
              do 425 iconstrn=1,nconstrn
425           tempp(iconstrn)=0.0
              do 426 iconstrn=1,nconstrn
426           tempp1(iconstrn)=0.0
              do 410 i=1,nperiods
                   itotitr=itotitr+1
                   do 490 itemp=1,n
490                t(itemp)=tinitial(itemp)
                   theta=envtdata(i,1)
                   ta=envtdata(i,2)
                   qsky=qqsky(i)
                   qdir=envtdata(i,5)
                   hhf=hf(i)
```

```
                hhw=hw(i)
                hht=ht(i)
                qtarm=qqtarm(i)
                ttarm=tttarm(i)
c find airplane temperature
                call newtraph(i,kkk,theta,ta,qsky,hhf,hhw,hht,qdir,
     &          qtarm,ttarm,absorbf,emisf,absorbw,emisw,
     &          eemisf,eemisw,rff,rfw)
                write(9,*)'STEADY STATE ANALYSIS'
                write(9,*)'Total # of Analysis (per period)=',itotitr
                write(9,*)'absorbf,emisf,absorbw,emisw,period,iteratns'
                write(9,*)absorbf,emisf,absorbw,emisw,i,kkk
                write(9,96)(ii,ii=1,n)
 96             format(7x,70(1x,i4))
                write(9,95)i,kkk,(temp(ii),ii=1,n)
                write(6,*)'STEADY STATE ANALYSIS'
                write(6,*)'Total # of Analysis (per period)=',itotitr
                write(6,*)'absorbf,emisf,absorbw,emisw,period,iteratns'
                write(6,*)absorbf,emisf,absorbw,emisw,i,kkk
                write(6,96)(ii,ii=1,n)
                write(6,95)i,kkk,(temp(ii),ii=1,n)
                do 430 iconstrn=1,nconstrn
                  if(temp(idtemp(iconstrn)).gt.tempp(iconstrn))
     &                  tempp(iconstrn)=temp(idtemp(iconstrn))
 430            continue
                if(ifindiff.eq.1)call trnsien1(itotitr,i,theta,ta,qsky,
     &          hhf,hhw,hht,qdir,qtarm,ttarm,absorbf,emisf,absorbw,
     &          emisw,eemisf,eemisw,rff,rfw)
                if(ifindiff.eq.2)call trnsien2(itotitr,i,theta,ta,qsky,
     &          hhf,hhw,hht,qdir,qtarm,ttarm,absorbf,emisf,absorbw,
     &          emisw,eemisf,eemisw,rff,rfw)
                write(6,*)'TRANSIENT ANALYSIS'
                write(9,*)'TRANSIENT ANALYSIS'
                write(6,95)i,kkk,(temptrn(ii),ii=1,n)
                write(9,95)i,kkk,(temptrn(ii),ii=1,n)
                do 431 iconstrn=1,nconstrn
                  if(temptrn(idtemp(iconstrn)).gt.tempp1(iconstrn))
     &                  tempp1(iconstrn)=temptrn(idtemp(iconstrn))
 431            continue
 410          continue
                do 435 iconstrn=1,nconstrn
 435            if(tempp(iconstrn).le.tempcons(iconstrn))
     &              itot=itot+1
                if(itot.eq.nconstrn)then
                  indicat(isumm,isum)='Y'
                  write(9,*)'passed the steady-state temp. constraints'
                  write(9,*)'absorbf,emisf,absorbw,emisw'
                  write(9,*)absorbf,emisf,absorbw,emisw
                  write(9,96)(ii,ii=1,n)
                  write(9,199)(temp(i),i=1,67)
 199              format(7x,70(1x,f4.0))
```

```
                endif
                do 436 iconstrn=1,nconstrn
436             if(tempp1(iconstrn).le.tempcons(iconstrn))
   &                 itot1=itot1+1
                if(itot1.eq.nconstrn)then
                  indicat1(isumm,isum)='Y'
                  write(9,*)'passed the transient temp. constraints'
                  write(9,*)'absorbf,emisf,absorbw,emisw'
                  write(9,*)absorbf,emisf,absorbw,emisw
                  write(9,96)(ii,ii=1,n)
                  write(9,199)(temptrn(i),i=1,67)
                endif
450       continue
470     continue
460   continue
440  continue
     nmatrix=(nparts+1)**2
     write(9,*)'STEADY STATE ANALYSIS ONLY'
     do 420 isumm=1,nmatrix
      write(9,495)(indicat(isumm,isum),isum=1,nmatrix)
420  continue
     write(9,*)'AT THE END OF TRANSIENT ANALYSIS'
     do 421 isumm=1,nmatrix
      write(9,495)(indicat1(isumm,isum),isum=1,nmatrix)
421  continue
495  format(150a1)
     endif
     close(9)
          close(10)
c      close(12)
c      close(13)
c      close(14)
c      close(15)
c      close(16)
c      close(17)
     return
     end
c
c
     subroutine hconvect(l,h)
c purpose: determines the convective coefficient
c calls: none
c called from: solution
     common/c7/nperiods,envtdata(100,20)
     common/c10/k,thdiffus,visckine,prandtl
     real l,llamn,nusllamn,k
     dimension h(100)
     parameter(rellamn=5.e5)
c
c Variables:
c h: convective coefficient
```

```
c l=length
c nusllamn=Nusselt number in the laminar zone
c rellamn=Reynold's number in the laminar zone
c
      do 10 i=1,nperiods
      v=envtdata(i,4)
      rel=v*l/visckine
      if(rel.le.rellamn)then
           nusllamn=0.664*rel**(1./2)*prandtl**(1./3)
           h(i)=k*nusllamn/l
c          write(12,*)'rel,nusllamn,h',rel,nusllamn,h(i)
      elseif(rel.gt.rellamn)then
           llamn=rellamn*visckine/v
           nusllamn=0.664*rellamn**(1./2)*prandtl**(1./3)
           hlamn=k*nusllamn/llamn
           hturb=0.0296*k/(l-llamn)*prandtl**(1./3)*(v/visckine)**(4./5)
     &          *(5./4)*(l**(4./5)-llamn**(4./5))
           h(i)=1./l*(llamn*hlamn+(l-llamn)*hturb)
c          write(12,*)'rel,llamn,hlamn,hturb,h',
c     &   rel,llamn,hlamn,hturb,h(i)
      endif
 10   continue
      end
c
c
      subroutine viewfact
c purpose: determines the view factor (controlling routine)
c calls: viewfc
c called from: solution
      common/c4/widthwng,lengtwng,hwng,locwng,lplane,lfuselg,hfuselg,
     &          wfuselg
      common/vf1/fbwa(6,6),fbwb(6,6)
      common/vf2/fa11,fa12,fa13,fa14,fa15,fa16,fa21,fa22,fa23,fa24,
     &          fa25,fa26,fa31,fa32,fa33,fa34,fa35,fa36,fa41,fa42,
     &          fa43,fa44,fa45,fa46,fa51,fa52,fa53,fa54,fa55,fa56,
     &          fa61,fa62,fa63,fa64,fa65,fa66
      common/vf4/fa57,fa68
      common/vf5/fc11,fc12,fc13,fc14,fc15,fc16,fc21,fc22,fc23,fc24,
     &          fc25,fc26,fc31,fc32,fc33,fc34,fc35,fc36,fc41,fc42,
     &          fc43,fc44,fc45,fc46,fc51,fc52,fc53,fc54,fc55,fc56,
     &          fc61,fc62,fc63,fc64,fc65,fc66
      dimension f(6,6)
      real lengtwng,l,locwng,lfuselg,lplane
c
c Variables:
c fbwa(,)=view factors for the wing bottom (LHS & RHS)
c fbwb(,)=view factors for the wing bottom (CENTER)
c fa11....fa66=view factors for the top fuselage-wing junction
c fa57,fa68=view factors for face 5 & 7; and 6 & 8, where 7 is
c           the fuselage face front of the wing and 8 is the
c           fuselage face aft of the wing.
```

```
cfc11....fc66=view factors for the fuselage inside (cabin)
c
c view factors for wingbottom
c LHS & RHS:
      x=widthwng
      y=(lengtwng-wfuselg)/2.
      z=hwng
      call viewfc(x,y,z,fbwa)
c CENTER (below fuselage):
      x=widthwng
      y=wfuselg
      z=hwng
      call viewfc(x,y,z,fbwb)
c
c view factors for the top fuselage-wing junction
      x=widthwng
      y=(lengtwng-wfuselg)/2
      l=hfuselg
      call viewfc(x,y,l,f)
      fa11=f(1,1)
      fa12=f(1,2)
      fa13=f(1,3)
      fa14=f(1,4)
      fa15=f(1,5)
      fa16=f(1,6)
      fa21=f(2,1)
      fa22=f(2,2)
      fa23=f(2,3)
      fa24=f(2,4)
      fa25=f(2,5)
      fa26=f(2,6)
      fa31=f(3,1)
      fa32=f(3,2)
      fa33=f(3,3)
      fa34=f(3,4)
      fa35=f(3,5)
      fa36=f(3,6)
      fa41=f(4,1)
      fa42=f(4,2)
      fa43=f(4,3)
      fa44=f(4,4)
      fa45=f(4,5)
      fa46=f(4,6)
      fa51=f(5,1)
      fa52=f(5,2)
      fa53=f(5,3)
      fa54=f(5,4)
      fa55=f(5,5)
      fa56=f(5,6)
      fa61=f(6,1)
      fa62=f(6,2)
```

```
      fa63=f(6,3)
      fa64=f(6,4)
      fa65=f(6,5)
      fa66=f(6,6)
c view factors for face 5 & 7; and 6 & 8, where 7 is the fuselage face
c front of the wing and 8 is the fuselage face aft of the wing.
c find fa57:
      x=hfuselg
      y=(lengtwng-wfuselg)/2
      l=locwng
      call viewfc(x,y,l,f)
      fa57=f(1,2)
c      write(9,*)'fa57=',fa57
c find fa68
      x=hfuselg
      y=(lengtwng-wfuselg)/2
      l=lplane-locwng-widthwng
      call viewfc(x,y,l,f)
      fa68=f(1,2)
c      write(9,*)'fa68=',fa68
c
c find fij's for the inside of the fuselage.
c that is find fc11..fc16; fc21..fc26; fc31..fc36; fc41..fc46
c fc51..fc56; fc61..fc66.  note fc11,fc22,fc33,fc44,fc55 & fc66
c are zeroes.
      x=lfuselg
      y=wfuselg
      l=hfuselg
      call viewfc(x,y,l,f)
      fc11=f(1,1)
      fc12=f(1,2)
      fc13=f(1,3)
      fc14=f(1,4)
      fc15=f(1,5)
      fc16=f(1,6)
      fc21=f(2,1)
      fc22=f(2,2)
      fc23=f(2,3)
      fc24=f(2,4)
      fc25=f(2,5)
      fc26=f(2,6)
      fc31=f(3,1)
      fc32=f(3,2)
      fc33=f(3,3)
      fc34=f(3,4)
      fc35=f(3,5)
      fc36=f(3,6)
      fc41=f(4,1)
      fc42=f(4,2)
      fc43=f(4,3)
      fc44=f(4,4)
```

```
      fc45=f(4,5)
      fc46=f(4,6)
      fc51=f(5,1)
      fc52=f(5,2)
      fc53=f(5,3)
      fc54=f(5,4)
      fc55=f(5,5)
      fc56=f(5,6)
      fc61=f(6,1)
      fc62=f(6,2)
      fc63=f(6,3)
      fc64=f(6,4)
      fc65=f(6,5)
      fc66=f(6,6)
      return
      end
c
      subroutine viewfc(x,y,l,f)
c purpose: determines the view factors for: aligned parallel rectangles
c            and for: perpendicular rectangles with a common edge
c calls: vfacfij
c called from: viewfact
      dimension f(6,6)
      parameter(pi=3.141593)
      real l
      a1=x*y
      a2=x*l
      a3=a1
      a4=a2
      a5=l*y
      a6=a5
c find fij for aligned parallel rectangles (fig 13.4) Frank P. Incropera
c "fundamentals of heat and mass transfer"
      do 10 i=1,3
          if(i.eq.1)then
            xb=x/l
            yb=y/l
          elseif(i.eq.2)then
            xb=x/y
            yb=l/y
          elseif(i.eq.3)then
            xb=y/x
            yb=l/x
          endif
          a=alog((((1+xb**2)*(1+yb**2))/(1+xb**2+yb**2))**.5)
          b=xb*(1+yb**2)**.5*atan(xb/(1+yb**2)**.5)
          c=yb*(1+xb**2)**.5*atan(yb/(1+xb**2)**.5)
          d=xb*atan(xb)
          e=yb*atan(yb)
c         if(i.eq.1)write(9,*)'a,b,c,d,e',a,b,c,d,e
          fij=2/(pi*xb*yb)*(a+b+c-d-e)
```

```
          if(i.eq.1)f(1,3)=fij
          if(i.eq.2)f(2,4)=fij
          if(i.eq.3)f(5,6)=fij
 10   continue
          f(3,1)=f(1,3)
          f(4,2)=f(2,4)
          f(6,5)=f(5,6)
          do 20 i=1,6
 20       f(i,i)=0.

c find fij for perpendicular rectangles with a common edge
c (fig 13.6) Frank P. Incropera
c "fundamentals of heat and mass transfer"
c
c go about x-axis
      w=y/x
      h=l/x
      call vfacfij(w,h,fij)
      f(1,2)=fij
      f(3,4)=f(1,2)
      f(2,1)=f(1,2)*a1/a2
      f(4,3)=f(2,1)
      call vfacfij(h,w,fij)
      f(2,3)=fij
      f(4,1)=f(2,3)
      f(3,2)=f(2,3)*a2/a3
      f(1,4)=f(3,2)
c go about y-axis
      w=x/y
      h=l/y
      call vfacfij(w,h,fij)
      f(1,5)=fij
      f(3,6)=f(1,5)
      f(5,1)=f(1,5)*a1/a5
      f(6,3)=f(5,1)
      call vfacfij(h,w,fij)
      f(5,3)=fij
      f(6,1)=f(5,3)
      f(3,5)=f(5,3)*a5/a3
      f(1,6)=f(3,5)
c go about l-axis
      w=x/l
      h=y/l
      call vfacfij(w,h,fij)
      f(4,5)=fij
      f(2,6)=f(4,5)
      f(5,4)=f(4,5)*a4/a5
      f(6,2)=f(5,4)
      call vfacfij(h,w,fij)
      f(5,2)=fij
      f(6,4)=f(5,2)
```

```
      f(2,5)=f(5,2)*a5/a2
      f(4,6)=f(2,5)
c      do 50 i=1,6
c 50   write(9,*)(f(i,j),j=1,6)
      return
      end
c
      subroutine vfacfij(w,h,fij)
c purpose: find fij for perpendicular rectangles with a common edge
c           (fig 13.6) Frank P. Incropera
c           "fundamentals of heat and mass transfer"
c calls: none
c called from: viewfc
      parameter(pi=3.141593)
      a=w*atan(1/w)
      b=h*atan(1/h)
      c=(h**2+w**2)**.5*atan(1/(h**2+w**2)**.5)
      d=((1+w**2)*(1+h**2))/(1+w**2+h**2)
      e=((w**2*(1+w**2+h**2))/((1+w**2)*(w**2+h**2)))**w**2
      f=((h**2*(1+h**2+w**2))/((1+h**2)*(h**2+w**2)))**h**2
c      write(9,10)a,b,c,d,e,f
c 10   format(6f10.5)
      fij=1/(pi*w)*(a+b-c+.25*alog(d*e*f))
      return
      end
c
c
      subroutine newtraph(iperiod,k,theta,ta,qsky,hhf,hhw,hht,qdir,
     &                    qtarm,ttarm,absorbf,emisf,absorbw,emisw,
     &                    eemisf,eemisw,rff,rfw)
c purpose: this subroutine calls: linear solvers; ludcmp and lubksb.
c given an initial guess x for a root in n dimensions, take
c ntrial Newton-Raphson steps to improve the root.  stop if the
c root converges in either summed absolute variable increments tolx or summed
c absolute function values tolf.
c calls: thermodl,ludcmp,lubksb
c called from: solution
      common/c1/n,ntrial,tolx,tolf
      common/c2/x(200),fvec(200),jacob(200,200)
      common/sc1/indx(200),p(200)
      common/result/temp(200),temptrn(200)
c
c Variables:
c ipower=exponent of 10.  to ensure solution converges in positive numbers
c
      ipower=1
 50   do 14 k=1,ntrial
c user subroutine supplies function values at x in fvec and
c Jacobian matrix in jacob.
      call thermodl(iperiod,k,theta,ta,qsky,hhf,hhw,hht,qdir,
     &              qtarm,ttarm,absorbf,emisf,absorbw,emisw,
```

```
     &                    eemisf,eemisw,rff,rfw)
c check function convergence
           errf=0.
           do 11 i=1,n
             errf=errf+abs(fvec(i))
 11        continue
c          if(errf.le.tolf) goto 20
c right-hand side of linear equations
           do 12 i=1,n
             p(i)=-fvec(i)
 12        continue
c solve linear eqns. using LU decomposition
           call ludcmp
c forward and back substitution
           call lubksb
c check root convergence; and update solution
           errx=0.
           do 13 i=1,n
             errx=errx+abs(p(i))
             x(i)=x(i)+p(i)
 13        continue
      write(14,*)'k(trial#),errx,errf',k,errx,errf
           if(errf.le.tolf.and.errx.le.tolx) goto 20
 14    continue
 20    loopindc=0
      do 30 i=1,n
           if(x(i).lt.0.0)then
             write(6,*)'i=',i,x(i)
             x(i)=10**ipower
             loopindc=1
           endif
 30    continue
      if(loopindc.eq.1)then
           ipower=ipower+1
           goto 50
      endif
c rearrange all temperatures and radiosity in a neat manner as in
c Fig 1. of the report
      temp(1)=x(1)
      temp(2)=x(2)
      temp(3)=x(3)
      temp(4)=x(4)
      temp(5)=x(62)
      temp(6)=x(63)
      temp(7)=x(5)
      temp(8)=x(6)
      temp(9)=x(7)
      temp(10)=x(8)
      temp(11)=x(9)
      temp(12)=x(10)
      temp(13)=x(11)
```

```
temp(14)=x(12)
temp(15)=x(64)
temp(16)=x(65)
temp(17)=x(13)
temp(18)=x(14)
temp(19)=x(15)
temp(20)=x(16)
temp(21)=x(59)
temp(22)=x(58)
temp(23)=x(57)
temp(24)=x(60)
temp(25)=x(61)
temp(26)=x(35)
temp(27)=x(34)
temp(28)=x(33)
temp(29)=x(32)
temp(30)=x(31)
temp(31)=(x(31)+x(28))/2.
temp(32)=(x(31)+x(28))/2.
temp(33)=(x(31)+x(28))/2.
temp(34)=(x(31)+x(28))/2.
temp(35)=x(28)
temp(36)=x(27)
temp(37)=x(26)
temp(38)=x(25)
temp(39)=x(17)
temp(40)=x(18)
temp(41)=x(19)
temp(42)=x(20)
temp(43)=x(38)
temp(44)=x(39)
temp(45)=x(21)
temp(46)=x(22)
temp(47)=x(23)
temp(48)=x(24)
temp(49)=x(37)
temp(50)=x(36)
temp(51)=x(51)
temp(52)=x(52)
temp(53)=x(53)
temp(54)=x(40)
temp(55)=x(41)
temp(56)=x(42)
temp(57)=x(43)
temp(58)=x(44)
temp(59)=x(45)
temp(60)=x(46)
temp(61)=x(47)
temp(62)=x(48)
temp(63)=x(49)
temp(64)=x(50)
```

```
      temp(65)=x(54)
      temp(66)=x(55)
      temp(67)=x(56)
      do 100 i=1,53
  100  temp(i)=temp(i)-459.67
      return
      end
c
      subroutine thermodl(iperiod,ik,theta,ta,qsky,hhf,hhw,hht,qdir,
     &                    qtarm,ttarm,absorbf,emisf,absorbw,emisw,
     &                    eemisf,eemisw,rff,rfw)
c purpose: calculates and return the function value for each function fn
c and the jacobian values jacob; all at each new t values for each
c new newton-raphson trials.  core of the thermal model
c called from: newtraph
c calls:jacobian
      common/c1/n,ntrial,tolt,tolfn
      common/c2/t(200),fn(200),jacob(200,200)
      common/c3/th(100),k(100)
      common/c4/widthwng,lengtwng,hwng,locwng,lplane,lfuselg,hfuselg,
     &          wfuselg
      common/c5/trnsm,absorbta,emista,tarmd,densta,conducta,shcta
      common/c6/absorbff,emisff,absorbww,emisww,absorbfl,emisfl,absorbfi
     &,emisfi,absorbpg,emispg,absorftp,emisrftp,absorfbt,emisrfbt
     &,absorbfb,emisfb
      common/c7/nperiods,envtdata(100,20)
      common/c10/aircondc,thdiffus,visckine,prandtl
      common/c12/a1,a2,a3,a4,a5,a6(100),a7(100)
      common/reflecq/qreflin(6,100),qscabsin(6,100),qreflfwr(6,100),
     &qreflfwl(6,100),qscabfwr(6,100),qscabfwl(6,100),qabstwa1(6,100),
     &qabstwa2(6,100),qabstwb(6,100)
      common/vf1/fbwa(6,6),fbwb(6,6)
      common/vf2/fa11,fa12,fa13,fa14,fa15,fa16,fa21,fa22,fa23,fa24,
     &          fa25,fa26,fa31,fa32,fa33,fa34,fa35,fa36,fa41,fa42,
     &          fa43,fa44,fa45,fa46,fa51,fa52,fa53,fa54,fa55,fa56,
     &          fa61,fa62,fa63,fa64,fa65,fa66
      common/vf4/fa57,fa68
      common/vf5/fc11,fc12,fc13,fc14,fc15,fc16,fc21,fc22,fc23,fc24,
     &          fc25,fc26,fc31,fc32,fc33,fc34,fc35,fc36,fc41,fc42,
     &          fc43,fc44,fc45,fc46,fc51,fc52,fc53,fc54,fc55,fc56,
     &          fc61,fc62,fc63,fc64,fc65,fc66
      common/facttarm/fact
      dimension jj(20)
      real jj,jacob,k,nusselt1,nusselt2
      real lengtwng,locwng,lfuselg
      parameter(fpi=3.141593/180.)
      parameter(sig=0.1714e-8)
      parameter(gravity=32.2)
      data fact/0.3/
c
c Variables:
```

```
c nusselt1=Nusselt number inside the fuselage (vertical)
c nusselt2=Nusselt number inside the fuselage (horizontal)
c sig=Stefan-Boltzmann constant
c fact=allows for modification of temperature of the tarmac shade
c underneath the wing
c qreflin(,)=intercepted solar radiation (both direct and specular)
c              in the cabin
c qscabsin(,)=absorbed diffuse solar radiation in the cabin
c qreflfwr(,)=intercepted solar radiation (both direct and specular)
c              by right wing
c qreflfwl(,)=intercepted solar radiation (both direct and specular)
c              by left wing
c qscabfwr(,)=absorbed diffuse solar radiation by the right wing
c qscabfwl(,)=absorbed diffuse solar radiation by the left wing
c qabstwa1(,)=intercepted solar radiation (direct)
c              by the tarmac underneath the wing (LHS)
c qabstwa2(,)=intercepted solar radiation (direct)
c              by the tarmac underneath the wing         (RHS)
c qabstwb(,)=intercepted solar radiation (direct)
c              by the tarmac underneath the wing(CENTER)
c
c input t(from 40 to 50) into jj(1 to 11): jj=radiosities
      do 10 i=1,11
 10   jj(i)=t(39+i)
c input t(from 54 to 56) into jj(12 to 14): jj=radiosities
      do 15 i=1,3
 15   jj(11+i)=t(53+i)
c note t(51) to t(53) are for temperatures of tarmac under the wing
c
c find the values for each functions, fn, using the current t values
c
c left wing (conduction): Eqns. 1,2,3,4,5,6,62&63
c
      fn(1)=-k(1)/th(1)*(t(1)-t(2))+k(2)/th(2)*(t(2)-t(3))
      fn(2)=-k(2)/th(2)*(t(2)-t(3))+k(3)/th(3)*(t(3)-t(4))
      fn(3)=-k(3)/th(3)*(t(3)-t(4))+k(4)/th(4)*(t(4)-t(62))
      fn(4)=-k(4)/th(4)*(t(4)-t(62))+k(29)/th(29)*(t(62)-t(63))
      fn(62)=-k(29)/th(29)*(t(62)-t(63))+k(30)/th(30)*(t(63)-t(5))
      fn(63)=-k(30)/th(30)*(t(63)-t(5))+k(5)/th(5)*(t(5)-t(6))
      fn(5)=-k(5)/th(5)*(t(5)-t(6))+k(6)/th(6)*(t(6)-t(7))
      fn(6)=-k(6)/th(6)*(t(6)-t(7))+k(7)/th(7)*(t(7)-t(8))
c
c right wing (conduction): Eqns. 7,8,9,10,11,12,64&65
c
      fn(7)=-k(1)/th(1)*(t(9)-t(10))+k(2)/th(2)*(t(10)-t(11))
      fn(8)=-k(2)/th(2)*(t(10)-t(11))+k(3)/th(3)*(t(11)-t(12))
      fn(9)=-k(3)/th(3)*(t(11)-t(12))+k(4)/th(4)*(t(12)-t(64))
      fn(10)=-k(4)/th(4)*(t(12)-t(64))+k(29)/th(29)*(t(64)-t(65))
      fn(64)=-k(29)/th(29)*(t(64)-t(65))+k(30)/th(30)*(t(65)-t(13))
      fn(65)=-k(30)/th(30)*(t(65)-t(13))+k(5)/th(5)*(t(13)-t(14))
      fn(11)=-k(5)/th(5)*(t(13)-t(14))+k(6)/th(6)*(t(14)-t(15))
```

```
      fn(12)=-k(6)/th(6)*(t(14)-t(15))+k(7)/th(7)*(t(15)-t(16))
c
c left fuselage (conduction).   Eqns 13,14,17
      do 40 i=13,14
           fn(i)=-k(i-5)*((t(i+4)-t(i+5))/th(i-5))
     &          +k(i-4)*((t(i+5)-t(i+6))/th(i-4))
 40   continue
c Eqn. 17 recently modified
      fn(17)=-k(10)/th(10)*(t(19)-t(20))
     &          +k(23)/th(23)*(t(20)-t(38))
c right fuselage (conduction). Eqns 15,16,18
      ii=0
      do 50 i=15,16
           fn(i)=-k(10-ii)*((t(i+6)-t(i+7))/th(10-ii))
     &          +k(9-ii)*((t(i+7)-t(i+8))/th(9-ii))
           ii=ii+1
 50   continue
c  Eqn. 18 recently modified
      fn(18)=-k(23)/th(23)*(t(39)-t(21))
     &          +k(10)/th(10)*(t(21)-t(22))
c
c Conduction Eqns. 32,33,34,35,36,37,38,39,40,66&67. These eqns model
c the spar-box and floor section within the cabin.  Green house effect
c is part of this addition.  This effect is considered through
c JJ8 to JJ11 around the four sides of the cabin interior
c
c Eqns. 32,33&34:
c
      do 53 j=1,3
           fn(31+j)=-k(12+j)/th(12+j)*(t(26+j)-t(25+j))
     &               +k(11+j)/th(11+j)*(t(25+j)-t(24+j))
 53   continue
c
c Eqns. 37,38,39&40:
c
      do 55 j=1,4
           fn(36+j)=-k(17+j)/th(17+j)*(t(31+j)-t(30+j))
     &               +k(16+j)/th(16+j)*(t(30+j)-t(29+j))
 55   continue
c
c  Eqns. 35,36,66&67:
c
      fn(35)=-k(32)/th(32)*(t(67)-t(29))+k(15)/th(15)*(t(29)-t(28))
      fn(36)=-k(31)/th(31)*(t(66)-t(67))+k(32)/th(32)*(t(67)-t(29))
      fn(66)=-k(16)/th(16)*(t(30)-t(66))+k(31)/th(31)*(t(66)-t(67))
      fn(67)=-k(17)/th(17)*(t(31)-t(30))+k(16)/th(16)*(t(30)-t(66))
c
c wing bottom, facing tarmac. there are a total of 12 eqns. to consider
c within three sections of the wing: LHS(section: 1); RHS (section 2)
c MIDDLE (section 3, ie underneath the fuselage). these eqns. are:
c LHS(section 1): fn19(t8),fn20(j2),fn51(t51),fn54(j12);
```

```
c RHS(section 2): fn21(t16),fn22(j4),fn53(t53),fn56(j14);
c MIDDLE(section 3): fn31(t25),fn46(j7),fn52(t52),fn55(j13).
c simple two-dimensional conduction from the unsheltered tarmac
c surface to the sheltered surface is considered.  a tarmac
c thickness tarmd is assumed.  also the bottom of the sheltered
c tarmac is considered adiabatic (insulated) so that no q
c is assumed to sip into the ground (being conservative).
c also for the depth, tarmd, the temperature of the unsheltered
c tarmac is assumed constant.  note, qtarm and ttarm are known,
c for they are unsheltered tarmac temperatures.
c
      qskytarm=qsky+0.5*qtarm+0.5*(1.-emista)*qsky
      rlwng=(lengtwng-wfuselg)/2.
c
c LHS(section 1): fn19(t8),fn20(j2),fn51(t51),fn54(j12):
c
      qnetsky=(sig*t(8)**4-jj(2))/((1.-emisw)/emisw)
      rad32skt=jj(14)*fbwa(4,1)+qskytarm*fbwa(4,2)+
     &          qskytarm*fbwa(4,5)+qskytarm*fbwa(4,6)
      rad12skt=jj(13)*fbwb(4,1)+rad32skt*fbwb(4,2)+
     &          qskytarm*fbwb(4,5)+qskytarm*fbwb(4,6)
      fn(19)=qabstwa1(3,iperiod)-qnetsky-hhw*(t(8)-ta)+
     &        k(7)/th(7)*(t(7)-t(8))
      fn(20)=-qnetsky+
     &        (jj(2)-jj(12))/(1./fbwa(3,1))+
     &        (jj(2)-rad12skt)/(1./fbwa(3,2))+
     &        (jj(2)-qskytarm)/(1./fbwa(3,4))+
     &        (jj(2)-qskytarm)/(1./fbwa(3,5))+
     &        (jj(2)-qskytarm)/(1./fbwa(3,6))
      qnetsky=(sig*t(51)**4-jj(12))/((1.-emista)/emista)
      fn(51)=(qabstwa1(1,iperiod)-qnetsky-hht*(t(51)-ta))*
     &      rlwng*widthwng+
     &      2.*(conducta/(fact*widthwng)*(ttarm-t(51)))*tarmd*rlwng+
     &      conducta/(fact*widthwng)*(ttarm-t(51))*tarmd*widthwng-
     &      conducta/(.5*wfuselg+.5*rlwng)*(t(51)-t(52))*tarmd*widthwng
      rad32sk=qsky*fbwa(4,2)+jj(4)*fbwa(4,3)+qsky*fbwa(4,5)+
     &         qsky*fbwa(4,6)
      rad12sk=rad32sk*fbwb(4,2)+jj(7)*fbwb(4,3)+
     &         qsky*fbwb(4,5)+qsky*fbwb(4,6)
      fn(54)=-qnetsky+
     &        (jj(12)-rad12sk)/(1./fbwa(1,2))+
     &        (jj(12)-jj(2))/(1./fbwa(1,3))+
     &        (jj(12)-qsky)/(1./fbwa(1,4))+
     &        (jj(12)-qsky)/(1./fbwa(1,5))+
     &        (jj(12)-qsky)/(1./fbwa(1,6))
c
c RHS(section 2): fn21(t16),fn22(j4),fn53(t53),fn56(j14):
c
      qnetsky=(sig*t(16)**4-jj(4))/((1.-emisw)/emisw)
      rad34skt=jj(12)*fbwa(2,1)+qskytarm*fbwa(2,4)
     &         +qskytarm*fbwa(2,5)+qskytarm*fbwa(2,6)
```

```
      rad24skt=jj(13)*fbwb(2,1)+rad34skt*fbwb(2,4)
     &           +qskytarm*fbwb(2,5)+qskytarm*fbwb(2,6)
      fn(21)=qabstwa2(3,iperiod)-qnetsky-hhw*(t(16)-ta)+
     &         k(7)/th(7)*(t(15)-t(16))
      fn(22)=-qnetsky+
     &         (jj(4)-jj(14))/(1./fbwa(3,1))+
     &         (jj(4)-qskytarm)/(1./fbwa(3,2))+
     &         (jj(4)-rad24skt)/(1./fbwa(3,4))+
     &         (jj(4)-qskytarm)/(1./fbwa(3,5))+
     &         (jj(4)-qskytarm)/(1./fbwa(3,6))
      qnetsky=(sig*t(53)**4-jj(14))/((1.-emista)/emista)
      fn(53)=(qabstwa2(1,iperiod)-qnetsky-hht*(t(53)-ta))*
     &      rlwng*widthwng+
     &      2.*(conducta/(fact*widthwng)*(ttarm-t(53)))*tarmd*rlwng+
     &      conducta/(fact*widthwng)*(ttarm-t(53))*tarmd*widthwng-
     &      conducta/(.5*wfuselg+.5*rlwng)*(t(53)-t(52))*tarmd*widthwng
      rad34sk=jj(2)*fbwa(2,3)+qsky*fbwa(2,4)+qsky*fbwa(2,5)+
     &          qsky*fbwa(2,6)
      rad24sk=jj(7)*fbwb(2,3)+rad34sk*fbwb(2,4)+
     &          qsky*fbwb(2,5)+qsky*fbwb(2,6)
      fn(56)=-qnetsky+
     &         (jj(14)-qsky)/(1./fbwa(1,2))+
     &         (jj(14)-jj(4))/(1./fbwa(1,3))+
     &         (jj(14)-rad24sk)/(1./fbwa(1,4))+
     &         (jj(14)-qsky)/(1./fbwa(1,5))+
     &         (jj(14)-qsky)/(1./fbwa(1,6))
c
c MIDDLE(section 3): fn31(t25),fn46(j7),fn52(t52),fn55(j13).
c
      qnetsky=(sig*t(25)**4-jj(7))/((1.-emisfb)/emisfb)
      fn(31)=qabstwb(3,iperiod)-qnetsky-hhf*(t(25)-ta)+
     &         k(12)/th(12)*(t(26)-t(25))
      fn(46)=-qnetsky+
     &         (jj(7)-jj(13))/(1./fbwb(3,1))+
     &         (jj(7)-rad32skt)/(1./fbwb(3,2))+
     &         (jj(7)-rad34skt)/(1./fbwb(3,4))+
     &         (jj(7)-qskytarm)/(1./fbwb(3,5))+
     &         (jj(7)-qskytarm)/(1./fbwb(3,6))
      qnetsky=(sig*t(52)**4-jj(13))/((1.-emista)/emista)
      fn(52)=(qabstwb(1,iperiod)-qnetsky-hht*(t(52)-ta))*
     &      wfuselg*widthwng+
     &      2.*(conducta/(fact*widthwng)*(ttarm-t(52)))*tarmd*wfuselg+
     &      conducta/(.5*wfuselg+.5*rlwng)*(t(51)-t(52))*tarmd*widthwng+
     &      conducta/(.5*wfuselg+.5*rlwng)*(t(53)-t(52))*tarmd*widthwng
      fn(55)=-qnetsky+
     &         (jj(13)-rad32sk)/(1./fbwb(1,2))+
     &         (jj(13)-jj(7))/(1./fbwb(1,3))+
     &         (jj(13)-rad34sk)/(1./fbwb(1,4))+
     &         (jj(13)-qsky)/(1./fbwb(1,5))+
     &         (jj(13)-qsky)/(1./fbwb(1,6))
c
```

```
c equations for the fuselage-wing junction facing the sky
c there are a total of 8 eqns. (4 for left half and 4 for right half)
c consider the wings first (a total of 4 eqns: 2 on each side)
c eqns. 23, 24, 25 & 26.
c
c when ii=1 (eqn. 23 & 24), left hand side; when ii=2 (eqn. 25 & 26),
c right hand side
      do 80 ii=1,2
       qnetsky=(sig*t(8*(ii-1)+1)**4-rfw*jj(1+(ii-1)*2))/
     &           ((1.-rfw*eemisw)/eemisw)
       if(ii.eq.1)fn(23+(ii-1)*2)=absorbw*qreflfwl(1,iperiod)*
     & sin(fpi*theta)+qscabfwl(1,iperiod)-qnetsky-hhw*
     & (t(8*(ii-1)+1)-ta)-k(1)*((t(8*(ii-1)+1)-t(8*(ii-1)+2))/th(1))
       if(ii.eq.2)fn(23+(ii-1)*2)=absorbw*qreflfwr(1,iperiod)*
     & sin(fpi*theta)+qscabfwr(1,iperiod)-qnetsky-hhw*
     & (t(8*(ii-1)+1)-ta)-k(1)*((t(8*(ii-1)+1)-t(8*(ii-1)+2))/th(1))
       fn(24+(ii-1)*2)=-qnetsky
     & +(((jj(1+(ii-1)*2)-jj(5+(ii-1)))/(1./fa12))
     & +((jj(1+(ii-1)*2)-qsky)/(1./fa13))
     & +((jj(1+(ii-1)*2)-qsky)/(1./fa14))
     & +((jj(1+(ii-1)*2)-qsky-fa57*(emisf*sig*t(17+(ii-1)*7)
     & **4+(1-emisf)*(qsky+.5*qtarm+.5*(1.-emista)*qsky)))/(1./fa15))
     & +((jj(1+(ii-1)*2)-qsky-fa68*(emisf*sig*t(17+(ii-1)*7)
     & **4+(1-emisf)*(qsky+.5*qtarm+.5*(1.-emista)*qsky)))/(1./fa16)))
 80   continue
c now consider the 4 eqns. of the above related to the fuselage.
c 2 eqns. on the left hand side (eqns. 27 & 28) and 2 eqns. on
c the right hand side (eqns. 29 & 30).
c
c when ii=1, left hand side; when ii=2, right hand side
      do 90 ii=1,2
           qnetsky=(sig*t(17+(ii-1)*7)**4-rff*jj(5+(ii-1)))/
     &              ((1.-rff*eemisf)/eemisf)
           if(ii.eq.1)fn(27+(ii-1)*2)=absorbf*qreflfwl(2,iperiod)*
     &     cos(fpi*theta)+qscabfwl(2,iperiod)-qnetsky-hhf*
     &     (t(17+(ii-1)*7)-ta)+
     &     (-1)**ii*k(8)*((t(17+(ii-1)*6)-t(18+(ii-1)*6))/th(8))
           if(ii.eq.2)fn(27+(ii-1)*2)=qscabfwr(2,iperiod)-qnetsky-hhf*
     &     (t(17+(ii-1)*7)-ta)+
     &     (-1)**ii*k(8)*((t(17+(ii-1)*6)-t(18+(ii-1)*6))/th(8))
           fn(28+(ii-1)*2)=-qnetsky
     &     +(jj(5+(ii-1))-jj(1+(ii-1)*2))/(1/fa21)
     &     +(jj(5+(ii-1))-qsky)/(1/fa23)
     &     +(jj(5+(ii-1))-qsky-.5*qtarm-.5*(1.-emista)*qsky)/(1/fa24)
     &     +(jj(5+(ii-1))-qsky-.5*qtarm-.5*(1.-emista)*qsky)/(1/fa25)
     &     +(jj(5+(ii-1))-qsky-.5*qtarm-.5*(1.-emista)*qsky)/(1/fa26)
 90   continue
c Recent modification has added a total of 9 eqns within the cabin.
c These eqns. are : 4 temperatures within the cabin (Eqn. 41,42,44,45);
c 1 temperature outside plexiglass (Eqn. 43); and 4 JJ's within
c the cabin (Eqns. 47,48,49,50).
```

```
c
c In order to consider the effects of the roof cover, five
c equations (eqn. 57, 58, 59, 60 & 61) have been added, giving temperatures
c t57, t58, t59, t60 & t61.  note that in these equations, areas are
c kept to indicate their comparative influence.
c also note that eqns. 42 & 43 have been modified.
c surface 4 (combined roof and glass bottom) is treated as one
c unit having a uniform temperature, tpgrf; uniform radiosity JJ9;and
c uniform emissivity; in order to obtain a uniform qnet within the cabin.
c
c equation 58 (conduction):
      fn(58)=k(27)/th(27)*(t(59)-t(58))*a2
     &       -k(26)/th(26)*(t(58)-t(57))*a2
c equation 57 (conduction):
      fn(57)=k(26)/th(26)*(t(58)-t(57))*a2
     &       -k(25)/th(25)*(t(57)-t(60))*a2
c equation 60 (conduction):
      fn(60)=k(25)/th(25)*(t(57)-t(60))*a2
     &       -k(28)/th(28)*(t(60)-t(61))*a2
c
c top of plexiglass and roof top facing the sky & tarmac.
c eqn 43 (t37(plexiglass) & eqn 59 (t59 (roof top))
c
      fn(43)=-emispg*sig*t(37)**4*a1
     & -hhf*(t(37)-ta)*a1
     & -k(22)/th(22)*(t(37)-t(36))*a1
     & +emispg*qsky*a1
     & +emispg*.5*(1.-emista)*qsky*a5
     & +emispg*.5*qtarm*a5
     & +.5*absorbpg*qdir*cos(fpi*theta)*a6(iperiod)
     & +.5*absorbpg*qdir*sin(fpi*theta)*a7(iperiod)
     & +.5*absorbpg*.5*(1.-absorbta)*qdir*sin(fpi*theta)*a5
     & +.5*absorbpg*qreflin(4,iperiod)*sin(fpi*theta)*a3
     & +.5*absorbpg*qscabsin(4,iperiod)*lfuselg*wfuselg
     & *a3/(absorbpg*a3+absorfbt*a4)
c
      fn(59)=-emisrftp*sig*t(59)**4*a2
     & -hhf*(t(59)-ta)*a2
     & -k(27)/th(27)*(t(59)-t(58))*a2
     & +emisrftp*qsky*a2
     & +absorftp*qdir*sin(fpi*theta)*a2
c
c find the weighted average temperature of the ends, tend
      aa1=lfuselg*wfuselg
      aa2=a1
      aa3=lfuselg*hfuselg
      aa4=aa3
      aa5=a2
      atot=aa1+aa2+aa3+aa4+aa5
      cc1=aa1/atot
      cc2=aa2/atot
```

```
      cc3=aa3/atot
      cc4=aa4/atot
      cc5=aa5/atot
      tend=cc1*t(35)+cc2*t(36)+cc3*t(38)+cc4*t(39)+cc5*t(61)
c
c for eqns: 42 (bottom of plexiglass facing the cabin floor below);
c 41 (floor of cabin inside (surface B)); 44 (left hand side of cabin
c inside (surface C)); and 45 (right hand side of cabin inside
c (surface A)): the effective convection coefficient must be found.
c these coeffs. are coupled with the surface temperatures.  therefore
c need to read in thermal diffusivity (thdiffus); kinematic viscosity
c (visckine); gravity (gravity); and Prandtl # (prandtl).
c from these, Rayleigh number (rayleigh); and Nusselt # (nusselt)
c must be found within the system of equation.        keff=k * nusselt.
c
c find the weighted plexiglass and roof bottom temperatures:
      c1=a1/(a1+a2)
      c2=a2/(a1+a2)
      tpgrf=c1*t(36)+c2*t(61)
c
      rayleig1=gravity*1./((tpgrf+t(35))/2.)*(t(35)-tpgrf)*th(24)**3/
     &           (thdiffus*visckine)
      if(t(35).lt.0.0.or.tpgrf.lt.0.0)then
           nusselt1=1.0
      else
           if(rayleig1.le.3e5)then
            nusselt1=1.0
           elseif(rayleig1.gt.3e5.and.rayleig1.le.7e9)then
            nusselt1=0.069*rayleig1**(1./3.)*prandtl**.074
           elseif(rayleig1.gt.7e9)then
            nusselt1=0.069*7e9**(1./3.)*prandtl**.074
c this is to ensure a reasonable nusselt1 number.  we do not want
c a runaway solution during the Newton-Raphson solution of the
c system of non-linear equations.
c           write(9,*)'Rayleigh number exceeded 7e9 for vertical'
           endif
      endif
c     write(9,*)'vertical',iperiod,ik,t(35),tpgrf,rayleig1,nusselt1
      rayleig2=gravity*1./((t(38)+t(39))/2.)*abs(t(38)-t(39))*
     &           th(11)**3/(thdiffus*visckine)
      if(t(38).lt.0.0.or.t(39).lt.0.0)then
           nusselt2=1.0
      else
           if(rayleig2.le.(1e3*(0.2+prandtl)/prandtl))then
             nusselt2=1.0
           elseif(rayleig2.gt.(1e3*(0.2+prandtl)/prandtl).and.rayleig2.lt.
     &          1.0e9)then
             nusselt2=0.18*((prandtl/(0.2+prandtl))*rayleig2)**0.29
           elseif(rayleig2.gt.1.0e9)then
             nusselt2=0.18*((prandtl/(0.2+prandtl))*1.0e9)**0.29
c this is to ensure a reasonable nusselt1 number.  we do not want
```

```
c a runaway solution during the Newton-Raphson solution of the
c system of non-linear equations.
c           write(9,*)'Rayleigh number exceeded 1e9 for horizontal'
           endif
      endif
c     write(9,*)'horizontal',iperiod,ik,t(38),t(39),rayleig2,nusselt2
c
c bottom of plexiglass facing the cabin floor below.
c eqns: eqn 42 (t36);& eqn 48 (JJ9)
c the plexiglass and roof bottom are treated as "one" unit,
c (surface 4), for determining radiosity JJ9 and qnet
      emispgrf=a1/(a1+a2)*emispg+a2/(a1+a2)*emisrfbt
      qnet=(sig*tpgrf**4-jj(9))/((1.-emispgrf)/emispgrf)
      qpg=emispg*sig*t(36)**4-emispg/(a3*emispg+a4*emisrfbt)*
     &    (a3*emispg*sig*t(36)**4+a4*emisrfbt*sig*t(61)**4-qnet*(a3+a4))
      fn(42)=-qpg*a3
     & -nusselt1*k(24)/th(24)*(tpgrf-t(35))*a3
     & +k(22)/th(22)*(t(37)-t(36))*a1
     & +.5*absorbpg*qdir*cos(fpi*theta)*a6(iperiod)
     & +.5*absorbpg*qdir*sin(fpi*theta)*a7(iperiod)
     & +.5*absorbpg*.5*(1.-absorbta)*qdir*sin(fpi*theta)*a5
     & +.5*absorbpg*qreflin(4,iperiod)*sin(fpi*theta)*a3
     & +.5*absorbpg*qscabsin(4,iperiod)*lfuselg*wfuselg
     & *a3/(absorbpg*a3+absorfbt*a4)
c fn48:
      fn(48)=-qnet+(jj(9)-jj(11))/(1./fc31)+(jj(9)-jj(10))/(1./fc32)
     & +(jj(9)-jj(8))/(1./fc34)+(jj(9)-sig*tend**4)/(1./fc35)
     & +(jj(9)-sig*tend**4)/(1./fc36)
c
c equation 61 (t61) (roof bottom surface):
      qrfbt=emisrfbt*sig*t(61)**4-emisrfbt/(a3*emispg+a4*emisrfbt)*
     &    (a3*emispg*sig*t(36)**4+a4*emisrfbt*sig*t(61)**4-qnet*(a3+a4))
      fn(61)=-qrfbt*a4
     & -nusselt1*k(24)/th(24)*(tpgrf-t(35))*a4
     & +k(28)/th(28)*(t(60)-t(61))*a2
     & +absorfbt*qreflin(4,iperiod)*sin(fpi*theta)*a4
     & +absorfbt*qscabsin(4,iperiod)*lfuselg*wfuselg
     & *a4/(absorbpg*a3+absorfbt*a4)
c
c left hand side of cabin inside (surface C)
c eqn 44 (t38);& eqn 47 (JJ8)
      qnet=(sig*t(38)**4-jj(8))/((1.-emisfi)/emisfi)
      fn(44)=-qnet-nusselt2*k(11)/th(11)*(t(38)-t(39))
     & +k(23)/th(23)*(t(20)-t(38))
     & +absorbfi*qreflin(3,iperiod)*cos(fpi*theta)
     & +qscabsin(3,iperiod)
      fn(47)=-qnet+(jj(8)-jj(11))/(1./fc41)+(jj(8)-jj(10))/(1./fc42)
     & +(jj(8)-jj(9))/(1./fc43)+(jj(8)-sig*tend**4)/(1./fc45)
     & +(jj(8)-sig*tend**4)/(1./fc46)
c right hand side of cabin inside (surface A)
c eqn 45 (t39);& eqn 49 (JJ10)
```

```
      qnet=(sig*t(39)**4-jj(10))/((1.-emisfi)/emisfi)
      fn(45)=-qnet-k(23)/th(23)*(t(39)-t(21))
     & +nusselt2*k(11)/th(11)*(t(38)-t(39))
     & +absorbfi*qreflin(1,iperiod)*cos(fpi*theta)
     & +qscabsin(1,iperiod)
      fn(49)=-qnet+(jj(10)-jj(11))/(1./fc21)+(jj(10)-jj(9))/(1./fc23)
     & +(jj(10)-jj(8))/(1./fc24)+(jj(10)-sig*tend**4)/(1./fc25)
     & +(jj(10)-sig*tend**4)/(1./fc26)
c floor of cabin inside (surface B)
c eqn 41 (t35):& eqn 50 (JJ11)
      qnet=(sig*t(35)**4-jj(11))/((1.-emisfl)/emisfl)
      fn(41)=-qnet-k(21)/th(21)*(t(35)-t(34))
     & +nusselt1*k(24)/th(24)*(tpgrf-t(35))
     & +absorbfl*qreflin(2,iperiod)*sin(fpi*theta)
     & +qscabsin(2,iperiod)
      fn(50)=-qnet+(jj(11)-jj(10))/(1./fc12)+(jj(11)-jj(9))/(1./fc13)
     & +(jj(11)-jj(8))/(1./fc14)+(jj(11)-sig*tend**4)/(1./fc15)
     & +(jj(11)-sig*tend**4)/(1./fc16)
c
c now find the jacobian values for the current t values
c
      call jacobian(hhf,hhw,hht,emisf,emisw,eemisf,eemisw,rff,
     &                 rfw,nusselt1,nusselt2,c1,c2,cc1,cc2,cc3,
     &                 cc4,cc5,tend,tpgrf,emispgrf,rlwng)
c
c just a dummy for using ik, (otherwise compiler warning)
c ik maybe necessary for Rayleigh check, in case during debugging
      dummyik=ik
      return
      end
c
      subroutine jacobian(hhf,hhw,hht,emisf,emisw,eemisf,eemisw,rff,
     &                       rfw,nusselt1,nusselt2,c1,c2,cc1,cc2,cc3,
     &                       cc4,cc5,tend,tpgrf,emispgrf,rlwng)
c purpose: calculates and return the jacobian values
c at each new t values
c called from: thermodl
c calls:none
      common/c1/n,ntrial,tolt,tolfn
      common/c2/t(200),fn(200),jacob(200,200)
      common/c3/th(100),k(100)
      common/c4/widthwng,lengtwng,hwng,locwng,lplane,lfuselg,hfuselg,
     &          wfuselg
      common/c5/trnsm,absorbta,emista,tarmd,densta,conducta,shcta
      common/c6/absorbff,emisff,absorbww,emisww,absorbfl,emisfl,absorbfi
     &,emisfi,absorbpg,emispg,absorftp,emisrftp,absorfbt,emisrfbt
     &,absorbfb,emisfb
      common/c7/nperiods,envtdata(100,20)
      common/c10/aircondc,thdiffus,visckine,prandtl
      common/c12/a1,a2,a3,a4,a5,a6(100),a7(100)
      common/vf1/fbwa(6,6),fbwb(6,6)
```

```
      common/vf2/fa11,fa12,fa13,fa14,fa15,fa16,fa21,fa22,fa23,fa24,
     &            fa25,fa26,fa31,fa32,fa33,fa34,fa35,fa36,fa41,fa42,
     &            fa43,fa44,fa45,fa46,fa51,fa52,fa53,fa54,fa55,fa56,
     &            fa61,fa62,fa63,fa64,fa65,fa66
      common/vf4/fa57,fa68
      common/vf5/fc11,fc12,fc13,fc14,fc15,fc16,fc21,fc22,fc23,fc24,
     &            fc25,fc26,fc31,fc32,fc33,fc34,fc35,fc36,fc41,fc42,
     &            fc43,fc44,fc45,fc46,fc51,fc52,fc53,fc54,fc55,fc56,
     &            fc61,fc62,fc63,fc64,fc65,fc66
      common/facttarm/fact
      real jacob,k,nusselt1,nusselt2
      parameter(sig=0.1714e-8)
      parameter(gravity=32.2)
c
c initialize: (most jacobian coefficients are zero)
      do 110 i=1,n
           do 110 j=1,n
             jacob(i,j)=0.
 110  continue
c
c left-wing conduction (eqn. 1 & 2)
c
      do 120 i=1,2
            jacob(i,i)=-k(i)/th(i)
            jacob(i,i+1)=k(i)/th(i)+k(i+1)/th(i+1)
            jacob(i,i+2)=-k(i+1)/th(i+1)
 120  continue
c
c left-wing conduction (eqn. 5 & 6)
c
      do 125 i=5,6
            jacob(i,i)=-k(i)/th(i)
            jacob(i,i+1)=k(i)/th(i)+k(i+1)/th(i+1)
            jacob(i,i+2)=-k(i+1)/th(i+1)
 125  continue
c
c left-wing conduction (eqn. 3,4,62&63)
c
      jacob(3,3)=-k(3)/th(3)
      jacob(3,4)=k(3)/th(3)+k(4)/th(4)
      jacob(3,62)=-k(4)/th(4)
c
      jacob(4,4)=-k(4)/th(4)
      jacob(4,62)=k(4)/th(4)+k(29)/th(29)
      jacob(4,63)=-k(29)/th(29)
c
      jacob(62,5)=-k(30)/th(30)
      jacob(62,62)=-k(29)/th(29)
      jacob(62,63)=k(29)/th(29)+k(30)/th(30)
c
      jacob(63,5)=k(30)/th(30)+k(5)/th(5)
```

```
      jacob(63,6)=-k(5)/th(5)
      jacob(63,63)=-k(30)/th(30)
c
c right-wing conduction (eqn. 7 & 8)
c
      do 130 i=1,2
            jacob(i+6,i+8)=-k(i)/th(i)
            jacob(i+6,i+9)=k(i)/th(i)+k(i+1)/th(i+1)
            jacob(i+6,i+10)=-k(i+1)/th(i+1)
 130  continue
c
c right-wing conduction (eqn. 11 & 12)
c
      do 135 i=5,6
            jacob(i+6,i+8)=-k(i)/th(i)
            jacob(i+6,i+9)=k(i)/th(i)+k(i+1)/th(i+1)
            jacob(i+6,i+10)=-k(i+1)/th(i+1)
 135  continue
c
c right-wing conduction (eqn. 9,10,64&65)
c
      jacob(9,11)=-k(3)/th(3)
      jacob(9,12)=k(3)/th(3)+k(4)/th(4)
      jacob(9,64)=-k(4)/th(4)
c
      jacob(10,12)=-k(4)/th(4)
      jacob(10,64)=k(4)/th(4)+k(29)/th(29)
      jacob(10,65)=-k(29)/th(29)
c
      jacob(64,13)=-k(30)/th(30)
      jacob(64,64)=-k(29)/th(29)
      jacob(64,65)=k(29)/th(29)+k(30)/th(30)
c
      jacob(65,13)=k(30)/th(30)+k(5)/th(5)
      jacob(65,14)=-k(5)/th(5)
      jacob(65,65)=-k(30)/th(30)
c
c left fuselage conduction (eqn. 13 to 14)
      do 140 i=1,2
            jacob(i+12,i+16)=-k(i+7)/th(i+7)
            jacob(i+12,i+17)=k(i+7)/th(i+7)+k(i+8)/th(i+8)
            jacob(i+12,i+18)=-k(i+8)/th(i+8)
 140  continue
c add eqn. 17, recently modified
      jacob(17,19)=-k(10)/th(10)
      jacob(17,20)=k(10)/th(10)+k(23)/th(23)
      jacob(17,38)=-k(23)/th(23)
c right fuselage conduction (eqn. 15 to 16)
      do 150 i=1,2
            jacob(i+14,i+20)=-k(11-i)/th(11-i)
            jacob(i+14,i+21)=k(11-i)/th(11-i)+k(10-i)/th(10-i)
```

```
            jacob(i+14,i+22)=-k(10-i)/th(10-i)
 150  continue
c add eqn. 18, recently modified
      jacob(18,21)=k(23)/th(23)+k(10)/th(10)
      jacob(18,22)=-k(10)/th(10)
      jacob(18,39)=-k(23)/th(23)
c fuselage-wing junction
c wing portion (i=1 implies left hand side. i=2 implies right hand side)
c (eqns. 23 to 26)
      do 180 i=1,2
           jacob(23+(i-1)*2,1+(i-1)*8)=-(4*sig*t(1+(i-1)*8)**3)/
     &                                 ((1-rfw*eemisw)/eemisw)-hhw-k(1)/th(1)
           jacob(23+(i-1)*2,2+(i-1)*8)=k(1)/th(1)
           jacob(23+(i-1)*2,40+(i-1)*2)=1.*rfw/((1.-rfw*eemisw)/eemisw)
           jacob(24+(i-1)*2,1+(i-1)*8)=-(4*sig*t(1+(i-1)*8)**3)/
     &                                   ((1-rfw*eemisw)/eemisw)
           jacob(24+(i-1)*2,17+(i-1)*7)=-(4*fa57*emisf*sig*t(17+(i-1)*7)**3
     &    /(1/fa15))-(4*fa68*emisf*sig*t(17+(i-1)*7)**3/(1/fa16))
           jacob(24+(i-1)*2,40+(i-1)*2)=1.*rfw/((1.-rfw*eemisw)/eemisw)
     &                +(1/(1/fa12)+1/(1/fa13)+1/(1/fa14)+1/(1/fa15)+1/
     &                 (1/fa16))
           jacob(24+(i-1)*2,44+(i-1))=-1/(1/fa12)
 180  continue
c fuselage portion (i=1 implies left hand side. i=2 implies right hand side)
c (eqns. 27 to 30)
      do 190 i=1,2
      jacob(27+(i-1)*2,17+(i-1)*7)=-(4*sig*t(17+(i-1)*7)**3)/
     &                            ((1-rff*eemisf)/eemisf)-hhf-k(8)/th(8)
      jacob(27+(i-1)*2,18+(i-1)*5)=k(8)/th(8)
      jacob(27+(i-1)*2,44+(i-1))=1.*rff/((1.-rff*eemisf)/eemisf)
      jacob(28+(i-1)*2,17+(i-1)*7)=-(4*sig*t(17+(i-1)*7)**3)/
     &                                   ((1-rff*eemisf)/eemisf)
      jacob(28+(i-1)*2,40+(i-1)*2)=-1/(1/fa21)
      jacob(28+(i-1)*2,44+(i-1))=1.*rff/((1.-rff*eemisf)/eemisf)
     &                +(1/(1/fa21)+1/(1/fa23)+1/(1/fa24)+1/(1/fa25)+1/
     &                 (1/fa26))
 190  continue
c
c Eqns. 32...40; & 66,67 for conduction in the middle section of fuselage
c (through: bottom skin cover; through the spar; through the
c the upper skin of the spar box cap)
c
c Eqns. 32,33 & 34:
c
      do 195 i=1,3
           jacob(31+i,24+i)=-k(11+i)/th(11+i)
           jacob(31+i,25+i)=k(12+i)/th(12+i)+k(11+i)/th(11+i)
           jacob(31+i,26+i)=-k(12+i)/th(12+i)
 195  continue
c
c Eqns. 37,38,39 & 40:
```

```
c
      do 200 i=6,9
           jacob(31+i,24+i)=-k(11+i)/th(11+i)
           jacob(31+i,25+i)=k(12+i)/th(12+i)+k(11+i)/th(11+i)
           jacob(31+i,26+i)=-k(12+i)/th(12+i)
 200  continue
c
c Eqns. 35,36,66&67:
c
      jacob(35,28)=-k(15)/th(15)
      jacob(35,29)=k(32)/th(32)+k(15)/th(15)
      jacob(35,67)=-k(32)/th(32)
c
      jacob(36,29)=-k(32)/th(32)
      jacob(36,66)=-k(31)/th(31)
      jacob(36,67)=k(31)/th(31)+k(32)/th(32)
c
      jacob(66,30)=-k(16)/th(16)
      jacob(66,66)=k(16)/th(16)+k(31)/th(31)
      jacob(66,67)=-k(31)/th(31)
c
      jacob(67,30)=k(17)/th(17)+k(16)/th(16)
      jacob(67,31)=-k(17)/th(17)
      jacob(67,66)=-k(16)/th(16)
c
c add jacobian 43 for top of plexiglass:
      jacob(43,36)=k(22)/th(22)*a1
      jacob(43,37)=-4*emispg*sig*t(37)**3*a1
     &                -hhf*a1
     &                -k(22)/th(22)*a1
c add jacobian 59 for top of roof cover:
      jacob(59,58)=k(27)/th(27)*a2
      jacob(59,59)=-4*emisrftp*sig*t(59)**3*a2
     &                -hhf*a2
     &                -k(27)/th(27)*a2
c
c jacobian 57, 58 & 60 for internal conduction of roof cover:
c jacobian(57; 57, 58, 60):
      jacob(57,57)=-k(26)/th(26)*a2
     &                -k(25)/th(25)*a2
      jacob(57,58)=k(26)/th(26)*a2
      jacob(57,60)=k(25)/th(25)*a2
c jacobian(58: 57,58,59):
      jacob(58,57)=k(26)/th(26)*a2
      jacob(58,58)=-k(27)/th(27)*a2
     &                -k(26)/th(26)*a2
      jacob(58,59)=k(27)/th(27)*a2
c jacobian(60: 57, 60, 61)
      jacob(60,57)=k(25)/th(25)*a2
      jacob(60,60)=-k(25)/th(25)*a2
     &                -k(28)/th(28)*a2
```

```
      jacob(60,61)=k(28)/th(28)*a2
c
c for eqns: 42 (bottom of plexiglass facing the cabin floor below);
c 41 (floor of cabin inside (surface B)); 44 (left hand side of cabin
c inside (surface C)); and 45 (right hand side of cabin inside
c (surface A)): the effective convection coefficent must be found.
c these coeffs. are coupled with the surface temperatures.  therefore
c need to read in thermal diffusivity (thdiffus); kinematic viscosity
c (visckine); gravity (gravity); and Prandtl # (prandtl).
c from these, Rayleigh number (rayleigh); and Nusselt # (nusselt)
c must be found within the system of equation.        keff=k * nusselt.
c
c
c add jacobians 42, 61 & 48 (J9) for bottom of plexiglass
c and the bottom of roof cover (all inside cabin)
c     jacobian 42:
      if(nusselt1.eq.1.0)then
      jacob(42,35)=nusselt1*k(24)/th(24)*a3
      jacob(42,36)=-(4*emispg*sig*t(36)**3-
     &                emispg/(a3*emispg+a4*emisrfbt)*
     &    (4*a3*emispg*sig*t(36)**3-(a3+a4)/((1.-emispgrf)/emispgrf)*
     &    (4*sig*tpgrf**3*c1)))*a3
     &                -nusselt1*k(24)/th(24)*c1*a3
     &                -k(22)/th(22)*a1
      jacob(42,37)=k(22)/th(22)*a1
      jacob(42,48)=emispg/(a3*emispg+a4*emisrfbt)*
     &                (a3+a4)/((1.-emispgrf)/emispgrf)*a3
      jacob(42,61)=-(-emispg/(a3*emispg+a4*emisrfbt)*
     &    (4*a4*emisrfbt*sig*t(61)**3-(a3+a4)/((1.-emispgrf)/emispgrf)*
     &    (4*sig*tpgrf**3*c2)))*a3
     &                -nusselt1*k(24)/th(24)*c2*a3
      else
      value1=-0.069*(gravity/(.5*thdiffus*visckine))**(1./3.)
     &        *prandtl**0.074*th(24)
      partl35=(t(35)+tpgrf)**(-1./3.)*(4./3.)*(t(35)-tpgrf)**(1./3.)
     &          -(t(35)-tpgrf)**(4./3.)*(1./3.)*(t(35)+tpgrf)**(-4./3.)
      facnusel=-value1*partl35
      jacob(42,35)=facnusel*k(24)/th(24)*a3
      partl36=-(t(35)+tpgrf)**(-1./3.)*(4./3.)*(t(35)-tpgrf)**(1./3.)
     &          -(t(35)-tpgrf)**(4./3.)*(1./3.)*(t(35)+tpgrf)**(-4./3.)
      facnusel=value1*partl36
      jacob(42,36)=-(4*emispg*sig*t(36)**3-
     &                emispg/(a3*emispg+a4*emisrfbt)*
     &    (4*a3*emispg*sig*t(36)**3-(a3+a4)/((1.-emispgrf)/emispgrf)*
     &    (4*sig*tpgrf**3*c1)))*a3
     &                -facnusel*k(24)/th(24)*c1*a3
     &                -k(22)/th(22)*a1
      jacob(42,37)=k(22)/th(22)*a1
      jacob(42,48)=emispg/(a3*emispg+a4*emisrfbt)*
     &                (a3+a4)/((1.-emispgrf)/emispgrf)*a3
      partl61=-(t(35)+tpgrf)**(-1./3.)*(4./3.)*(t(35)-tpgrf)**(1./3.)
```

```
     &          -(t(35)-tpgrf)**(4./3.)*(1./3.)*(t(35)+tpgrf)**(-4./3.)
      facnusel=value1*partl61
      jacob(42,61)=-(-emispg/(a3*emispg+a4*emisrfbt)*
     &    (4*a4*emisrfbt*sig*t(61)**3-(a3+a4)/((1.-emispgrf)/emispgrf)*
     &    (4*sig*tpgrf**3*c2)))*a3
     &                -facnusel*k(24)/th(24)*c2*a3
      endif
c
c     jacobian 61:
      if(nusselt1.eq.1.0)then
      jacob(61,35)=nusselt1*k(24)/th(24)*a4
      jacob(61,36)=-(-emisrfbt/(a3*emispg+a4*emisrfbt)*
     &    (4*a3*emispg*sig*t(36)**3-(a3+a4)/((1.-emispgrf)/emispgrf)*
     &    (4*sig*tpgrf**3*c1)))*a4
     &                -nusselt1*k(24)/th(24)*c1*a4
      jacob(61,48)=emisrfbt/(a3*emispg+a4*emisrfbt)*
     &                (a3+a4)/((1.-emispgrf)/emispgrf)*a4
      jacob(61,60)=k(28)/th(28)*a2
      jacob(61,61)=-(4*emisrfbt*sig*t(61)**3-
     &                emisrfbt/(a3*emispg+a4*emisrfbt)*
     &    (4*a4*emisrfbt*sig*t(61)**3-(a3+a4)/((1.-emispgrf)/emispgrf)*
     &    (4*sig*tpgrf**3*c2)))*a4
     &                -nusselt1*k(24)/th(24)*c2*a4
     &                -k(28)/th(28)*a2
      else
      facnusel=-value1*partl35
      jacob(61,35)=facnusel*k(24)/th(24)*a4
      facnusel=value1*partl36
      jacob(61,36)=-(-emisrfbt/(a3*emispg+a4*emisrfbt)*
     &    (4*a3*emispg*sig*t(36)**3-(a3+a4)/((1.-emispgrf)/emispgrf)*
     &    (4*sig*tpgrf**3*c1)))*a4
     &                -facnusel*k(24)/th(24)*c1*a4
      jacob(61,48)=emisrfbt/(a3*emispg+a4*emisrfbt)*
     &                (a3+a4)/((1.-emispgrf)/emispgrf)*a4
      jacob(61,60)=k(28)/th(28)*a2
      facnusel=value1*partl61
      jacob(61,61)=-(4*emisrfbt*sig*t(61)**3-
     &                emisrfbt/(a3*emispg+a4*emisrfbt)*
     &    (4*a4*emisrfbt*sig*t(61)**3-(a3+a4)/((1.-emispgrf)/emispgrf)*
     &    (4*sig*tpgrf**3*c2)))*a4
     &                -facnusel*k(24)/th(24)*c2*a4
     &                -k(28)/th(28)*a2
      endif
c
c     jacobian 48:
      jacob(48,35)=-4*sig*tend**3*cc1/(1./fc35)
     &                -4*sig*tend**3*cc1/(1./fc36)
      jacob(48,36)=-4*sig*(tpgrf)**3*c1/
     &                ((1.-emispgrf)/emispgrf)
     &                -4*sig*tend**3*cc2/(1./fc35)
     &                -4*sig*tend**3*cc2/(1./fc36)
```

```
      jacob(48,38)=-4*sig*tend**3*cc3/(1./fc35)
     &                -4*sig*tend**3*cc3/(1./fc36)
      jacob(48,39)=-4*sig*tend**3*cc4/(1./fc35)
     &                -4*sig*tend**3*cc4/(1./fc36)
      jacob(48,61)=-4*sig*(tpgrf)**3*c2/
     &                ((1.-emispgrf)/emispgrf)
     &                -4*sig*tend**3*cc5/(1./fc35)
     &                -4*sig*tend**3*cc5/(1./fc36)
      jacob(48,47)=-1./(1/fc34)
      jacob(48,48)=1./((1.-emispgrf)/emispgrf)
     &                +(1/(1/fc31)+1/(1/fc32)+1/(1/fc34)+1/(1/fc35)+1/
     &                 (1/fc36))
      jacob(48,49)=-1./(1/fc32)
      jacob(48,50)=-1./(1/fc31)
c add eqns. 44 & 47 (left hand side of cabin interior (surface C))
c     jacobian 44:
      if(nusselt2.eq.1.0)then
      jacob(44,20)=k(23)/th(23)
      jacob(44,38)=-4*sig*t(38)**3/((1.-emisfi)/emisfi)
     &                -nusselt2*k(11)/th(11)-k(23)/th(23)
      jacob(44,39)=nusselt2*k(11)/th(11)
      jacob(44,47)=1./((1.-emisfi)/emisfi)
      else
      jacob(44,20)=k(23)/th(23)
      value2=0.18*(prandtl/(0.2+prandtl)*gravity/(.5*thdiffus*visckine)
     &        *th(11)**3)**0.29
      ft38t391=(t(38)+t(39))**(-0.29)*(t(38)-t(39))
     &    *0.29*(abs(t(38)-t(39)))**(-0.71)+(abs(t(38)-t(39)))**0.29
     &    *((t(38)-t(39))*(-0.29)*(t(38)+t(39))**(-1.29)
     &    +(t(38)+t(39))**(-0.29))
      facnusel=value2*ft38t391
      jacob(44,38)=-4*sig*t(38)**3/((1.-emisfi)/emisfi)
     &                -facnusel*k(11)/th(11)-k(23)/th(23)
      ft38t392=(t(38)+t(39))**(-0.29)*(t(38)-t(39))
     &    *(-0.29)*(abs(t(38)-t(39)))**(-0.71)+(abs(t(38)-t(39)))**0.29
     &    *((t(38)-t(39))*(-0.29)*(t(38)+t(39))**(-1.29)
     &    +(-1.)*(t(38)+t(39))**(-0.29))
      facnusel=-value2*ft38t392
      jacob(44,39)=facnusel*k(11)/th(11)
      jacob(44,47)=1./((1.-emisfi)/emisfi)
      endif
c
c     jacobian 47:
      jacob(47,35)=-4*sig*tend**3*cc1/(1./fc45)
     &                -4*sig*tend**3*cc1/(1./fc46)
      jacob(47,36)=-4*sig*tend**3*cc2/(1./fc45)
     &                -4*sig*tend**3*cc2/(1./fc46)
      jacob(47,38)=-4*sig*t(38)**3/((1.-emisfi)/emisfi)
     &                -4*sig*tend**3*cc3/(1./fc45)
     &                -4*sig*tend**3*cc3/(1./fc46)
      jacob(47,39)=-4*sig*tend**3*cc4/(1./fc45)
```

```
     &                -4*sig*tend**3*cc4/(1./fc46)
      jacob(47,61)=-4*sig*tend**3*cc5/(1./fc45)
     &                -4*sig*tend**3*cc5/(1./fc46)
      jacob(47,47)=1./((1.-emisfi)/emisfi)
     &                +(1/(1/fc41)+1/(1/fc42)+1/(1/fc43)+1/(1/fc45)+1/
     &                 (1/fc46))
      jacob(47,48)=-1./(1/fc43)
      jacob(47,49)=-1./(1/fc42)
      jacob(47,50)=-1./(1/fc41)
c add eqns. 45 & 49 (left hand side of cabin interior (surface C))
c     jacobian 45:
      if(nusselt2.eq.1.0)then
      jacob(45,21)=k(23)/th(23)
      jacob(45,38)=nusselt2*k(11)/th(11)
      jacob(45,39)=-4*sig*t(39)**3/((1.-emisfi)/emisfi)
     &                -nusselt2*k(11)/th(11)-k(23)/th(23)
      jacob(45,49)=1./((1.-emisfi)/emisfi)
      else
      jacob(45,21)=k(23)/th(23)
      facnusel=value2*ft38t391
      jacob(45,38)=facnusel*k(11)/th(11)
      facnusel=-value2*ft38t392
      jacob(45,39)=-4*sig*t(39)**3/((1.-emisfi)/emisfi)
     &                -facnusel*k(11)/th(11)-k(23)/th(23)
      jacob(45,49)=1./((1.-emisfi)/emisfi)
      endif
c
c
c     jacobian 49:
      jacob(49,35)=-4*sig*tend**3*cc1/(1./fc25)
     &                -4*sig*tend**3*cc1/(1./fc26)
      jacob(49,36)=-4*sig*tend**3*cc2/(1./fc25)
     &                -4*sig*tend**3*cc2/(1./fc26)
      jacob(49,38)=-4*sig*tend**3*cc3/(1./fc25)
     &                -4*sig*tend**3*cc3/(1./fc26)
      jacob(49,39)=-4*sig*t(39)**3/((1.-emisfi)/emisfi)
     &                -4*sig*tend**3*cc4/(1./fc25)
     &                -4*sig*tend**3*cc4/(1./fc26)
      jacob(49,61)=-4*sig*tend**3*cc5/(1./fc25)
     &                -4*sig*tend**3*cc5/(1./fc26)
      jacob(49,47)=-1./(1/fc24)
      jacob(49,48)=-1./(1/fc23)
      jacob(49,49)=1./((1.-emisfi)/emisfi)
     &                +(1/(1/fc21)+1/(1/fc23)+1/(1/fc24)+1/(1/fc25)+1/
     &                 (1/fc26))
      jacob(49,50)=-1./(1/fc21)
c add eqns. 41 & 50 (floor (top of spar cap) of cabin interior
c (surface C))
c     jacobian 41:
      if(nusselt1.eq.1.0)then
      jacob(41,34)=k(21)/th(21)
```

```
      jacob(41,35)=-4*sig*t(35)**3/((1.-emisfl)/emisfl)
     &                -nusselt1*k(24)/th(24)-k(21)/th(21)
      jacob(41,36)=nusselt1*k(24)/th(24)*c1
      jacob(41,50)=1./((1.-emisfl)/emisfl)
      jacob(41,61)=nusselt1*k(24)/th(24)*c2
      else
      jacob(41,34)=k(21)/th(21)
      facnusel=-value1*partl35
      jacob(41,35)=-4*sig*t(35)**3/((1.-emisfl)/emisfl)
     &                -facnusel*k(24)/th(24)-k(21)/th(21)
      facnusel=value1*partl36
      jacob(41,36)=facnusel*k(24)/th(24)*c1
      jacob(41,50)=1./((1.-emisfl)/emisfl)
      facnusel=value1*partl61
      jacob(41,61)=facnusel*k(24)/th(24)*c2
      endif
c
c     jacobian 50:
      jacob(50,35)=-4*sig*t(35)**3/((1.-emisfl)/emisfl)
     &                -4*sig*tend**3*cc1/(1./fc15)
     &                -4*sig*tend**3*cc1/(1./fc16)
      jacob(50,36)=-4*sig*tend**3*cc2/(1./fc15)
     &                -4*sig*tend**3*cc2/(1./fc16)
      jacob(50,38)=-4*sig*tend**3*cc3/(1./fc15)
     &                -4*sig*tend**3*cc3/(1./fc16)
      jacob(50,39)=-4*sig*tend**3*cc4/(1./fc15)
     &                -4*sig*tend**3*cc4/(1./fc16)
      jacob(50,61)=-4*sig*tend**3*cc5/(1./fc15)
     &                -4*sig*tend**3*cc5/(1./fc16)
      jacob(50,47)=-1./(1/fc14)
      jacob(50,48)=-1./(1/fc13)
      jacob(50,49)=-1./(1/fc12)
      jacob(50,50)=1./((1.-emisfl)/emisfl)
     &                +(1/(1/fc12)+1/(1/fc13)+1/(1/fc14)+1/(1/fc15)+1/
     &                 (1/fc16))
c
c
c wing bottom, facing tarmac. there are a total of 12 eqns. to consider
c within three sections of the wing: LHS(section: 1); RHS (section 2)
c MIDDLE (section 3, ie underneath the fuselage). these eqns. are:
c LHS(section 1): fn19(t8),fn20(j2),fn51(t51),fn54(j12);
c RHS(section 2): fn21(t16),fn22(j4),fn53(t53),fn56(j14);
c MIDDLE(section 3): fn31(t25),fn46(j7),fn52(t52),fn55(j13).
c simple two-dimensional conduction from the unsheltered tarmac
c surface to the sheltered surface is considered.  a tarmac
c thickness tarmd is assumed.  also the bottom of the sheltered
c tarmac is considered adiabatic (insulated) so that no q
c is assumed to sip into the ground (being conservative).
c also for the depth, tarmd, the temperature of the unsheltered
c tarmac is assumed constant.  note, qtarm and ttarm are known,
c for they are unsheltered tarmac temperatures.
```

```
c
c
c LHS(section 1): jacobian: 19;20;51&54;
      jacob(19,7)=k(7)/th(7)
      jacob(19,8)=-(4*sig*t(8)**3)/((1-emisw)/emisw)
     &            -hhw-k(7)/th(7)
      jacob(19,41)=1./((1.-emisw)/emisw)
      jacob(20,8)=-(4*sig*t(8)**3)/((1-emisw)/emisw)
      jacob(20,41)=1./((1.-emisw)/emisw)
     &     +1/(1/fbwa(3,1))+1/(1/fbwa(3,2))+1/(1/fbwa(3,4))
     &     +1/(1/fbwa(3,5))+1/(1/fbwa(3,6))
      jacob(20,54)=-1/(1/fbwa(3,1))
      jacob(20,55)=-fbwb(4,1)/(1/fbwa(3,2))
      jacob(20,56)=-fbwa(4,1)*fbwb(4,2)/(1/fbwa(3,2))
      jacob(51,51)=(-4*sig*t(51)**3/((1.-emista)/emista)-hht)
     &            *rlwng*widthwng
     &  -2*conducta/(fact*widthwng)*tarmd*rlwng
     &  -conducta/(fact*widthwng)*tarmd*widthwng
     &  -conducta/(0.5*wfuselg+0.5*rlwng)*tarmd*widthwng
      jacob(51,52)=conducta/(0.5*wfuselg+0.5*rlwng)*tarmd*widthwng
      jacob(51,54)=1./((1.-emista)/emista)*rlwng*widthwng
      jacob(54,51)=-4*sig*t(51)**3/((1.-emista)/emista)
      jacob(54,43)=-fbwa(4,3)*fbwb(4,2)/(1/fbwa(1,2))
      jacob(54,46)=-fbwb(4,3)/(1/fbwa(1,2))
      jacob(54,54)=1/((1-emista)/emista)
     &     +1/(1/fbwa(1,2))+1/(1/fbwa(1,3))+1/(1/fbwa(1,4))
     &     +1/(1/fbwa(1,5))+1/(1/fbwa(1,6))
      jacob(54,41)=-1/(1/fbwa(1,3))
c
c RHS(section 2): jacobian: 21;22;53&56;
      jacob(21,15)=k(7)/th(7)
      jacob(21,16)=-(4*sig*t(16)**3)/((1-emisw)/emisw)
     &            -hhw-k(7)/th(7)
      jacob(21,43)=1./((1.-emisw)/emisw)
      jacob(22,16)=-(4*sig*t(16)**3)/((1-emisw)/emisw)
      jacob(22,43)=1./((1.-emisw)/emisw)
     &     +1/(1/fbwa(3,1))+1/(1/fbwa(3,2))+1/(1/fbwa(3,4))
     &     +1/(1/fbwa(3,5))+1/(1/fbwa(3,6))
      jacob(22,54)=-fbwa(2,1)*fbwb(2,4)/(1/fbwa(3,4))
      jacob(22,55)=-fbwb(2,1)/(1/fbwa(3,4))
      jacob(22,56)=-1/(1/fbwa(3,1))
      jacob(53,52)=conducta/(0.5*wfuselg+0.5*rlwng)*tarmd*widthwng
      jacob(53,53)=(-4*sig*t(53)**3/((1.-emista)/emista)-hht)
     &            *rlwng*widthwng
     &  -2*conducta/(fact*widthwng)*tarmd*rlwng
     &  -conducta/(fact*widthwng)*tarmd*widthwng
     &  -conducta/(0.5*wfuselg+0.5*rlwng)*tarmd*widthwng
      jacob(53,56)=1./((1.-emista)/emista)*rlwng*widthwng
      jacob(56,53)=-4*sig*t(53)**3/((1.-emista)/emista)
      jacob(56,41)=-fbwa(2,3)*fbwb(2,4)/(1/fbwa(1,4))
      jacob(56,43)=-1/(1/fbwa(1,3))
```

```
      jacob(56,46)=-fbwb(2,3)/(1/fbwa(1,4))
      jacob(56,56)=1/((1-emista)/emista)
     &     +1/(1/fbwa(1,2))+1/(1/fbwa(1,3))+1/(1/fbwa(1,4))
     &     +1/(1/fbwa(1,5))+1/(1/fbwa(1,6))
c
c MIDDLE(section 3): jacobian: 31;46;52&55:
c
      jacob(31,25)=-(4*sig*t(25)**3)/((1-emisfb)/emisfb)
     &            -hhf-k(12)/th(12)
      jacob(31,26)=k(12)/th(12)
      jacob(31,46)=1./((1.-emisfb)/emisfb)
      jacob(46,25)=-(4*sig*t(25)**3)/((1-emisfb)/emisfb)
      jacob(46,46)=1./((1.-emisfb)/emisfb)
     &     +1/(1/fbwb(3,1))+1/(1/fbwb(3,2))+1/(1/fbwb(3,4))
     &     +1/(1/fbwb(3,5))+1/(1/fbwb(3,6))
      jacob(46,54)=-fbwa(2,1)/(1/fbwb(3,4))
      jacob(46,55)=-1/(1/fbwb(3,1))
      jacob(46,56)=-fbwa(4,1)/(1/fbwb(3,2))
      jacob(52,51)=conducta/(0.5*wfuselg+0.5*rlwng)*tarmd*widthwng
      jacob(52,52)=(-4*sig*t(52)**3/((1.-emista)/emista)-hht)
     &            *wfuselg*widthwng
     &  -2*conducta/(fact*widthwng)*tarmd*wfuselg
     &  -conducta/(0.5*wfuselg+0.5*rlwng)*tarmd*widthwng
     &  -conducta/(0.5*wfuselg+0.5*rlwng)*tarmd*widthwng
      jacob(52,53)=conducta/(0.5*wfuselg+0.5*rlwng)*tarmd*widthwng
      jacob(52,55)=1./((1.-emista)/emista)*wfuselg*widthwng
      jacob(55,52)=-4*sig*t(52)**3/((1.-emista)/emista)
      jacob(55,41)=-fbwa(2,3)/(1/fbwb(1,4))
      jacob(55,43)=-fbwa(4,3)/(1/fbwb(1,2))
      jacob(55,46)=-1/(1/fbwb(1,3))
      jacob(55,55)=1/((1-emista)/emista)
     &     +1/(1/fbwb(1,2))+1/(1/fbwb(1,3))+1/(1/fbwb(1,4))
     &     +1/(1/fbwb(1,5))+1/(1/fbwb(1,6))
      return
      end
c
      subroutine tarmmodl(absorbta,emista,qtarm,t)
c purpose: determine the tarmac emission and tarmac temperature
c called from: solution
c calls: none
      common/c7/nperiods,envtdata(100,20)
      common/convect/hf(100),hw(100),ht(100)
      parameter(fpi=3.141593/180.)
      parameter(sig=0.1714e-8)
      parameter(ntrial=1000,tolt=0.0001,tolf=0.0001)
      real jacob
      dimension qtarm(100),t(100)
c assume no heat loss through the ground
c (ie ground is adiabatic/insulated).
      do 20 i=1,nperiods
      theta=envtdata(i,1)
```

```
      ta=envtdata(i,2)
      tsky=envtdata(i,3)
      qdir=envtdata(i,5)
      h=ht(i)
      t(i)=100.
      do 10 k=1,ntrial
          f=absorbta*qdir*sin(fpi*theta)-emista*sig*(t(i)**4-tsky**4)
     &    -h*(t(i)-ta)
          errf=abs(f)
          if(errf.le.tolf)then
            qtarm(i)=emista*sig*t(i)**4
            goto 20
          endif
          p=-f
          jacob=-4*emista*sig*t(i)**3-h
          delt=p/jacob
          t(i)=t(i)+delt
          errt=abs(delt)
          if(errt.le.tolt)then
            qtarm(i)=emista*sig*t(i)**4
            goto 20
          endif
 10   continue
 20   continue
      return
      end
c
      subroutine infrqsky(qqsky)
c purpose: determines the sky radiation
c called from: solution
c calls: none
      common/c7/nperiods,envtdata(100,20)
      dimension qqsky(100)
      parameter(sig=0.1714e-8)
      do 10 i=1,nperiods
          tsky=envtdata(i,3)
 10   qqsky(i)=sig*tsky**4
      return
      end
c
      subroutine ludcmp
      common/c1/n,ntrial,tolx,tolf
      common/c2/x(200),fvec(200),jacob(200,200)
      common/sc1/indx(200),p(200)
      real jacob
      parameter(tiny=1.0e-20)
c purpose: given jacob(1:n,1:n), with physical dimension 100 by 100,
c this routine replaces it by the LU decomposition of a rowwise
c permutation of itself. jacob is also output, arranged as in eqn(2.3.14)
c of Numerical Recipes in Fortran (William H. press et.al).
c indx(1:n) is an output vector that records the row permutation
```

```
c affected by the partial pivot; d is output as plus minus 1 depending on
c whether the number of row interchanges was even or odd, respectively.
c this routine is used in combination with lubksb to solve linear equations
c or invert a matrix.  note: tiny=a small number (for ill-conditioned pivot)
c called from: newtraph, updradio
c calls: none
      dimension vv(200)
c vv stores the implicit scaling of each row
c no row interchanges yet
      d=1.
c loop over rows to get the implicit scaling information
      do 12 i=1,n
          aamax=0.
          do 11 j=1,n
            if(abs(jacob(i,j)).gt.aamax)aamax=abs(jacob(i,j))
 11       continue
          if(aamax.eq.0)pause 'singular matrix in ludcmp'
c no nonzero largest element
c save the scaling
          vv(i)=1./aamax
 12   continue
c this is the loop over columns of Crout's method; this is
c equation (2.3.12), except for i=j
      do 19 j=1,n
          do 14 i=1,j-1
            sum=jacob(i,j)
            do 13 k=1,i-1
              sum=sum-jacob(i,k)*jacob(k,j)
 13         continue
            jacob(i,j)=sum
 14       continue
c initialize for the search for largest pivot element
          aamax=0.
c this is i=j of eqn.(2.3.12) and i=j+1...n of eqn.(2.3.13)
          do 16 i=j,n
            sum=jacob(i,j)
            do 15 k=1,j-1
              sum=sum-jacob(i,k)*jacob(k,j)
 15         continue
            jacob(i,j)=sum
c figure of merit for the pivot; is it better than the best so far?
            dum=vv(i)*abs(sum)
            if (dum.ge.aamax)then
              imax=i
              aamax=dum
            endif
 16       continue
c do we need to interchange rows? yes, do so
          if(j.ne.imax)then
            do 17 k=1,n
              dum=jacob(imax,k)
```

```
            jacob(imax,k)=jacob(j,k)
            jacob(j,k)=dum
 17       continue
c ...and change the parity of d; also interchange the scale factor
          d=-d
          vv(imax)=vv(j)
        endif
        indx(j)=imax
        if(jacob(j,j).eq.0)jacob(j,j)=tiny
c if the pivot element is zero the matrix is singular (at least
c to the precision of the algorithm). for some applications on singular
c matrices, it is desirable to substitute tiny for zero.
c now, finally divide by the pivot element
        if(j.ne.n)then
          dum=1./jacob(j,j)
          do 18 i=j+1,n
            jacob(i,j)=jacob(i,j)*dum
 18       continue
        endif
c go back for the next column in the reduction
 19   continue
      return
      end
c
      subroutine lubksb
      common/c1/n,ntrial,tolx,tolf
      common/c2/x(200),fvec(200),jacob(200,200)
      common/sc1/indx(200),b(200)
      real jacob
c purpose: solves the set of n linear equations a.x=b.
c here jacob is input, not as the
c matrix jacob but rather as its LU decomposition, determined by the routine
c ludcmp. indx is input as the permutation vector returned by ludcmp.
c b(1:n) is input as the right-hand side vector b, and returns with the
c solution vector.  jacob and index are not modified by this routine and can
c be left in place for successive calls with different right-hand sides b.
c this    routine takes into account the possibility that b will begin with many
c zero elements, so it is efficient for use in matrix inversion (if needed).
c called from: newtraph,updradio
c calls: none
      ii=0
c when ii is set to a positive value, it will become the index
c of the first nonvanishing element of b.  we now do the forward substitution,
c eqn. (2.3.6).  the only new wrinkle is to unscramble the permutation as we
c go.
      do 12 i=1,n
        ll=indx(i)
        sum=b(ll)
        b(ll)=b(i)
        if(ii.ne.0)then
          do 11 j=ii,i-1
```

```
            sum=sum-jacob(i,j)*b(j)
 11         continue
           elseif(sum.ne.0)then
c a nonzero element was encountered, so from now on we will have
c to do the sums in the loop above.
            ii=i
           endif
           b(i)=sum
 12   continue
c now we do the backsubstitution, eqn. (2.3.7)
      do 14 i=n,1,-1
           sum=b(i)
           do 13 j=i+1,n
            sum=sum-jacob(i,j)*b(j)
 13        continue
c store a component of the solution vector x.
           b(i)=sum/jacob(i,i)
 14   continue
      return
      end

subroutine qrefcab
c purpose: determines the intercepted solar radiation and the absorbed
c            diffuse radiation in the cabin.  cabin treated as a partial
c            cavity
c called from: solution
c calls: diffsola
      common/c4/widthwng,lengtwng,hwng,locwng,lplane,lfuselg,hfuselg,
     &              wfuselg
      common/c5/trnsm,absorbta,emista,tarmd,densta,conducta,shcta
      common/c6/absorbff,emisff,absorbww,emisww,absorbfl,emisfl,absorbfi
     &,emisfi,absorbpg,emispg,absorftp,emisrftp,absorfbt,emisrfbt
     &,absorbfb,emisfb
      common/c7/nperiods,envtdata(100,20)
      common/c9/scatffl,scatffi,scatfw,scatff
      common/c12/a1,a2,a3,a4,a5,a6(100),a7(100)
      common/reflecq/qreflin(6,100),qscabsin(6,100),qreflfwr(6,100),
     &qreflfwl(6,100),qscabfwr(6,100),qscabfwl(6,100),qabstwa1(6,100),
     &qabstwa2(6,100),qabstwb(6,100)
      common/vf5/fc11,fc12,fc13,fc14,fc15,fc16,fc21,fc22,fc23,fc24,
     &              fc25,fc26,fc31,fc32,fc33,fc34,fc35,fc36,fc41,fc42,
     &              fc43,fc44,fc45,fc46,fc51,fc52,fc53,fc54,fc55,fc56,
     &              fc61,fc62,fc63,fc64,fc65,fc66
      dimension qscat(6,100)
      dimension f(6,6),absorb(6),ttrnsm(6,100)
      parameter(fpi=3.141593/180.)
      real lfuselg
c
c Variables:
c qreflin(,)=intercepted solar radiation (both direct and specular)
c             in the cabin
```

```
c qscabsin(,)=absorbed diffuse solar radiation in the cabin
c
c     initialize
      do 9 j=1,nperiods
           do 9 i=1,6
             ttrnsm(i,j)=0.0
             qreflin(i,j)=0.0
 9           qscat(i,j)=0.0
c find qrefl for surface A (right hand side of cabin interior)
c right hand side means as you seated normally and face the wind shield
      do 10 i=1,nperiods
       theta=fpi*envtdata(i,1)
       qdir=envtdata(i,5)
       fopndirs=envtdata(i,8)
       if(theta.ge.0.0.and.theta.le.atan(hfuselg/(2*wfuselg)))then
           qreflin(1,i)=qdir*trnsm*fopndirs
           qscat(1,i)=scatffi*(1.-absorbfi)*qreflin(1,i)*cos(theta)
       elseif(theta.gt.atan(hfuselg/(2*wfuselg)).and.theta.lt.
     & atan(hfuselg/wfuselg))then
           qreflin(1,i)=qdir*trnsm*fopndirs*(1.+(1.-scatffl)*(1.-absorbfl)
     &     *(1.-scatffi)**2*(1.-absorbfi)**2)
           qscat(1,i)=scatffi*(1.-absorbfi)*qreflin(1,i)*cos(theta)
       elseif(theta.eq.atan(hfuselg/wfuselg))then
           qreflin(1,i)=qdir*trnsm*fopndirs
           qscat(1,i)=scatffi*(1.-absorbfi)*qreflin(1,i)*cos(theta)
       elseif(theta.gt.atan(hfuselg/wfuselg).and.theta.le.(fpi*90))
     & then
           qreflin(1,i)=qdir*trnsm*fopndirs*(1.+(1.-scatffl)*(1.-absorbfl))
           qscat(1,i)=scatffi*(1.-absorbfi)*qreflin(1,i)*cos(theta)
       endif
 10    continue
c find qrefl for surface B (floor of cabin interior)
       do 20 i=1,nperiods
       theta=fpi*envtdata(i,1)
       qdir=envtdata(i,5)
       fopndirs=envtdata(i,8)
       if(theta.ge.0.0.and.theta.le.atan(hfuselg/(2*wfuselg)))then
           qreflin(2,i)=qdir*trnsm*fopndirs*(1.-scatffi)**2*
     &                                        (1.-absorbfi)**2
           qscat(2,i)=scatffl*(1.-absorbfl)*qreflin(2,i)*sin(theta)
       elseif(theta.gt.atan(hfuselg/(2*wfuselg)).and.theta.lt.
     & atan(hfuselg/wfuselg))then
           qreflin(2,i)=qdir*trnsm*fopndirs*((1.-scatffi)*(1.-absorbfi)
     &                          +(1.-scatffi)**2*(1.-absorbfi)**2)
           qscat(2,i)=scatffl*(1.-absorbfl)*qreflin(2,i)*sin(theta)
       elseif(theta.eq.atan(hfuselg/wfuselg))then
           qreflin(2,i)=qdir*trnsm*fopndirs*(1.-scatffi)*(1.-absorbfi)
           qscat(2,i)=scatffl*(1.-absorbfl)*qreflin(2,i)*sin(theta)
       elseif(theta.gt.atan(hfuselg/wfuselg).and.theta.le.(fpi*90))
     & then
           qreflin(2,i)=qdir*trnsm*fopndirs*(1.+(1.-scatffi)*(1.-absorbfi))
```

```
          qscat(2,i)=scatffl*(1.-absorbfl)*qreflin(2,i)*sin(theta)
        endif
 20     continue
c find qrefl for surface C (left hand side of cabin interior)
        do 30 i=1,nperiods
        theta=fpi*envtdata(i,1)
        qdir=envtdata(i,5)
        fopndirs=envtdata(i,8)
        if(theta.ge.0.0.and.theta.le.atan(hfuselg/(2*wfuselg)))then
          qreflin(3,i)=qdir*trnsm*fopndirs*(1.-scatffi)*(1.-absorbfi)
          qscat(3,i)=scatffi*(1.-absorbfi)*qreflin(3,i)*cos(theta)
        elseif(theta.gt.atan(hfuselg/(2*wfuselg)).and.theta.lt.
     & atan(hfuselg/wfuselg))then
          qreflin(3,i)=qdir*trnsm*fopndirs*((1.-scatffi)*(1.-absorbfi)+
     &    (1.-scatffl)*(1.-absorbfl)*(1.-scatffi)*(1.-absorbfi))
          qscat(3,i)=scatffi*(1.-absorbfi)*qreflin(3,i)*cos(theta)
        elseif(theta.ge.atan(hfuselg/wfuselg).and.theta.lt.
     & atan(2*hfuselg/wfuselg))then
          qreflin(3,i)=qdir*trnsm*fopndirs*(1.-scatffl)*(1.-absorbfl)
     &                *(1.-scatffi)*(1.-absorbfi)
          qscat(3,i)=scatffi*(1.-absorbfi)*qreflin(3,i)*cos(theta)
        elseif(theta.ge.atan(2*hfuselg/wfuselg).and.theta.le.(fpi*90))
     & then
          qreflin(3,i)=0.0
          qscat(3,i)=0.0
        endif
 30     continue
c find qrefl for plexiglass surface on the top of cabin interior
        do 40 i=1,nperiods
        theta=fpi*envtdata(i,1)
        qdir=envtdata(i,5)
        fopndirs=envtdata(i,8)
        if(theta.ge.0.0.and.theta.le.atan(hfuselg/(2*wfuselg)))then
          qreflin(4,i)=qdir*trnsm*fopndirs*(1.-scatffl)*(1.-absorbfl)
     &    *(1.-scatffi)**4*(1.-absorbfi)**4
          qscat(4,i)=0.0
        elseif(theta.gt.atan(hfuselg/(2*wfuselg)).and.theta.lt.
     & atan(hfuselg/wfuselg))then
          qreflin(4,i)=qdir*trnsm*fopndirs*((1.-scatffl)*(1.-absorbfl)*
     &      (1.-scatffi)**2*(1.-absorbfi)**2+
     &      (1.-scatffl)*(1.-absorbfl)*(1.-scatffi)**3*(1.-absorbfi)**3)
          qscat(4,i)=0.0
        elseif(theta.eq.atan(hfuselg/wfuselg))then
          qreflin(4,i)=qdir*trnsm*fopndirs*(1.-scatffl)*(1.-absorbfl)*
     &                (1.-scatffi)**2*(1.-absorbfi)**2
          qscat(4,i)=0.0
        elseif(theta.gt.atan(hfuselg/wfuselg).and.theta.lt.
     & atan(2*hfuselg/wfuselg))then
          qreflin(4,i)=qdir*trnsm*fopndirs*((1.-scatffl)*(1.-absorbfl)*
     &      (1.-scatffi)*(1.-absorbfi)+
     &      (1.-scatffl)*(1.-absorbfl)*(1.-scatffi)**2*(1.-absorbfi)**2)
```

```
            qscat(4,i)=0.0
          elseif(theta.eq.atan(2*hfuselg/wfuselg))then
            qreflin(4,i)=qdir*trnsm*fopndirs*(1.-scatffi)*(1.-absorbfi)
     &                  *(1.-scatffl)*(1.-absorbfl)
            qscat(4,i)=0.0
          elseif(theta.gt.atan(2*hfuselg/wfuselg).and.theta.le.(fpi*90))
     & then
            qreflin(4,i)=qdir*trnsm*fopndirs*((1.-scatffl)*(1.-absorbfl)+
     &     (1.-scatffi)*(1.-absorbfi)*(1.-scatffl)*(1.-absorbfl))
            qscat(4,i)=0.0
          endif
 40     continue
c
c qscat(4,i) is modified to consider direct solar rays reflected from
c the tarmac as diffused solar rays, which subsequently hit the glass
          do 50 i=1,nperiods
            theta=fpi*envtdata(i,1)
            qdir=envtdata(i,5)
            fopndifs=a5/(a1+a2)
 50     qscat(4,i)=trnsm*fopndifs*.5*(1.-absorbta)*qdir*sin(theta)
c
c now find the total scattered energy absorbed at surface A(RHS-inside)
c , surface B(floor-bottom), surface C(LHS-inside)
c and the plexiglass for each period.  note: surface A=1; surface B=2;
c surface C=3; and inside plexiglass surface=4.  Note: surfaces
c 5 & 6 are assumed to be ideal black bodies.  they absorb all scattered
c rays coming from other surfaces and reflect none (ie qscat=0.0). note
c that no direct rays actually falls onto these 2 surfaces
c because of the way the plane is positioned (ie the fuselage is-
c perpendicular to the rays)
          f(1,1)=fc22
          f(1,2)=fc21
          f(1,3)=fc24
          f(1,4)=fc23
          f(1,5)=fc25
          f(1,6)=fc26
          f(2,1)=fc12
          f(2,2)=fc11
          f(2,3)=fc14
          f(2,4)=fc13
          f(2,5)=fc15
          f(2,6)=fc16
          f(3,1)=fc42
          f(3,2)=fc41
          f(3,3)=fc44
          f(3,4)=fc43
          f(3,5)=fc45
          f(3,6)=fc46
          f(4,1)=fc32
          f(4,2)=fc31
          f(4,3)=fc34
```

```
      f(4,4)=fc33
      f(4,5)=fc35
      f(4,6)=fc36
      f(5,1)=fc52
      f(5,2)=fc51
      f(5,3)=fc54
      f(5,4)=fc53
      f(5,5)=fc55
      f(5,6)=fc56
      f(6,1)=fc62
      f(6,2)=fc61
      f(6,3)=fc64
      f(6,4)=fc63
      f(6,5)=fc65
      f(6,6)=fc66
      absorb(1)=absorbfi
      absorb(2)=absorbfl
      absorb(3)=absorbfi
      absorb(4)=a1/(a1+a2)*absorbpg+a2/(a1+a2)*absorfbt
      absorb(5)=1.0
      absorb(6)=1.0
      do 60 i=1,nperiods
           fopndifs=a1/(a1+a2)
c note: fopndifs=fraction open that allows diffused solar ray to get
c out of the cabin.  this value is the same as the fraction of
c infrared sky radiation entering the cabin.
 60   ttrnsm(4,i)=trnsm*fopndifs
      call diffsola(f,absorb,ttrnsm,qscat,qscabsin)
      return
      end
c
c
      subroutine diffsola(f,absorb,trnsm,e,qscabs)
c purpose: determines the diffuse solar radiation that is absorbed by the
c            surfaces. multiple absorption and reflections considered.
c called from: qrefcab and qreffw
c calls: none
      common/c7/nperiods,envtdata(100,20)
      dimension f(6,6),absorb(6),trnsm(6,100),e(6,100),qscabs(6,100),
     &               sumdq(6),edum(6)
      real intcepq(6)
      parameter(qismall=1e-23,toldq=0.00001)
c
      do 150 j=1,nperiods
c initialize
           do 20 i=1,6
             edum(i)=e(i,j)
 20        qscabs(i,j)=qismall
           do 110 iter=1,1000
             do 40 i=1,6
               intcepq(i)=0.0
```

```
            do 40 ii=1,6
 40           intcepq(i)=intcepq(i)+f(i,ii)*edum(ii)
            do 50 i=1,6
              sumdq(i)=absorb(i)*intcepq(i)
              qscabs(i,j)=qscabs(i,j)+sumdq(i)
              edum(i)=(1.-absorb(i)-trnsm(i,j))*intcepq(i)
              if(edum(i).lt.0.0)edum(i)=0.0
 50         continue
            if(sumdq(1)/qscabs(1,j).le.toldq.and.
     &         sumdq(2)/qscabs(2,j).le.toldq.and.
     &         sumdq(3)/qscabs(3,j).le.toldq.and.
     &         sumdq(4)/qscabs(4,j).le.toldq.and.
     &         sumdq(5)/qscabs(5,j).le.toldq.and.
     &         sumdq(6)/qscabs(6,j).le.toldq)goto 150
 110  continue
 150  continue
c      do 170 j=1,nperiods
c       write(13,*)'period,e(i,j)'
c       write(13,*)'j=',j,(e(i,j),i=1,6)
c       write(13,*)'period,qscabs(i,j)'
c 170   write(13,*)'j=',j,(qscabs(i,j),i=1,6)
      return
      end
c
      subroutine qreffw(absorbf,absorbw)
c purpose: determines the intercepted solar radiation and the absorbed
c            diffuse radiation at the fuselage/wing junction.
c called from: solution
c calls: diffsola
      common/c4/widthwng,lengtwng,hwng,locwng,lplane,lfuselg,hfuselg,
     &               wfuselg
      common/c5/trnsm,absorbta,emista,tarmd,densta,conducta,shcta
      common/vf4/fa57,fa68
      common/c7/nperiods,envtdata(100,20)
      common/c9/scatffl,scatffi,scatfw,scatff
      common/reflecq/qreflin(6,100),qscabsin(6,100),qreflfwr(6,100),
     &qreflfwl(6,100),qscabfwr(6,100),qscabfwl(6,100),qabstwa1(6,100),
     &qabstwa2(6,100),qabstwb(6,100)
      common/vf2/fa11,fa12,fa13,fa14,fa15,fa16,fa21,fa22,fa23,fa24,
     &               fa25,fa26,fa31,fa32,fa33,fa34,fa35,fa36,fa41,fa42,
     &               fa43,fa44,fa45,fa46,fa51,fa52,fa53,fa54,fa55,fa56,
     &               fa61,fa62,fa63,fa64,fa65,fa66
      common/fillet/f11w,f11f
      dimension qscatfwr(6,100),qscatfwl(6,100)
      dimension f(6,6),absorb(6),ttrnsm(6,100),tempab(6,100)
      real lengtwng
      parameter(fpi=3.141593/180.)
c
c Variables:
c qreflfwr(,)=intercepted solar radiation (both direct and specular)
c               by right wing
```

```
c qreflfwl(,)=intercepted solar radiation (both direct and specular)
c               by left wing
c qscabfwr(,)=absorbed diffuse solar radiation by the right wing
c qscabfwl(,)=absorbed diffuse solar radiation by the left wing
c
c initialize
          do 10 j=1,nperiods
            do 10 i=1,6
              ttrnsm(i,j)=0.0
              qscatfwr(i,j)=0.0
              qscatfwl(i,j)=0.0
              qreflfwr(i,j)=0.0
              qreflfwl(i,j)=0.0
              qscabfwr(i,j)=0.0
 10           qscabfwl(i,j)=0.0
c reference f(i,j)'s
          f(1,1)=fa11
          f(1,2)=fa12
          f(1,3)=fa13
          f(1,4)=fa14
          f(1,5)=fa15
          f(1,6)=fa16
          f(2,1)=fa21
          f(2,2)=fa22
          f(2,3)=fa23
          f(2,4)=fa24
          f(2,5)=fa25
          f(2,6)=fa26
          f(3,1)=fa31
          f(3,2)=fa32
          f(3,3)=fa33
          f(3,4)=fa34
          f(3,5)=fa35
          f(3,6)=fa36
          f(4,1)=fa41
          f(4,2)=fa42
          f(4,3)=fa43
          f(4,4)=fa44
          f(4,5)=fa45
          f(4,6)=fa46
          f(5,1)=fa51
          f(5,2)=fa52
          f(5,3)=fa53
          f(5,4)=fa54
          f(5,5)=fa55
          f(5,6)=fa56
          f(6,1)=fa61
          f(6,2)=fa62
          f(6,3)=fa63
          f(6,4)=fa64
          f(6,5)=fa65
```

```
          f(6,6)=fa66
          absorb(3)=0.0
          absorb(4)=0.0
          absorb(5)=0.0
          absorb(6)=0.0
          do 15 j=1,nperiods
            do 15 i=3,6
 15       ttrnsm(i,j)=1.0
      fdiffsw=1./(1.-f11w*(1.-absorbw))
      fdiffsf=1./(1.-f11f*(1.-absorbf))
      absorb(1)=absorbw*fdiffsw
      absorb(2)=absorbf*fdiffsf
c find qreflfwr, qreflfwl, qscabfwr and qscabfwl:
c
c LHS of fuselage:
c
c diffused solar interaction between fuselage/wing only
c
      do 20 i=1,nperiods
           theta=fpi*envtdata(i,1)
           qdir=envtdata(i,5)
           qreflfwl(1,i)=(1.+(1.-scatff)*(1.-absorbf))*qdir
           qscatfwl(1,i)=scatfw*(1.-absorbw)*qreflfwl(1,i)*sin(theta)
           qreflfwl(2,i)=(1.+(1.-scatfw)*(1.-absorbw))*qdir
           qscatfwl(2,i)=scatff*(1.-absorbf)*qreflfwl(2,i)*cos(theta)
 20   continue
      call diffsola(f,absorb,ttrnsm,qscatfwl,qscabfwl)
c store temporarily
c      write(13,*)'Partial diffuse solar fuselage/wing only-LHS'
      do 25 j=1,nperiods
c       write(13,*)(qscabfwl(i,j),i=1,6)
       do 25 i=1,6
 25        tempab(i,j)=qscabfwl(i,j)
c
c now consider diffused solar reflection from the tarmac subsequently
c absorbed by the fuselage/wing
c
c reinitialize
      do 125 j=1,nperiods
       do 125 i=1,6
 125      qscatfwl(i,j)=0.0
      do 135 j=1,nperiods
       theta=fpi*envtdata(j,1)
       qdir=envtdata(j,5)
       qtemp=.5*(1.-absorbta)*qdir*sin(theta)
       qscatfwl(4,j)=qtemp
       qscatfwl(5,j)=qtemp
 135   qscatfwl(6,j)=qtemp
      f(1,4)=0.0
      f(1,5)=0.0
      f(1,6)=0.0
```

```
      call diffsola(f,absorb,ttrnsm,qscatfwl,qscabfwl)
c      write(13,*)'Partial diffuse solar reflected from tarmac-LHS'
      do 145 j=1,nperiods
c       write(13,*)(qscabfwl(i,j),i=1,6)
       do 145 i=1,6
 145     tempab(i,j)=tempab(i,j)+qscabfwl(i,j)
c replace f(1,4),f(1,5),f(1,6):
      f(1,4)=fa14
      f(1,5)=fa15
      f(1,6)=fa16
c
c now consider diffused reflection from the fuselage (both direct ray
c as well as from the tarmac) that fall onto surface 5 & 6
c
c reinitialize
      do 126 j=1,nperiods
       do 126 i=1,6
 126      qscatfwl(i,j)=0.0
      do 136 j=1,nperiods
       theta=fpi*envtdata(j,1)
       qdir=envtdata(j,5)
       qscatfwl(5,j)=fa57*((1.-absorbf)*(.5*(1.-absorbta)*qdir*
     &                   sin(theta))+scatff*(1.-absorbf)*qdir*cos(theta))
       qscatfwl(6,j)=fa68*((1.-absorbf)*(.5*(1.-absorbta)*qdir*
     &                   sin(theta))+scatff*(1.-absorbf)*qdir*cos(theta))
 136  continue
      f(2,5)=0.0
      f(2,6)=0.0
      call diffsola(f,absorb,ttrnsm,qscatfwl,qscabfwl)
      write(13,*)'Partial diffuse solar reflected from the fuselage',
     &               '(both direct ray as well as from the tarmac) that',
     &               'fall onto surface 5 & 6 -LHS'
      do 146 j=1,nperiods
       write(13,*)(qscabfwl(i,j),i=1,6)
       do 146 i=1,6
 146     qscabfwl(i,j)=tempab(i,j)+qscabfwl(i,j)
c replace f(2,5),f(2,6):
      f(2,5)=fa25
      f(2,6)=fa26
c
c RHS of fuselage:
c
c diffused solar interaction between fuselage/wing only
c
      do 30 i=1,nperiods
           theta=fpi*envtdata(i,1)
           qdir=envtdata(i,5)
           if(theta.ge.atan(hfuselg/(0.5*lengtwng)))then
            qreflfwr(1,i)=qdir
            qscatfwr(1,i)=scatfw*(1.-absorbw)*qreflfwr(1,i)*sin(theta)
           endif
```

```
          qreflfwr(2,i)=0.0
          qscatfwr(2,i)=0.0
 30   continue
      call diffsola(f,absorb,ttrnsm,qscatfwr,qscabfwr)
c store temporarily
      write(13,*)'Partial diffuse solar fuselage/wing only-RHS'
      do 325 j=1,nperiods
       write(13,*)(qscabfwr(i,j),i=1,6)
       do 325 i=1,6
 325      tempab(i,j)=qscabfwr(i,j)
c
c now consider diffused solar reflection from the tarmac subsequently
c absorbed by the fuselage/wing
c
c reinitialize
      do 225 j=1,nperiods
       do 225 i=1,6
 225      qscatfwr(i,j)=0.0
      do 235 j=1,nperiods
       theta=fpi*envtdata(j,1)
       qdir=envtdata(j,5)
       qtemp=.5*(1.-absorbta)*qdir*sin(theta)
       qscatfwr(4,j)=qtemp
       qscatfwr(5,j)=qtemp
 235   qscatfwr(6,j)=qtemp
      f(1,4)=0.0
      f(1,5)=0.0
      f(1,6)=0.0
      call diffsola(f,absorb,ttrnsm,qscatfwr,qscabfwr)
      write(13,*)'Partial diffuse solar reflected from tarmac-RHS'
      do 245 j=1,nperiods
       write(13,*)(qscabfwr(i,j),i=1,6)
       do 245 i=1,6
 245     tempab(i,j)=tempab(i,j)+qscabfwr(i,j)
c replace f(1,4),f(1,5),f(1,6)
      f(1,4)=fa14
      f(1,5)=fa15
      f(1,6)=fa16
c
c now consider diffused reflection from the fuselage (originating
c from the tarmac) that fall onto surface 5 & 6
c
c reinitialize
      do 226 j=1,nperiods
       do 226 i=1,6
 226      qscatfwr(i,j)=0.0
      do 236 j=1,nperiods
       theta=fpi*envtdata(j,1)
       qdir=envtdata(j,5)
       qscatfwr(5,j)=fa57*(1.-absorbf)*(.5*(1.-absorbta)*qdir*
     &                  sin(theta))
```

```
      qscatfwr(6,j)=fa68*(1.-absorbf)*(.5*(1.-absorbta)*qdir*
     &                    sin(theta))
 236  continue
      f(2,5)=0.0
      f(2,6)=0.0
      call diffsola(f,absorb,ttrnsm,qscatfwr,qscabfwr)
      write(13,*)'Partial diffuse solar reflected from the fuselage',
     &               '(originating from the tarmac) that',
     &               'fall onto surface 5 & 6 -LHS'
      do 246 j=1,nperiods
       write(13,*)(qscabfwr(i,j),i=1,6)
       do 246 i=1,6
 246     qscabfwr(i,j)=tempab(i,j)+qscabfwr(i,j)
      return
      end
c
      subroutine qreftw(absorbw)
c purpose: determines the intercepted solar radiation and the absorbed
c            diffuse radiation between the wing bottom and the tarmac.
c called from: solution
c calls: difslwng
      common/c5/trnsm,absorbta,emista,tarmd,densta,conducta,shcta
      common/c6/absorbff,emisff,absorbww,emisww,absorbfl,emisfl,absorbfi
     &,emisfi,absorbpg,emispg,absorftp,emisrftp,absorfbt,emisrfbt
     &,absorbfb,emisfb
      common/c7/nperiods,envtdata(100,20)
      common/vf1/fbwaa(6,6),fbwbb(6,6)
      common/reflecq/qreflin(6,100),qscabsin(6,100),qreflfwr(6,100),
     &qreflfwl(6,100),qscabfwr(6,100),qscabfwl(6,100),qabstwa1(6,100),
     &qabstwa2(6,100),qabstwb(6,100)
      dimension fbwa1(6,6),fbwa2(6,6),fbwb(6,6),
     &e1(6,100),e2(6,100),e3(6,100)
      dimension absorb1(6),absorb2(6),absorb3(6),trnsm1(6),
     &trnsm2(6),trnsm3(6)
      parameter(fpi=3.141593/180.)
c
c Variables:
c qabstwa1(,)=intercepted solar radiation (direct)
c               by the tarmac underneath the wing (LHS)
c qabstwa2(,)=intercepted solar radiation (direct)
c               by the tarmac underneath the wing         (RHS)
c qabstwb(,)=intercepted solar radiation (direct)
c               by the tarmac underneath the wing(CENTER)
c
c initialize the diffused solar energy entering each surface
      do 10 j=1,nperiods
       do 10 i=1,6
          e1(i,j)=0.0
          e2(i,j)=0.0
 10       e3(i,j)=0.0
c initialize/reference absorb, trnsm & fbw
```

```
      do 20 i=1,6
           absorb1(i)=0.0
           absorb2(i)=0.0
           absorb3(i)=0.0
           trnsm1(i)=1.0
           trnsm2(i)=1.0
           trnsm3(i)=1.0
           do 20 j=1,6
             fbwa1(i,j)=fbwaa(i,j)
             fbwa2(i,j)=fbwaa(i,j)
             fbwb(i,j)=fbwbb(i,j)
 20   continue
c find diffused solar energy entering each surface, e(i,j)'s
      do 30 i=1,nperiods
           theta=fpi*envtdata(i,1)
           qdir=envtdata(i,5)
           qqscat=0.5*(1.-absorbta)*qdir*sin(theta)
           e1(4,i)=qqscat
           e1(5,i)=qqscat
           e1(6,i)=qqscat
           e2(2,i)=qqscat
           e2(5,i)=qqscat
           e2(6,i)=qqscat
           e3(5,i)=qqscat
           e3(6,i)=qqscat
 30   continue
c input absorb
           absorb1(1)=absorbta
           absorb2(1)=absorbta
           absorb3(1)=absorbta
c input trnsm
      trnsm1(1)=0.0
      trnsm1(3)=0.0
      trnsm2(1)=0.0
      trnsm2(3)=0.0
      trnsm3(1)=0.0
      trnsm3(3)=0.0
c some of the reflected diffused solar radiation does not affect
c surface 1 right away: because f14=f41*a4/a1, therefore if f41=0, f14
c should also = 0.
c     fbwa1(4,1)=0.0
c     fbwa1(5,1)=0.0
c     fbwa1(6,1)=0.0
c     fbwa2(2,1)=0.0
c     fbwa2(5,1)=0.0
c     fbwa2(6,1)=0.0
c     fbwb(5,1)=0.0
c     fbwb(6,1)=0.0
      fbwa1(1,4)=0.0
      fbwa1(1,5)=0.0
      fbwa1(1,6)=0.0
```

```
      fbwa2(1,2)=0.0
      fbwa2(1,5)=0.0
      fbwa2(1,6)=0.0
      fbwb(1,5)=0.0
      fbwb(1,6)=0.0
c input absorb that changes
      absorb1(3)=absorbw
      absorb2(3)=absorbw
      absorb3(3)=absorbfb
      call difslwng(fbwa1,fbwa2,fbwb,absorb1,absorb2,absorb3,
     &trnsm1,trnsm2,trnsm3,e1,e2,e3,qabstwa1,qabstwa2,qabstwb)
      return
      end
c
      subroutine difslwng(fbwa1,fbwa2,fbwb,absorb1,absorb2,absorb3,
     &trnsm1,trnsm2,trnsm3,e1,e2,e3,qabstwa1,qabstwa2,qabstwb)
c purpose: determines the diffuse solar radiation that is absorbed by the
c          wing bottom and tarmac surfaces. multiple absorption and
c          reflections considered.  region divided into 3 portions
c called from: qreftw
c calls: none
      common/c7/nperiods,envtdata(100,20)
      dimension fbwa1(6,6),fbwa2(6,6),fbwb(6,6),
     &          absorb1(6),absorb2(6),absorb3(6),
     &          trnsm1(6),trnsm2(6),trnsm3(6),
     &          e1(6,100),e2(6,100),e3(6,100),
     &          qabstwa1(6,100),qabstwa2(6,100),qabstwb(6,100)
      dimension sumdq1(6),sumdq2(6),sumdq3(6),
     &          edum1(6),edum2(6),edum3(6),
     &          trnsmtd1(6),trnsmtd2(6),trnsmtd3(6)
      real intcepq1(6),intcepq2(6),intcepq3(6)
      parameter(qismall=1e-23,toldq=0.00001)
c
      do 150 j=1,nperiods
c initialize
          do 20 i=1,6
            edum1(i)=e1(i,j)
            edum2(i)=e2(i,j)
            edum3(i)=e3(i,j)
            qabstwa1(i,j)=qismall
            qabstwa2(i,j)=qismall
            qabstwb(i,j)=qismall
 20       continue
          igo1=0
          igo2=0
          igo3=0
          do 110 iter=1,1000
            do 40 i=1,6
              intcepq1(i)=0.0
              intcepq2(i)=0.0
              intcepq3(i)=0.0
```

```
            do 40 ii=1,6
              intcepq1(i)=intcepq1(i)+fbwa1(i,ii)*edum1(ii)
              intcepq2(i)=intcepq2(i)+fbwa2(i,ii)*edum2(ii)
              intcepq3(i)=intcepq3(i)+fbwb(i,ii)*edum3(ii)
 40         continue
            trnsmtd1(2)=trnsm1(2)*intcepq1(2)
            trnsmtd2(4)=trnsm2(4)*intcepq2(4)
            trnsmtd3(4)=trnsm3(4)*intcepq3(4)
            trnsmtd3(2)=trnsm3(2)*intcepq3(2)
c
            do 50 i=1,6
c LHS (Section 1):
              if(igo1.eq.0)then
                sumdq1(i)=absorb1(i)*intcepq1(i)
                qabstwa1(i,j)=qabstwa1(i,j)+sumdq1(i)
                if(i.eq.2)then
                    edum1(2)=trnsmtd3(4)
                else
                    edum1(i)=(1.-absorb1(i)-trnsm1(i))*intcepq1(i)
                endif
              endif
c RHS (section 2):
              if(igo2.eq.0)then
                sumdq2(i)=absorb2(i)*intcepq2(i)
                qabstwa2(i,j)=qabstwa2(i,j)+sumdq2(i)
                if(i.eq.4)then
                    edum2(4)=trnsmtd3(2)
                else
                    edum2(i)=(1.-absorb2(i)-trnsm2(i))*intcepq2(i)
                endif
              endif
c CENTER (underneath the fuselage; Section 3):
              if(igo3.eq.0)then
                sumdq3(i)=absorb3(i)*intcepq3(i)
                qabstwb(i,j)=qabstwb(i,j)+sumdq3(i)
                if(i.eq.2)then
                    edum3(2)=trnsmtd2(4)
                elseif(i.eq.4)then
                    edum3(4)=trnsmtd1(2)
                else
                    edum3(i)=(1.-absorb3(i)-trnsm3(i))*intcepq3(i)
                endif
              endif
 50         continue
c LHS (Section 1):
            if(sumdq1(1)/qabstwa1(1,j).le.toldq.and.
     &        sumdq1(2)/qabstwa1(2,j).le.toldq.and.
     &        sumdq1(3)/qabstwa1(3,j).le.toldq.and.
     &        sumdq1(4)/qabstwa1(4,j).le.toldq.and.
     &        sumdq1(5)/qabstwa1(5,j).le.toldq.and.
     &        sumdq1(6)/qabstwa1(6,j).le.toldq)igo1=1
```

```
c RHS (section 2):
            if(sumdq2(1)/qabstwa2(1,j).le.toldq.and.
     &         sumdq2(2)/qabstwa2(2,j).le.toldq.and.
     &         sumdq2(3)/qabstwa2(3,j).le.toldq.and.
     &         sumdq2(4)/qabstwa2(4,j).le.toldq.and.
     &         sumdq2(5)/qabstwa2(5,j).le.toldq.and.
     &         sumdq2(6)/qabstwa2(6,j).le.toldq)igo2=1
c CENTER (underneath the fuselage; Section 3):
            if(sumdq3(1)/qabstwb(1,j).le.toldq.and.
     &         sumdq3(2)/qabstwb(2,j).le.toldq.and.
     &         sumdq3(3)/qabstwb(3,j).le.toldq.and.
     &         sumdq3(4)/qabstwb(4,j).le.toldq.and.
     &         sumdq3(5)/qabstwb(5,j).le.toldq.and.
     &         sumdq3(6)/qabstwb(6,j).le.toldq)igo3=1
            if(igo1.eq.1.and.igo2.eq.1.and.igo3.eq.1)goto 150
 110  continue
 150  continue
c
      write(13,*)'LHS (Section 1):  '
      do 170 j=1,nperiods
       write(13,*)'period,e1(i,j)'
       write(13,*)'j=',j,(e1(i,j),i=1,6)
       write(13,*)'period,qabstwa1(i,j)'
 170   write(13,*)'j=',j,(qabstwa1(i,j),i=1,6)
      write(13,*)'RHS (section 2):'
      do 180 j=1,nperiods
       write(13,*)'period,e2(i,j)'
       write(13,*)'j=',j,(e2(i,j),i=1,6)
       write(13,*)'period,qabstwa2(i,j)'
 180   write(13,*)'j=',j,(qabstwa2(i,j),i=1,6)
      write(13,*)'CENTER (underneath the fuselage; Section 3):  '
      do 190 j=1,nperiods
       write(13,*)'period,e3(i,j)'
       write(13,*)'j=',j,(e3(i,j),i=1,6)
       write(13,*)'period,qabstwb(i,j)'
 190   write(13,*)'j=',j,(qabstwb(i,j),i=1,6)
      return
      end
c
      subroutine sbfillet(icodef11,percent,f11w,f11f)
c purpose: determines the view factors for a portion of a quadrant surface to
c            be used for determining the effective absorbtivities
c            and emissivities
c called from: solution
c calls: none
      real l
      parameter(fpi=3.141592654/180, r=1.0,l=1000.)
c
c Variables:
c icodef11=1: the normal scenario where the wing paint extend beyond
c               the fillet-fuselage junction. the wing will
```

```
c              be assigned an (infrared & diffused solar) absorbtivity,
c              and emissivity modified by the fillet factor,
c              the fuselage will have f11f=0.0, implying that the flat
c              absorbtivity and emissivity (normal) will be used throughout
c              the fuselage.
c
c icodef11=2: the abnormal scenario where the fuselage paint extend
c              beyond the fillet-wing junction, and into the wing to
c              some extend. the fuselage will
c              be assigned an (infrared & diffused solar) absorbtivity,
c              and emissivity modified by the fillet factor, whereas the
c              wing will have f11w=0.0, implying that the flat absorbtivity
c              and emissivity (normal) will be used throughout the wing.
c
c icodef11=3: the wing-paint/fuselage paint junction is within the fillet
c              region.      you need the percentage of the fillet occupied by the
c              wing paint (percentage range from 0 to 100%).
c
c r &l=just dummies
c
      if(icodef11.eq.1)percent=100.
      if(icodef11.eq.2)percent=0.0
      theta=.9*percent
c wing region (region a):
c initialize:
      f11=0.0
      if(theta.eq.0)goto 10
      w1=theta*fpi*r
      a1=w1*l
      w2=2.*r*sin(fpi*theta/2.)
      a2=w2*l
      f21=1.
      f12=a2/a1*f21
      f11=1.-f12
 10   f11w=f11
c      write(9,*)'wing region, theta, f11w',theta,f11w
c fuselage region (region b):
c initialize
      f11=0.0
      if(theta.eq.90.)goto 20
      theta1=90.-theta
      w1=theta1*fpi*r
      a1=w1*l
      w2=2.*r*sin(fpi*theta1/2.)
      a2=w2*l
      f21=1.
      f12=a2/a1*f21
      f11=1.-f12
 20   f11f=f11
c      write(9,*)'fuselage region, theta, f11f',theta,f11f
      return
```

```
      end

subroutine trnsien1(itotitr,iperiod,theta,ta,qsky,
     &              hhfo,hhwo,hhto,qdir,qtarm,ttarm,absorbf,emisf,absorbw,
     &              emisw,eemisf,eemisw,rff,rfw)
c purpose: controls the transient analysis
c called from: solution
c calls: lhswng1, rhswng1, fuslglr1, fuslgrf1, tarmac1, updradio
      common/c1/n,ntrial,tolx,tolf
      common/c4/widthwng,lengtwng,hwng,locwng,lplane,lfuselg,hfuselg,
     &              wfuselg
      common/c7/nperiods,envtdata(100,20)
      common/c12/a1,a2,a3,a4,a5,a6(100),a7(100)
      common/c13/nintervl,vel(100),timeintv(100)
      common/c16/ifindiff,deltime,amcabtmp,intvprnt
      common/temp1/t1(1000)
      common/temp2/t2(1000)
      common/temp3/t3(1000)
      common/temp4/t4(1000),tpg1,tpg2,tpg3
      common/temp5/t5(1000)
      common/radiosit/radiosj(14)
      common/data1/ddeltime
      common/result/temp(200),temptrn(200)
      dimension tvel(100),tottime(100)
      real lfuselg,lplane
      parameter(fhhc=1.0)
      parameter(sunf=0.5,sunf2=0.5)
      parameter(temptoln=0.000001)
c
c Variables:
c t1()...t5()=temperatures
c radiosj()=updated radiosity
c deltime=time increment in transient analysis (sec)
c temp=steady state temperature
c temptrn=transient state temperature
c amcabtmp=ambient cab temperature (Rankine)
c fhhc=factor for convection in cabin
c temptoln=difference between the current ambient cabin temp and the
c             previous one: to prevent infinite loop
c intvprnt=intervals for printing purposes
c sunf=assume there is a fifty percent chance that a spot will be under
c      direct sun throughout the cooling phase.
c sunf2=only fifty percent of the sun gets into the cabin.  or take it
c          the average between nothing getting through to all of the direct rays
c          getting through.
c
      if(itotitr.eq.1)then
      ddeltime=deltime/3600
c convert the velocity from mph to ft/sec
          do 50 i=1,nintervl+1
 50       tvel(i)=vel(i)*5280./3600
```

```
c find the total time from taxi till the application of limit load & beyond
          tottime(1)=0.0
          do 60 i=1,nintervl
 60       tottime(i+1)=tottime(i)+timeintv(i)
      endif
c      if(iperiod.ne.3)return
c
c formulate transient cooling:
c
c initial cooling when the door is opened
c
      icool=1
c sunfact is assumed to be always=1, during initial cooling
      sunfact=1.0
      if(itotitr.le.10*nperiods)then
      do 15 i=1,2
      write(13+i,*)'Total # of analysis=',itotitr
      write(13+i,*)'TRANSIENT ANALYSIS-Temperatures'
 15   write(13+i,*)'cooling when door is opened, iperiod=',iperiod
c      write(16,*)'Total # of analysis=',itotitr
c      write(16,*)'TRANSIENT ANALYSIS-Radiosity'
c      write(16,*)'cooling when door is opened, iperiod=',iperiod
      write(10,*)''
          write(10,*)''
      write(10,*)'TRANSIENT TEMPERATURES FOR PERIOD:',iperiod
          write(10,*)''
      write(10,*)'COOLING WHILE DOOR IS OPENED:'
          write(10,*)''
      write(10,90)(i,i=1,53)
      write(14,90)(i,i=1,20)
      write(15,90)(i,i=21,53)
c      write(16,90)(i,i=54,67)
 90   format(1x,'time(sec)',1x,500(1x,i5))
      endif
      do 75 i=1,n
 75   temptrn(i)=temp(i)
      iprint=1
      nprn=0
      istep=0
c find convective coefficient in the cabin; assume it to be a function of:
          hhc=fhhc*(hhfo+hhwo+hhto)/3.
          if(itotitr.eq.1)then
c find weights for tend and tambcab
          aa1=lfuselg*wfuselg
          aa2=a1
          aa3=lfuselg*hfuselg
          aa4=aa3
          aa5=a2
          atot=aa1+aa2+aa3+aa4+aa5
          cc1=aa1/atot
          cc2=aa2/atot
```

```
          cc3=aa3/atot
          cc4=aa4/atot
          cc5=aa5/atot
          aa6=hfuselg*wfuselg
          aa7=aa6
          atot1=aa1+aa2+aa3+aa4+aa5+aa6+aa7
          dd1=aa1/atot1
          dd2=aa2/atot1
          dd3=aa3/atot1
          dd4=aa4/atot1
          dd5=aa5/atot1
          dd6=aa6/atot1
          dd7=aa7/atot1
          endif
       tempert2=1000.0
 10       istep=istep+1
          call lhswng1(itotitr,iperiod,istep,theta,ta,hhwo,rfw,absorbw,
     &                  emisw,eemisw,sunfact)
          call rhswng1(itotitr,iperiod,istep,theta,ta,hhwo,rfw,absorbw,
     &                  emisw,eemisw,sunfact)
          call fuslglr1(itotitr,icool,iperiod,istep,theta,ta,hhfo,hhc,rff,
     &                 absorbf,eemisf,sunfact,sunfact2)
          call fuslgrf1(itotitr,icool,iperiod,istep,theta,ta,hhfo,hhc,qdir,
     &                 qsky,qtarm,sunfact2)
          call tarmac1(itotitr,icool,iperiod,istep,ta,ttarm,hhto)
          call updradio(itotitr,iperiod,istep,qsky,qtarm,emisf,
     &                  emisw,eemisf,eemisw,rff,rfw)
          if(iprint.eq.istep)then
            nprn=1+nprn
            iprint=nprn*intvprnt+1
            if(itotitr.le.10*nperiods)then
              write(10,80)(istep-1)*deltime,(temptrn(i),i=1,53)
              write(14,80)(istep-1)*deltime,(temptrn(i),i=1,20)
              write(15,80)(istep-1)*deltime,(temptrn(i),i=21,53)
c             write(16,80)(istep-1)*deltime,(temptrn(i),i=54,67)
 80           format(f10.4,2x,500(1x,f5.1))
            endif
          endif
          tend=cc1*t4(16)+cc2*tpg3+cc3*t3(12)+cc4*t3(16)+cc5*t4(12)
          tempert1=tempert2
          tambcab=dd1*t4(16)+dd2*tpg3+dd3*t3(12)+dd4*t3(16)+dd5*t4(12)
     &            +dd6*tend+dd7*tend
          tempert2=tambcab
          write(14,*)'istep,t1,t2, absdiff',istep,tempert1,tempert2,
     &                                abs(tempert1-tempert2)
       if(tambcab.le.amcabtmp)goto 100
          goto 10
c
c cooling during taxi, stop, take-off, climb & cruise
c
 100  continue
```

```
      if(itotitr.le.10*nperiods)then
      do 16 i=1,3
 16   write(13+i,*)'cooling during taxi, stop, take-off, climb & cruise,
     &iperiod=',iperiod
           write(10,*)''
      write(10,*)'COOLING DURING AIRCRAFT MANEUVERS:'
           write(10,*)''
      write(10,90)(i,i=1,53)
      write(14,90)(i,i=1,20)
      write(15,90)(i,i=21,53)
c     write(16,90)(i,i=54,67)
      endif
      icool=2
      sunfact=sunf
      sunfact2=sunf2
      vnatural=envtdata(iperiod,4)
           v1=tvel(1)
      time1=0.0
 20   istep=istep+1
c find the convective coefficients for the fuselage and the wing, hhf & hhw
      time1=time1+deltime
      if(time1.gt.tottime(nintervl+1))goto 120
           do 130 j=1,nintervl
             if(time1.gt.tottime(j).and.time1.le.tottime(j+1))then
               jj=j
               goto 140
             endif
 130  continue
 140  v2=tvel(jj)+(tvel(jj+1)-tvel(jj))/timeintv(jj)*(time1-tottime(jj))
     &                                      +       vnatural
           v=(v1+v2)/2.
           v1=v2
      call hcoolcon(itotitr,lplane,v,hhf)
      call hcoolcon(itotitr,widthwng,v,hhw)
c
      call lhswng1(itotitr,iperiod,istep,theta,ta,hhw,rfw,absorbw,
     &                  emisw,eemisw,sunfact)
      call rhswng1(itotitr,iperiod,istep,theta,ta,hhw,rfw,absorbw,
     &                  emisw,eemisw,sunfact)
      call fuslglr1(itotitr,icool,iperiod,istep,theta,ta,hhf,hhc,rff,
     &                 absorbf,eemisf,sunfact,sunfact2)
      call fuslgrf1(itotitr,icool,iperiod,istep,theta,ta,hhf,hhc,qdir,
     &                 qsky,qtarm,sunfact2)
      call tarmac1(itotitr,icool,iperiod,istep,ta,ttarm,hhto)
      call updradio(itotitr,iperiod,istep,qsky,qtarm,emisf,
     &                   emisw,eemisf,eemisw,rff,rfw)
           if(iprint.eq.istep)then
             nprn=1+nprn
             iprint=nprn*intvprnt+1
             if(itotitr.le.10*nperiods)then
               write(10,80)(istep-1)*deltime,(temptrn(i),i=1,53)
```

```
              write(14,80)(istep-1)*deltime,(temptrn(i),i=1,20)
              write(15,80)(istep-1)*deltime,(temptrn(i),i=21,53)
c             write(16,80)(istep-1)*deltime,(temptrn(i),i=54,67)
            endif
          endif
      goto 20
c replace n: note n was changed to 14 in the updradio subroutine
 120  n=67
      return
      end
c
c
      subroutine trnsien2(itotitr,iperiod,theta,ta,qsky,
     &              hhfo,hhwo,hhto,qdir,qtarm,ttarm,absorbf,emisf,absorbw,
     &              emisw,eemisf,eemisw,rff,rfw)
c purpose: controls the transient analysis
c called from: solution
c calls: lhswng2, rhswng2, fuslglr2, fuslgrf2, tarmac2, updradio
      common/c1/n,ntrial,tolx,tolf
      common/c4/widthwng,lengtwng,hwng,locwng,lplane,lfuselg,hfuselg,
     &              wfuselg
      common/c7/nperiods,envtdata(100,20)
      common/c12/a1,a2,a3,a4,a5,a6(100),a7(100)
      common/c13/nintervl,vel(100),timeintv(100)
      common/c16/ifindiff,deltime,amcabtmp,intvprnt
      common/temp1/t1(1000)
      common/temp2/t2(1000)
      common/temp3/t3(1000)
      common/temp4/t4(1000),tpg1,tpg2,tpg3
      common/temp5/t5(1000)
      common/radiosit/radiosj(14)
      common/data1/ddeltime
      common/result/temp(200),temptrn(200)
      dimension tvel(100),tottime(100)
      real lfuselg,lplane
      parameter(fhhc=1.0)
      parameter(sunf=0.5,sunf2=0.5)
      parameter(temptoln=0.01)
c     parameter(temptoln=0.000001)
c
c Variables:
c t1()...t5()=temperatures
c radiosj()=updated radiosity
c deltime=time increment in transient analysis (sec)
c temp=steady state temperature
c temptrn=transient state temperature
c amcabtmp=ambient cab temperature (Rankine)
c fhhc=factor for convection in cabin
c temptoln=difference between the current ambient cabin temp and the
c           previous one: to prevent infinte loop
c intvprnt=intervals for printing purposes
```

```
c sunf=assume there is a fifty percent chance that a spot will be under
c      direct sun throughout the cooling phase.
c sunf2=only fifty percent of the sun gets into the cabin.  or take it
c          the average between nothing geting through to all of the direct rays
c          getting through.
c
      if(itotitr.eq.1)then
      ddeltime=deltime/3600
c convert the velocity from mph to ft/sec
          do 50 i=1,nintervl+1
 50       tvel(i)=vel(i)*5280./3600
c find the total time from taxi till the application of limit load & beyond
          tottime(1)=0.0
          do 60 i=1,nintervl
 60       tottime(i+1)=tottime(i)+timeintv(i)
      endif
c      if(iperiod.ne.3)return
c
c formulate transient cooling:
c
c initial cooling when the door is opened
c
      icool=1
c sunfact is assumed to be always=1, during initial cooling
      sunfact=1.0
      if(itotitr.le.10*nperiods)then
      do 15 i=1,2
      write(13+i,*)'Total # of analysis=',itotitr
      write(13+i,*)'TRANSIENT ANALYSIS-Temperatures'
 15   write(13+i,*)'cooling when door is opened, iperiod=',iperiod
      write(16,*)'Total # of analysis=',itotitr
      write(16,*)'TRANSIENT ANALYSIS-Radiosity'
      write(16,*)'cooling when door is opened, iperiod=',iperiod
          write(10,*)''
          write(10,*)''
      write(10,*)'TRANSIENT TEMPERATURES FOR PERIOD:',iperiod
          write(10,*)''
      write(10,*)'COOLING WHILE DOOR IS OPENED:'
          write(10,*)''
      write(10,90)(i,i=1,53)
      write(14,90)(i,i=1,20)
      write(15,90)(i,i=21,53)
      write(16,90)(i,i=54,67)
 90   format(1x,'time(sec)',1x,500(1x,i5))
      endif
      do 75 i=1,n
 75   temptrn(i)=temp(i)
      iprint=1
      nprn=0
      istep=0
c find convective coefficient in the cabin; assume it to be a function of:
```

```
          hhc=fhhc*(hhfo+hhwo+hhto)/3.
          if(itotitr.eq.1)then
c find weights for tend and tambcab
          aa1=lfuselg*wfuselg
          aa2=a1
          aa3=lfuselg*hfuselg
          aa4=aa3
          aa5=a2
          atot=aa1+aa2+aa3+aa4+aa5
          cc1=aa1/atot
          cc2=aa2/atot
          cc3=aa3/atot
          cc4=aa4/atot
          cc5=aa5/atot
          aa6=hfuselg*wfuselg
          aa7=aa6
          atot1=aa1+aa2+aa3+aa4+aa5+aa6+aa7
          dd1=aa1/atot1
          dd2=aa2/atot1
          dd3=aa3/atot1
          dd4=aa4/atot1
          dd5=aa5/atot1
          dd6=aa6/atot1
          dd7=aa7/atot1
          endif
       tempert2=1000.0
 10       istep=istep+1
      call newraph2(itotitr,iperiod,istep,theta,ta,hhwo,rfw,absorbw,
     &                    emisw,eemisw,sunfact,icool,hhfo,hhc,rff,absorbf,
     &                    eemisf,sunfact2,qdir,qsky,qtarm,ttarm,hhto)
          call updradio(itotitr,iperiod,istep,qsky,qtarm,emisf,
     &                    emisw,eemisf,eemisw,rff,rfw)
          if(iprint.eq.istep)then
            nprn=1+nprn
            iprint=nprn*intvprnt+1
            if(itotitr.le.10*nperiods)then
              write(10,80)(istep-1)*deltime,(temptrn(i),i=1,53)
              write(14,80)(istep-1)*deltime,(temptrn(i),i=1,20)
              write(15,80)(istep-1)*deltime,(temptrn(i),i=21,53)
              write(16,80)(istep-1)*deltime,(temptrn(i),i=54,67)
 80           format(f10.4,2x,500(1x,f5.1))
            endif
          endif
          tend=cc1*t4(16)+cc2*tpg3+cc3*t3(12)+cc4*t3(16)+cc5*t4(12)
          tempert1=tempert2
          tambcab=dd1*t4(16)+dd2*tpg3+dd3*t3(12)+dd4*t3(16)+dd5*t4(12)
     &              +dd6*tend+dd7*tend
          tempert2=tambcab
          write(14,*)'tempert1,tempert2, absdiff',tempert1,tempert2,
     &                              abs(tempert1-tempert2)
       if(tambcab.le.amcabtmp)goto 100
```

```
          goto 10

c
c cooling during taxi, stop, take-off, climb & cruise
c
 100  continue
      if(itotitr.le.10*nperiods)then
      do 16 i=1,3
 16   write(13+i,*)'cooling during taxi, stop, take-off, climb & cruise,
     &iperiod=',iperiod
          write(10,*)''
      write(10,*)'COOLING DURING AIRCRAFT MANEUVERS:'
          write(10,*)''
      write(10,90)(i,i=1,53)
      write(14,90)(i,i=1,20)
      write(15,90)(i,i=21,53)
      write(16,90)(i,i=54,67)
      endif
      icool=2
      sunfact=sunf
      sunfact2=sunf2
      vnatural=envtdata(iperiod,4)
          v1=tvel(1)
      time1=0.0
 20   istep=istep+1
c find the convective coefficients for the fuselage and the wing, hhf & hhw
      time1=time1+deltime
      if(time1.gt.tottime(nintervl+1))goto 120
          do 130 j=1,nintervl
            if(time1.gt.tottime(j).and.time1.le.tottime(j+1))then
              jj=j
              goto 140
            endif
 130  continue
 140  v2=tvel(jj)+(tvel(jj+1)-tvel(jj))/timeintv(jj)*(time1-tottime(jj))
     &                                      +       vnatural
          v=(v1+v2)/2.
          v1=v2
      call hcoolcon(itotitr,lplane,v,hhf)
      call hcoolcon(itotitr,widthwng,v,hhw)
c
      call newraph2(itotitr,iperiod,istep,theta,ta,hhw,rfw,absorbw,
     &                    emisw,eemisw,sunfact,icool,hhf,hhc,rff,absorbf,
     &                    eemisf,sunfact2,qdir,qsky,qtarm,ttarm,hhto)
      call updradio(itotitr,iperiod,istep,qsky,qtarm,emisf,
     &                    emisw,eemisf,eemisw,rff,rfw)
          if(iprint.eq.istep)then
            nprn=1+nprn
            iprint=nprn*intvprnt+1
            if(itotitr.le.10*nperiods)then
              write(10,80)(istep-1)*deltime,(temptrn(i),i=1,53)
```

```
            write(14,80)(istep-1)*deltime,(temptrn(i),i=1,20)
            write(15,80)(istep-1)*deltime,(temptrn(i),i=21,53)
            write(16,80)(istep-1)*deltime,(temptrn(i),i=54,67)
          endif
        endif
        goto 20
c restore n to 67: note n was changed to 120 in the newraph2 subroutine and
c to 14 in the updradio subroutine
 120  n=67
      return
      end
c
c
      subroutine newraph2(itotitr,iperiod,istep,theta,ta,hhwo,rfw,
     &            absorbw,emisw,eemisw,sunfact,icool,hhfo,hhc,rff,
     &            absorbf,eemisf,sunfact2,qdir,qsky,qtarm,ttarm,hhto)
c
c purpose: this subroutine calls: linear solvers; ludcmp and lubksb.
c given an initial guess x for a root in n dimensions, take
c ntrial Newton-Raphson steps to improve the root.  stop if the
c root converges in either summed absolute variable increments tolx or summed
c absolute function values tolf.
c calls: lhswng2,rhswng2,fuslglr2,fuslgrf2,ludcmp,tarmac2,lubksb
c called from: trnsien2
      common/c1/n,ntrial,tolx,tolf
      common/c2/x(200),fvec(200),jacob(200,200)
      common/sc1/indx(200),p(200)
      real jacob
c
c change n to 120 to reflect the 120 equations related to the 120 temperatures to be
c found for each time step, istep for the implicit finite difference method.
c
      n=120
c
c Variables:
c isolfoun=indicator of whether solution is found or not: =1 means found;
c =0 means not found yet.
c ipower=exponent of 10.  to ensure solution converges in positive numbers
c
      isolfoun=0
      ipower=1
 50   do 14 k=1,ntrial
c user subroutines supply function values at x in fvec and
c Jacobian matrix in jacob.
c
c initialize jacobian jacob(120,120)
c note: most jacobian values are 0's.  also note that the local jacobians
c tjacob in subroutines below are also initialized to 0's.  this initialization
c is redundant but simplifies programming.
c
       do 70 ijacob=1,n
```

```
        do 70 jjacob=1,n
  70    jacob(ijacob,jjacob)=0.0
c
          call lhswng2(k,itotitr,iperiod,istep,theta,ta,hhwo,rfw,absorbw,
     &                  emisw,eemisw,sunfact,isolfoun)
          call rhswng2(k,itotitr,iperiod,istep,theta,ta,hhwo,rfw,absorbw,
     &                  emisw,eemisw,sunfact,isolfoun)
          call fuslglr2(k,itotitr,icool,iperiod,istep,theta,ta,hhfo,hhc,rff,
     &                 absorbf,eemisf,sunfact,sunfact2,isolfoun)
          call fuslgrf2(k,itotitr,icool,iperiod,istep,theta,ta,hhfo,hhc,qdir
     &                 ,qsky,qtarm,sunfact2,isolfoun)
          call tarmac2(k,itotitr,icool,iperiod,istep,ta,ttarm,hhto,isolfoun)
c return to trnsien2 for the first step (istep=1) where only initialization has
c taken place in the above called subroutines.  note that the local temperature
c variables have assumed the steady state temperature tt(i) (ie x(i)) in the
c the above subroutines.  after step 1, the steady state temperature values are
c all destroyed, and instead filled up with the new temperature values, newt(i).
c to retrieve the steady state temperatures, find them in /result/temp(i),
c where temp(i) is in deg Fahrenheit, and not in absolute Rankine.
        write(14,*)'istep,trial number=',istep,k
c          do 170 ijk=1,n
c          write(14,*)'row=',ijk
c 170   write(14,*)(jacob(ijk,jjj),jjj=1,n)
        if(istep.eq.1)return
c check function convergence
          errf=0.
          do 11 i=1,n
            errf=errf+abs(fvec(i))
 11       continue
c         if(errf.le.tolf) goto 20
c right-hand side of linear equations
          do 12 i=1,n
            p(i)=-fvec(i)
 12       continue
c solve linear eqns. using LU decomposition
          call ludcmp
c forward and back substitution
          call lubksb
c check root convergence; and update solution
          errx=0.
          do 13 i=1,n
            errx=errx+abs(p(i))
            x(i)=x(i)+p(i)
 13       continue
      write(14,*)'k(trial#),errx,errf',k,errx,errf
          if(errf.le.tolf.and.errx.le.tolx) goto 20
 14   continue
 20   loopindc=0
      do 30 i=1,n
          if(x(i).lt.0.0)then
            write(6,*)'i=',i,x(i)
```

```
            x(i)=10**ipower
            loopindc=1
          endif
 30   continue
      if(loopindc.eq.1)then
          ipower=ipower+1
          goto 50
      endif
c call the subroutines one more time, indicating a solution has been found
c for the time step istep.  this call also updates the previous temperatures
c with the solved new (current) temperatures in these called subroutines.
      isolfoun=1
          call lhswng2(k,itotitr,iperiod,istep,theta,ta,hhwo,rfw,absorbw,
     &                  emisw,eemisw,sunfact,isolfoun)
          call rhswng2(k,itotitr,iperiod,istep,theta,ta,hhwo,rfw,absorbw,
     &                  emisw,eemisw,sunfact,isolfoun)
          call fuslglr2(k,itotitr,icool,iperiod,istep,theta,ta,hhfo,hhc,rff,
     &                 absorbf,eemisf,sunfact,sunfact2,isolfoun)
          call fuslgrf2(k,itotitr,icool,iperiod,istep,theta,ta,hhfo,hhc,qdir
     &                 ,qsky,qtarm,sunfact2,isolfoun)
          call tarmac2(k,itotitr,icool,iperiod,istep,ta,ttarm,hhto,isolfoun)
      return
      end
c
c
c
      subroutine lhswng1(itotitr,iperiod,istep,theta,ta,hhw,rfw,
     &                        absorbw,emisw,eemisw,sunfact)
c purpose: transient analysis of the left wing (the wing that is not under
c           shade)
c called from: trnsien1
c calls: none
      common/c2/tt(200),fn(200),jacob(200,200)
      common/c3/tth(100),kk(100)
      common/c6/absorbff,emisff,absorbww,emisww,absorbfl,emisfl,absorbfi
     &,emisfi,absorbpg,emispg,absorftp,emisrftp,absorfbt,emisrfbt
     &,absorbfb,emisfb
      common/c10/aircondc,thdiffus,visckine,prandtl
      common/c14/thicknes(100),density(100),conductv(100),sheatcap(100)
      common/reflecq/qreflin(6,100),qscabsin(6,100),qreflfwr(6,100),
     &qreflfwl(6,100),qscabfwr(6,100),qscabfwl(6,100),qabstwa1(6,100),
     &qabstwa2(6,100),qabstwb(6,100)
      common/temp1/t(1000)
      common/data1/deltime
      common/radiosit/jj(14)
      common/result/temp(200),temptrn(200)
      dimension newt(100),k(100),th(100),dens(100),shc(100)
      real kk,k,jj,newt
      parameter(sig=.1714e-8)
      parameter(fpi=3.141593/180.)
      parameter(nlayer=9)
```

```
      parameter(lend=3*nlayer)
      parameter(layair=5)
      parameter(f=0.2)
c
c Variables:
c layair=the layer (or element) that is air space in the wing
c f=fraction of an element thickness
c
      if(itotitr.eq.1.and.istep.eq.1)then
c reference thickness (th):
      th(1)=tth(1)
      th(2)=tth(2)
      th(3)=tth(3)
      th(4)=tth(4)
      th(5)=tth(29)
      th(6)=tth(30)
      th(7)=tth(5)
      th(8)=tth(6)
      th(9)=tth(7)
c reference conductivity (k):
      k(1)=kk(1)
      k(2)=kk(2)
      k(3)=kk(3)
      k(4)=kk(4)
      k(5)=kk(29)
      k(6)=kk(30)
      k(7)=kk(5)
      k(8)=kk(6)
      k(9)=kk(7)
c reference density (dens):
      dens(1)=density(1)
      dens(2)=density(2)
      dens(3)=density(3)
      dens(4)=density(4)
      dens(6)=density(6)
      dens(7)=density(7)
      dens(8)=density(8)
      dens(9)=density(9)
c reference specific heat capacity (shc):
      shc(1)=sheatcap(1)
      shc(2)=sheatcap(2)
      shc(3)=sheatcap(3)
      shc(4)=sheatcap(4)
      shc(6)=sheatcap(6)
      shc(7)=sheatcap(7)
      shc(8)=sheatcap(8)
      shc(9)=sheatcap(9)
      endif
      if(istep.eq.1)then
c reference the initial temp. (t):
      t(1)=tt(1)
```

```
      t(2)=(tt(1)+tt(2))/2.
      t(3)=tt(2)
      t(4)=tt(2)
      t(5)=(tt(2)+tt(3))/2.
      t(6)=tt(3)
      t(7)=tt(3)
      t(8)=(tt(3)+tt(4))/2.
      t(9)=tt(4)
      t(10)=tt(4)
      t(11)=(tt(4)+tt(62))/2.
      t(12)=tt(62)
      t(16)=tt(63)
      t(17)=(tt(63)+tt(5))/2.
      t(18)=tt(5)
      t(19)=tt(5)
      t(20)=(tt(5)+tt(6))/2.
      t(21)=tt(6)
      t(22)=tt(6)
      t(23)=(tt(6)+tt(7))/2.
      t(24)=tt(7)
      t(25)=tt(7)
      t(26)=(tt(7)+tt(8))/2.
      t(27)=tt(8)
c reference the initial radiosity (jj)
      jj(1)=tt(40)
      jj(2)=tt(41)
      return
      endif
c
c formulate transient cooling:
c
c upper wing surface temp (t1), as well as internal temp t2 and t3:
            qnetsky=(sig*t(1)**4-rfw*jj(1))/((1.-rfw*eemisw)/eemisw)
            newt(1)=t(1)+deltime/(dens(1)*shc(1)*f/2*th(1))*
     &         ((absorbw*qreflfwl(1,iperiod)*sin(fpi*theta)+
     &           qscabfwl(1,iperiod))*sunfact+
     &          (absorbw*qreflfwr(1,iperiod)*sin(fpi*theta)+
     &           qscabfwr(1,iperiod))*(1-sunfact)
     &         -qnetsky-hhw*(t(1)-ta)-
     &         (t(1)-t(2))/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
            newt(2)=t(2)+deltime/(dens(1)*shc(1)*(1-f)*th(1))*
     &         ((t(1)-t(2))/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1))-
     &         (t(2)-t(3))/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
            newt(3)=t(3)+deltime/(dens(1)*shc(1)*f/2*th(1))*
     &         ((t(2)-t(3))/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1))-
     &         (t(3)-t(4))/(f/4*th(1)/k(1)+f/4*th(2)/k(2)))
c internal nodes (all conduction): t4-t24:
            do 20 i=1,nlayer
            if(i.eq.layair)goto 20
            if(i.eq.1.or.i.eq.nlayer)goto 20
            ii=(i-1)*3
```

```
c beginning element within layer i: t4,t7,t10,t13,t16,t19,t22:
          if(i.eq.layair+1)then
            newt(ii+1)=t(ii+1)+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &      ((t(ii-3)-t(ii+1))/(f/4*th(i-2)/k(i-2)+th(i-1)/k(i-1)+
     &                                              f/4*th(i)/k(i))-
     &      (t(ii+1)-t(ii+2))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
          else
            newt(ii+1)=t(ii+1)+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &      ((t(ii)-t(ii+1))/(f/4*th(i-1)/k(i-1)+f/4*th(i)/k(i))-
     &      (t(ii+1)-t(ii+2))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
          endif
c middle element within layer i: t5,t8,t11,t14,t17,t20,t23:
          newt(ii+2)=t(ii+2)+deltime/(dens(i)*shc(i)*(1-f)*th(i))*
     &    ((t(ii+1)-t(ii+2))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &    (t(ii+2)-t(ii+3))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
c ending element within layer i: t6,t9,t12,t15,t18,t21,t24:
          if(i.eq.layair-1)then
          newt(ii+3)=t(ii+3)+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &    ((t(ii+2)-t(ii+3))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &    (t(ii+3)-t(ii+7))/(f/4*th(i)/k(i)+th(i+1)/k(i+1)+
     &                                      f/4*th(i+2)/k(i+2)))
          else
          newt(ii+3)=t(ii+3)+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &    ((t(ii+2)-t(ii+3))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &    (t(ii+3)-t(ii+4))/(f/4*th(i)/k(i)+f/4*th(i+1)/k(i+1)))
          endif
 20       continue
c lower wing surface temp (t27), as well as internal temp t25 and t26:
          newt(lend-2)=t(lend-2)+
     &       deltime/(dens(nlayer)*shc(nlayer)*f/2*th(nlayer))*
     &       ((t(lend-3)-t(lend-2))/
     &       (f/4*th(nlayer-1)/k(nlayer-1)+f/4*th(nlayer)/k(nlayer))-
     &       (t(lend-2)-t(lend-1))/
     &       (f/4*th(nlayer)/k(nlayer)+(1-f)/2*th(nlayer)/k(nlayer)))
          newt(lend-1)=t(lend-1)+
     &       deltime/(dens(nlayer)*shc(nlayer)*(1-f)*th(nlayer))*
     &       ((t(lend-2)-t(lend-1))/
     &       (f/4*th(nlayer)/k(nlayer)+(1-f)/2*th(nlayer)/k(nlayer))-
     &       (t(lend-1)-t(lend))/
     &       (f/4*th(nlayer)/k(nlayer)+(1-f)/2*th(nlayer)/k(nlayer)))
          qnetsky=(sig*t(lend)**4-jj(2))/((1.-emisw)/emisw)
          newt(lend)=t(lend)+
     &       deltime/(dens(nlayer)*shc(nlayer)*f/2*th(nlayer))*
     &       (qabstwa1(3,iperiod)-qnetsky-hhw*(t(lend)-ta)+
     &       (t(lend-1)-t(lend))/
     &       (f/4*th(nlayer)/k(nlayer)+(1-f)/2*th(nlayer)/k(nlayer)))
        do 60 i=1,lend
 60     t(i)=newt(i)
        temptrn(1)=t(1)-459.67
        temptrn(2)=(t(3)+t(4))/2.-459.67
        temptrn(3)=(t(6)+t(7))/2.-459.67
```

```
      temptrn(4)=(t(9)+t(10))/2.-459.67
      temptrn(5)=t(12)-459.67
      temptrn(6)=t(16)-459.67
      temptrn(7)=(t(18)+t(19))/2.-459.67
      temptrn(8)=(t(21)+t(22))/2.-459.67
      temptrn(9)=(t(24)+t(25))/2.-459.67
      temptrn(10)=t(27)-459.67
      return
      end
c
c
      subroutine rhswng1(itotitr,iperiod,istep,theta,ta,hhw,rfw,
     &                         absorbw,emisw,eemisw,sunfact)
c purpose: transient analysis of the right wing (the wing that is under
c           shade)
c called from: trnsien1
c calls: none
      common/c2/tt(200),fn(200),jacob(200,200)
      common/c3/tth(100),kk(100)
      common/c6/absorbff,emisff,absorbww,emisww,absorbfl,emisfl,absorbfi
     &,emisfi,absorbpg,emispg,absorftp,emisrftp,absorfbt,emisrfbt
     &,absorbfb,emisfb
      common/c10/aircondc,thdiffus,visckine,prandtl
      common/c14/thicknes(100),density(100),conductv(100),sheatcap(100)
      common/reflecq/qreflin(6,100),qscabsin(6,100),qreflfwr(6,100),
     &qreflfwl(6,100),qscabfwr(6,100),qscabfwl(6,100),qabstwa1(6,100),
     &qabstwa2(6,100),qabstwb(6,100)
      common/temp2/t(1000)
      common/data1/deltime
      common/radiosit/jj(14)
      common/result/temp(200),temptrn(200)
      dimension newt(100),k(100),th(100),dens(100),shc(100)
      real kk,k,jj,newt
      parameter(sig=.1714e-8)
      parameter(fpi=3.141593/180.)
      parameter(nlayer=9)
      parameter(lend=3*nlayer)
      parameter(layair=5)
      parameter(f=0.2)
c
c Variables:
c layair=the layer (or element) that is air space in the wing
c f=fraction of an element thickness
c
      if(itotitr.eq.1.and.istep.eq.1)then
c reference thickness (th):
      th(1)=tth(1)
      th(2)=tth(2)
      th(3)=tth(3)
      th(4)=tth(4)
      th(5)=tth(29)
```

```
      th(6)=tth(30)
      th(7)=tth(5)
      th(8)=tth(6)
      th(9)=tth(7)
c reference conductivity (k):
      k(1)=kk(1)
      k(2)=kk(2)
      k(3)=kk(3)
      k(4)=kk(4)
      k(5)=kk(29)
      k(6)=kk(30)
      k(7)=kk(5)
      k(8)=kk(6)
      k(9)=kk(7)
c reference density (dens):
      dens(1)=density(1)
      dens(2)=density(2)
      dens(3)=density(3)
      dens(4)=density(4)
      dens(6)=density(6)
      dens(7)=density(7)
      dens(8)=density(8)
      dens(9)=density(9)
c reference specific heat capacity (shc):
      shc(1)=sheatcap(1)
      shc(2)=sheatcap(2)
      shc(3)=sheatcap(3)
      shc(4)=sheatcap(4)
      shc(6)=sheatcap(6)
      shc(7)=sheatcap(7)
      shc(8)=sheatcap(8)
      shc(9)=sheatcap(9)
      endif
      if(istep.eq.1)then
c reference the initial temp. (t):
      t(1)=tt(9)
      t(2)=(tt(9)+tt(10))/2.
      t(3)=tt(10)
      t(4)=tt(10)
      t(5)=(tt(10)+tt(11))/2.
      t(6)=tt(11)
      t(7)=tt(11)
      t(8)=(tt(11)+tt(12))/2.
      t(9)=tt(12)
      t(10)=tt(12)
      t(11)=(tt(12)+tt(64))/2.
      t(12)=tt(64)
      t(16)=tt(65)
      t(17)=(tt(65)+tt(13))/2.
      t(18)=tt(13)
      t(19)=tt(13)
```

```
      t(20)=(tt(13)+tt(14))/2.
      t(21)=tt(14)
      t(22)=tt(14)
      t(23)=(tt(14)+tt(15))/2.
      t(24)=tt(15)
      t(25)=tt(15)
      t(26)=(tt(15)+tt(16))/2.
      t(27)=tt(16)
c reference the initial radiosity (jj):
      jj(3)=tt(42)
      jj(4)=tt(43)
      return
      endif
c
c formulate transient cooling:
c
c upper wing surface temp (t1), as well as internal temp t2 and t3:
            qnetsky=(sig*t(1)**4-rfw*jj(3))/((1.-rfw*eemisw)/eemisw)
            newt(1)=t(1)+deltime/(dens(1)*shc(1)*f/2*th(1))*
     &         ((absorbw*qreflfwr(1,iperiod)*sin(fpi*theta)+
     &           qscabfwr(1,iperiod))*sunfact+
     &          (absorbw*qreflfwl(1,iperiod)*sin(fpi*theta)+
     &           qscabfwl(1,iperiod))*(1-sunfact)
     &         -qnetsky-hhw*(t(1)-ta)-
     &         (t(1)-t(2))/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
            newt(2)=t(2)+deltime/(dens(1)*shc(1)*(1-f)*th(1))*
     &         ((t(1)-t(2))/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1))-
     &         (t(2)-t(3))/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
            newt(3)=t(3)+deltime/(dens(1)*shc(1)*f/2*th(1))*
     &         ((t(2)-t(3))/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1))-
     &         (t(3)-t(4))/(f/4*th(1)/k(1)+f/4*th(2)/k(2)))
c internal nodes (all conduction): t4-t24:
            do 20 i=1,nlayer
            if(i.eq.layair)goto 20
            if(i.eq.1.or.i.eq.nlayer)goto 20
            ii=(i-1)*3
c beginning element within layer i: t4,t7,t10,t13,t16,t19,t22:
            if(i.eq.layair+1)then
              newt(ii+1)=t(ii+1)+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &       ((t(ii-3)-t(ii+1))/(f/4*th(i-2)/k(i-2)+th(i-1)/k(i-1)+
     &                                                 f/4*th(i)/k(i))-
     &       (t(ii+1)-t(ii+2))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
            else
              newt(ii+1)=t(ii+1)+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &       ((t(ii)-t(ii+1))/(f/4*th(i-1)/k(i-1)+f/4*th(i)/k(i))-
     &       (t(ii+1)-t(ii+2))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
            endif
c middle element within layer i: t5,t8,t11,t14,t17,t20,t23:
            newt(ii+2)=t(ii+2)+deltime/(dens(i)*shc(i)*(1-f)*th(i))*
     &       ((t(ii+1)-t(ii+2))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &       (t(ii+2)-t(ii+3))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
```

```
c ending element within layer i: t6,t9,t12,t15,t18,t21,t24:
          if(i.eq.layair-1)then
          newt(ii+3)=t(ii+3)+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &    ((t(ii+2)-t(ii+3))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &    (t(ii+3)-t(ii+7))/(f/4*th(i)/k(i)+th(i+1)/k(i+1)+
     &                                    f/4*th(i+2)/k(i+2)))
          else
          newt(ii+3)=t(ii+3)+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &    ((t(ii+2)-t(ii+3))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &    (t(ii+3)-t(ii+4))/(f/4*th(i)/k(i)+f/4*th(i+1)/k(i+1)))
          endif
 20       continue
c lower wing surface temp (t27), as well as internal temp t25 and t26:
          newt(lend-2)=t(lend-2)+
     &       deltime/(dens(nlayer)*shc(nlayer)*f/2*th(nlayer))*
     &       ((t(lend-3)-t(lend-2))/
     &       (f/4*th(nlayer-1)/k(nlayer-1)+f/4*th(nlayer)/k(nlayer))-
     &       (t(lend-2)-t(lend-1))/
     &       (f/4*th(nlayer)/k(nlayer)+(1-f)/2*th(nlayer)/k(nlayer)))
          newt(lend-1)=t(lend-1)+
     &       deltime/(dens(nlayer)*shc(nlayer)*(1-f)*th(nlayer))*
     &       ((t(lend-2)-t(lend-1))/
     &       (f/4*th(nlayer)/k(nlayer)+(1-f)/2*th(nlayer)/k(nlayer))-
     &       (t(lend-1)-t(lend))/
     &       (f/4*th(nlayer)/k(nlayer)+(1-f)/2*th(nlayer)/k(nlayer)))
          qnetsky=(sig*t(lend)**4-jj(4))/((1.-emisw)/emisw)
          newt(lend)=t(lend)+
     &       deltime/(dens(nlayer)*shc(nlayer)*f/2*th(nlayer))*
     &       (qabstwa2(3,iperiod)-qnetsky-hhw*(t(lend)-ta)+
     &       (t(lend-1)-t(lend))/
     &       (f/4*th(nlayer)/k(nlayer)+(1-f)/2*th(nlayer)/k(nlayer)))
      do 60 i=1,lend
 60   t(i)=newt(i)
      temptrn(11)=t(1)-459.67
      temptrn(12)=(t(3)+t(4))/2.-459.67
      temptrn(13)=(t(6)+t(7))/2.-459.67
      temptrn(14)=(t(9)+t(10))/2-459.67
      temptrn(15)=t(12)-459.67
      temptrn(16)=t(16)-459.67
      temptrn(17)=(t(18)+t(19))/2.-459.67
      temptrn(18)=(t(21)+t(22))/2.-459.67
      temptrn(19)=(t(24)+t(25))/2.-459.67
      temptrn(20)=t(27)-459.67
      return
      end
c
c
      subroutine fuslglr1(itotitr,icool,iperiod,istep,theta,ta,hhf,hhc,
     &                          rff,absorbf,eemisf,sunfact,sunfact2)
c purpose: transient analysis of the fuselage (left to right)
c called from: trnsien1
```

```
c calls: none
      common/c2/tt(200),fn(200),jacob(200,200)
      common/c3/tth(100),kk(100)
      common/c6/absorbff,emisff,absorbww,emisww,absorbfl,emisfl,absorbfi
     &,emisfi,absorbpg,emispg,absorftp,emisrftp,absorfbt,emisrfbt
     &,absorbfb,emisfb
      common/c10/aircondc,thdiffus,visckine,prandtl
      common/c14/thicknes(100),density(100),conductv(100),sheatcap(100)
      common/reflecq/qreflin(6,100),qscabsin(6,100),qreflfwr(6,100),
     &qreflfwl(6,100),qscabfwr(6,100),qscabfwl(6,100),qabstwa1(6,100),
     &qabstwa2(6,100),qabstwb(6,100)
      common/temp3/t(1000)
      common/data1/deltime
      common/radiosit/jj(14)
      common/result/temp(200),temptrn(200)
      dimension newt(100),k(100),th(100),dens(100),shc(100)
      real kk,k,jj,newt,nusselt2
      parameter(sig=.1714e-8,gravity=32.2)
      parameter(fpi=3.141593/180.)
      parameter(nlayer=9)
      parameter(lend=3*nlayer)
      parameter(layair=5)
      parameter(f=0.2)
c
c Variables:
c layair=the layer (or element) that is air space (the fuselage width)
c f=fraction of an element thickness
c
      if(itotitr.eq.1.and.istep.eq.1)then
c reference thickness (th):
      th(1)=tth(8)
      th(2)=tth(9)
      th(3)=tth(10)
      th(4)=tth(23)
      th(5)=tth(11)
      th(6)=tth(23)
      th(7)=tth(10)
      th(8)=tth(9)
      th(9)=tth(8)
c reference conductivity (k):
      k(1)=kk(8)
      k(2)=kk(9)
      k(3)=kk(10)
      k(4)=kk(23)
      k(5)=kk(11)
      k(6)=kk(23)
      k(7)=kk(10)
      k(8)=kk(9)
      k(9)=kk(8)
c reference density (dens):
      dens(1)=density(10)
```

```
      dens(2)=density(11)
      dens(3)=density(12)
      dens(4)=density(13)
      dens(6)=density(13)
      dens(7)=density(12)
      dens(8)=density(11)
      dens(9)=density(10)
c reference specific heat capacity (shc):
      shc(1)=sheatcap(10)
      shc(2)=sheatcap(11)
      shc(3)=sheatcap(12)
      shc(4)=sheatcap(13)
      shc(6)=sheatcap(13)
      shc(7)=sheatcap(12)
      shc(8)=sheatcap(11)
      shc(9)=sheatcap(10)
      endif
      if(istep.eq.1)then
c reference the initial temp. (t):
      t(1)=tt(17)
      t(2)=(tt(17)+tt(18))/2.
      t(3)=tt(18)
      t(4)=tt(18)
      t(5)=(tt(18)+tt(19))/2.
      t(6)=tt(19)
      t(7)=tt(19)
      t(8)=(tt(19)+tt(20))/2.
      t(9)=tt(20)
      t(10)=tt(20)
      t(11)=(tt(20)+tt(38))/2.
      t(12)=tt(38)
      t(16)=tt(39)
      t(17)=(tt(39)+tt(21))/2.
      t(18)=tt(21)
      t(19)=tt(21)
      t(20)=(tt(21)+tt(22))/2.
      t(21)=tt(22)
      t(22)=tt(22)
      t(23)=(tt(22)+tt(23))/2.
      t(24)=tt(23)
      t(25)=tt(23)
      t(26)=(tt(23)+tt(24))/2.
      t(27)=tt(24)
c reference the initial radiosity (jj)
      jj(5)=tt(44)
      jj(6)=tt(45)
      jj(8)=tt(47)
      jj(10)=tt(49)
      return
      endif
      if(icool.eq.2)then
```

```
          rayleig2=gravity*1./((t(12)+t(16))/2.)*abs(t(12)-t(16))*
     &          th(layair)**3/(thdiffus*visckine)
          if(rayleig2.le.(1e3*(0.2+prandtl)/prandtl))then
            nusselt2=1.0
          elseif(rayleig2.gt.(1e3*(0.2+prandtl)/prandtl).and.rayleig2.lt.
     &         1.0e9)then
            nusselt2=0.18*((prandtl/(0.2+prandtl))*rayleig2)**0.29
          endif
       endif
c
c formulate transient cooling:
c
c LHS surface temp (t1), as well as internal temp t2 and t3:
          qnetsky=(sig*t(1)**4-rff*jj(5))/((1.-rff*eemisf)/eemisf)
          newt(1)=t(1)+deltime/(dens(1)*shc(1)*f/2*th(1))*
     &       ((absorbf*qreflfwl(2,iperiod)*cos(fpi*theta)+
     &       qscabfwl(2,iperiod))*sunfact+
     &       qscabfwr(2,iperiod)*(1-sunfact)
     &       -qnetsky-hhf*(t(1)-ta)-
     &       (t(1)-t(2))/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
          newt(2)=t(2)+deltime/(dens(1)*shc(1)*(1-f)*th(1))*
     &       ((t(1)-t(2))/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1))-
     &       (t(2)-t(3))/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
          newt(3)=t(3)+deltime/(dens(1)*shc(1)*f/2*th(1))*
     &       ((t(2)-t(3))/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1))-
     &       (t(3)-t(4))/(f/4*th(1)/k(1)+f/4*th(2)/k(2)))
c internal nodes (all conduction): t4-t24:
          do 20 i=1,nlayer
          if(i.eq.layair)goto 20
          if(i.eq.1.or.i.eq.nlayer)goto 20
          ii=(i-1)*3
c beginning element within layer i: t4,t7,t10,t16,t19,t22:
          if(i.eq.layair+1)then
            qnetcab=(sig*t(ii+1)**4-jj(10))/((1.-emisfi)/emisfi)
            if(icool.eq.1)then
              newt(ii+1)=t(ii+1)+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &       (-(t(ii+1)-t(ii+2))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &       qnetcab+absorbfi*qreflin(1,iperiod)*cos(fpi*theta)+
     &       qscabsin(1,iperiod)-hhc*(t(ii+1)-ta))
            elseif(icool.eq.2)then
              newt(ii+1)=t(ii+1)+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &       ((t(ii-3)-t(ii+1))/(f/4*th(i-2)/k(i-2)+
     &                  th(i-1)/(nusselt2*k(i-1))+f/4*th(i)/k(i))-
     &       (t(ii+1)-t(ii+2))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &       qnetcab+
     &       (absorbfi*qreflin(1,iperiod)*cos(fpi*theta)+
     &       qscabsin(1,iperiod))*sunfact2)
c     &       (absorbfi*qreflin(3,iperiod)*cos(fpi*theta)+
c     &       qscabsin(3,iperiod))*(1-sunfact))
            endif
          else
```

```
            newt(ii+1)=t(ii+1)+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &      ((t(ii)-t(ii+1))/(f/4*th(i-1)/k(i-1)+f/4*th(i)/k(i))-
     &      (t(ii+1)-t(ii+2))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
           endif
c middle element within layer i: t5,t8,t14,t17,t20,t23:
           newt(ii+2)=t(ii+2)+deltime/(dens(i)*shc(i)*(1-f)*th(i))*
     &     ((t(ii+1)-t(ii+2))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &     (t(ii+2)-t(ii+3))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
c ending element within layer i: t6,t9,t12,t18,t21,t24:
           if(i.eq.layair-1)then
           qnetcab=(sig*t(ii+3)**4-jj(8))/((1.-emisfi)/emisfi)
           if(icool.eq.1)then
            newt(ii+3)=t(ii+3)+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &      ((t(ii+2)-t(ii+3))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &      qnetcab+absorbfi*qreflin(3,iperiod)*cos(fpi*theta)+
     &      qscabsin(3,iperiod)-hhc*(t(ii+3)-ta))
           elseif(icool.eq.2)then
            newt(ii+3)=t(ii+3)+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &      ((t(ii+2)-t(ii+3))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &       (t(ii+3)-t(ii+7))/(f/4*th(i)/k(i)+
     &                          th(i+1)/(nusselt2*k(i+1))+f/4*th(i+2)/k(i+2))-
     &      qnetcab+
     &      (absorbfi*qreflin(3,iperiod)*cos(fpi*theta)+
     &      qscabsin(3,iperiod))*sunfact2)
c     &      (absorbfi*qreflin(1,iperiod)*cos(fpi*theta)+
c     &      qscabsin(1,iperiod))*(1-sunfact))
           endif
           else
           newt(ii+3)=t(ii+3)+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &     ((t(ii+2)-t(ii+3))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &     (t(ii+3)-t(ii+4))/(f/4*th(i)/k(i)+f/4*th(i+1)/k(i+1)))
           endif
 20        continue
c RHS fuselage surface temp (t27), as well as internal temp t25 and t26:
           newt(lend-2)=t(lend-2)+
     &       deltime/(dens(nlayer)*shc(nlayer)*f/2*th(nlayer))*
     &       ((t(lend-3)-t(lend-2))/
     &       (f/4*th(nlayer-1)/k(nlayer-1)+f/4*th(nlayer)/k(nlayer))-
     &       (t(lend-2)-t(lend-1))/
     &       (f/4*th(nlayer)/k(nlayer)+(1-f)/2*th(nlayer)/k(nlayer)))
           newt(lend-1)=t(lend-1)+
     &       deltime/(dens(nlayer)*shc(nlayer)*(1-f)*th(nlayer))*
     &       ((t(lend-2)-t(lend-1))/
     &       (f/4*th(nlayer)/k(nlayer)+(1-f)/2*th(nlayer)/k(nlayer))-
     &       (t(lend-1)-t(lend))/
     &       (f/4*th(nlayer)/k(nlayer)+(1-f)/2*th(nlayer)/k(nlayer)))
           qnetsky=(sig*t(lend)**4-rff*jj(6))/((1.-rff*eemisf)/eemisf)
           newt(lend)=t(lend)+
     &       deltime/(dens(nlayer)*shc(nlayer)*f/2*th(nlayer))*
     &       (qscabfwr(2,iperiod)*sunfact+
     &        (absorbf*qreflfwl(2,iperiod)*cos(fpi*theta)+
```

```
     &          qscabfwl(2,iperiod))*(1-sunfact)
     &        -qnetsky-hhf*(t(lend)-ta)+
     &        (t(lend-1)-t(lend))/
     &        (f/4*th(nlayer)/k(nlayer)+(1-f)/2*th(nlayer)/k(nlayer)))
      do 60 i=1,lend
 60   t(i)=newt(i)
      temptrn(39)=t(1)-459.67
      temptrn(40)=(t(3)+t(4))/2.-459.67
      temptrn(41)=(t(6)+t(7))/2.-459.67
      temptrn(42)=(t(9)+t(10))/2.-459.67
      temptrn(43)=t(12)-459.67
      temptrn(44)=t(16)-459.67
      temptrn(45)=(t(18)+t(19))/2.-459.67
      temptrn(46)=(t(21)+t(22))/2.-459.67
      temptrn(47)=(t(24)+t(25))/2.-459.67
      temptrn(48)=t(27)-459.67
      return
      end
c
c
      subroutine fuslgrf1(itotitr,icool,iperiod,istep,theta,ta,hhf,hhc,
     &                          qdir,qsky,qtarm,sunfact2)
c purpose: transient analysis of the fuselage (top to bottom)
c called from: trnsien1
c calls: none
      common/c2/tt(200),fn(200),jacob(200,200)
      common/c3/tth(100),kk(100)
      common/c4/widthwng,lengtwng,hwng,locwng,lplane,lfuselg,hfuselg,
     &          wfuselg
      common/c6/absorbff,emisff,absorbww,emisww,absorbfl,emisfl,absorbfi
     &,emisfi,absorbpg,emispg,absorftp,emisrftp,absorfbt,emisrfbt
     &,absorbfb,emisfb
      common/c5/trnsm,absorbta,emista,tarmd,densta,conducta,shcta
      common/c10/aircondc,thdiffus,visckine,prandtl
      common/c12/a1,a2,a3,a4,a5,a6(100),a7(100)
      common/c14/thicknes(100),density(100),conductv(100),sheatcap(100)
      common/reflecq/qreflin(6,100),qscabsin(6,100),qreflfwr(6,100),
     &qreflfwl(6,100),qscabfwr(6,100),qscabfwl(6,100),qabstwa1(6,100),
     &qabstwa2(6,100),qabstwb(6,100)
      common/temp4/t(1000),tpg1,tpg2,tpg3
      common/data1/deltime
      common/radiosit/jj(14)
      common/result/temp(200),temptrn(200)
      dimension newt(100),k(100),th(100),dens(100),shc(100)
      real kk,k,jj,newt,nusselt1,lfuselg,kpg,newtpg1,newtpg2,newtpg3
      parameter(sig=.1714e-8,gravity=32.2)
      parameter(fpi=3.141593/180.)
      parameter(nlayer=13)
      parameter(lend=3*nlayer)
      parameter(layair1=5,layair2=10)
      parameter(f=0.2)
```

```
c
c Variables:
c layair1=the layer (or element) that is air space (the fuselage height)
c layair2=the layer (or element) that is air space (in between the floor
c           and belly-pan)
c f=fraction of an element thickness
c
      if(itotitr.eq.1.and. istep.eq.1)then
c reference thickness (th):
      th(1)=tth(27)
      th(2)=tth(26)
      th(3)=tth(25)
      th(4)=tth(28)
      th(5)=tth(24)
      th(6)=tth(21)
      th(7)=tth(20)
      th(8)=tth(19)
      th(9)=tth(18)
      th(10)=tth(31)
      th(11)=tth(14)
      th(12)=tth(13)
      th(13)=tth(12)
c reference conductivity (k):
      k(1)=kk(27)
      k(2)=kk(26)
      k(3)=kk(25)
      k(4)=kk(28)
      k(5)=kk(24)
      k(6)=kk(21)
      k(7)=kk(20)
      k(8)=kk(19)
      k(9)=kk(18)
      k(10)=kk(31)
      k(11)=kk(14)
      k(12)=kk(13)
      k(13)=kk(12)
c reference density (dens):
      dens(1)=density(15)
      dens(2)=density(16)
      dens(3)=density(17)
      dens(4)=density(18)
      dens(6)=density(20)
      dens(7)=density(21)
      dens(8)=density(22)
      dens(9)=density(23)
      dens(11)=density(25)
      dens(12)=density(26)
      dens(13)=density(27)
c reference specific heat capacity:
      shc(1)=sheatcap(15)
      shc(2)=sheatcap(16)
```

```
      shc(3)=sheatcap(17)
      shc(4)=sheatcap(18)
      shc(6)=sheatcap(20)
      shc(7)=sheatcap(21)
      shc(8)=sheatcap(22)
      shc(9)=sheatcap(23)
      shc(11)=sheatcap(25)
      shc(12)=sheatcap(26)
      shc(13)=sheatcap(27)
c also reference plexiglass thickness, conductivity, density
c and specific heat capacity:
      thpg=tth(22)
      kpg=kk(22)
      denspg=density(28)
      shcpg=sheatcap(28)
c also find these values:
      c1=a1/(a1+a2)
      c2=a2/(a1+a2)
      emispgrf=c1*emispg+c2*emisrfbt
      endif
      if(istep.eq.1)then
c reference the initial temp. (t):
      t(1)=tt(59)
      t(2)=(tt(59)+tt(58))/2.
      t(3)=tt(58)
      t(4)=tt(58)
      t(5)=(tt(58)+tt(57))/2.
      t(6)=tt(57)
      t(7)=tt(57)
      t(8)=(tt(57)+tt(60))/2.
      t(9)=tt(60)
      t(10)=tt(60)
      t(11)=(tt(60)+tt(61))/2.
      t(12)=tt(61)
      t(16)=tt(35)
      t(17)=(tt(35)+tt(34))/2.
      t(18)=tt(34)
      t(19)=tt(34)
      t(20)=(tt(34)+tt(33))/2.
      t(21)=tt(33)
      t(22)=tt(33)
      t(23)=(tt(33)+tt(32))/2.
      t(24)=tt(32)
      t(25)=tt(32)
      t(26)=(tt(32)+tt(31))/2.
      t(27)=tt(31)
      t(31)=tt(28)
      t(32)=(tt(28)+tt(27))/2.
      t(33)=tt(27)
      t(34)=tt(27)
      t(35)=(tt(27)+tt(26))/2.
```

```
      t(36)=tt(26)
      t(37)=tt(26)
      t(38)=(tt(26)+tt(25))/2.
      t(39)=tt(25)
c also reference the intial plexiglass temp.
      tpg1=tt(37)
      tpg2=(tt(37)+tt(36))/2.
      tpg3=tt(36)
c reference the initial radiosity
      jj(7)=tt(46)
      jj(9)=tt(48)
      jj(11)=tt(50)
      return
      endif
      tpgrf=c1*tpg3+c2*t(12)
      qnet=(sig*tpgrf**4-jj(9))/((1.-emispgrf)/emispgrf)
c
      if(icool.eq.2)then
           rayleig1=gravity*1./((tpgrf+t(16))/2.)*(t(16)-tpgrf)*
     &          th(5)**3/(thdiffus*visckine)
           if(rayleig1.le.3e5)then
             nusselt1=1.0
           elseif(rayleig1.gt.3e5.and.rayleig1.le.7e9)then
             nusselt1=0.069*rayleig1**(1./3.)*prandtl**.074
           endif
      endif
c
c formulate transient cooling:
c
c first for the only three temperatures of plexiglass
c
c
       newtpg1=tpg1+deltime/(a1*denspg*shcpg*f/2*thpg)*
     & (emispg*qsky*a1+emispg*.5*(1.-emista)*qsky*a5
     &    +emispg*.5*qtarm*a5
     &    +f/2*absorbpg*qdir*cos(fpi*theta)*a6(iperiod)
     &    +f/2*absorbpg*qdir*sin(fpi*theta)*a7(iperiod)
     &    +f/2*absorbpg*.5*(1.-absorbta)*qdir*sin(fpi*theta)*a5
     &    +f/2*absorbpg*qreflin(4,iperiod)*sin(fpi*theta)*a3
     &    +f/2*absorbpg*qscabsin(4,iperiod)*lfuselg*wfuselg
     &    *a3/(absorbpg*a3+absorfbt*a4)
     &    -emispg*sig*tpg1**4*a1
     &    -hhf*(tpg1-ta)*a1
     &    -(tpg1-tpg2)/(f/4*thpg/kpg+(1-f)/2*thpg/kpg)*a1)
       newtpg2=tpg2+deltime/(a1*denspg*shcpg*(1-f)*thpg)*
     & ((tpg1-tpg2)/(f/4*thpg/kpg+(1-f)/2*thpg/kpg)*a1
     &    -(tpg2-tpg3)/((1-f)/2*thpg/kpg+f/4*thpg/kpg)*a1
     &    +(1-f)*absorbpg*qdir*cos(fpi*theta)*a6(iperiod)
     &    +(1-f)*absorbpg*qdir*sin(fpi*theta)*a7(iperiod)
     &    +(1-f)*absorbpg*.5*(1.-absorbta)*qdir*sin(fpi*theta)*a5
     &    +(1-f)*absorbpg*qreflin(4,iperiod)*sin(fpi*theta)*a3
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```
     &    +(1-f)*absorbpg*qscabsin(4,iperiod)*lfuselg*wfuselg
     &    *a3/(absorbpg*a3+absorfbt*a4))
       qpg=emispg*sig*tpg3**4-emispg/(a3*emispg+a4*emisrfbt)*
     &    (a3*emispg*sig*tpg3**4+a4*emisrfbt*sig*t(12)**4-qnet*(a3+a4))
       if(icool.eq.1)then
            newtpg3=tpg3+deltime/(a1*denspg*shcpg*f/2*thpg)*
     &     ((tpg2-tpg3)/((1-f)/2*thpg/kpg+f/4*thpg/kpg)*a1
     &     -hhc*(tpg3-ta)*a1
     &     -qpg*a3
     &     +f/2*absorbpg*qdir*cos(fpi*theta)*a6(iperiod)
     &     +f/2*absorbpg*qdir*sin(fpi*theta)*a7(iperiod)
     &     +f/2*absorbpg*.5*(1.-absorbta)*qdir*sin(fpi*theta)*a5
     &     +f/2*absorbpg*qreflin(4,iperiod)*sin(fpi*theta)*a3
     &     +f/2*absorbpg*qscabsin(4,iperiod)*lfuselg*wfuselg
     &     *a3/(absorbpg*a3+absorfbt*a4))
       elseif(icool.eq.2)then
            newtpg3=tpg3+deltime/(a1*denspg*shcpg*f/2*thpg)*
     &     ((tpg2-tpg3)/((1-f)/2*thpg/kpg+f/4*thpg/kpg)*a1
     &      -(tpgrf-t(16))/(th(5)/(nusselt1*k(5)))*a3
     &     -qpg*a3
     &     +f/2*absorbpg*qdir*cos(fpi*theta)*a6(iperiod)
     &     +f/2*absorbpg*qdir*sin(fpi*theta)*a7(iperiod)
     &     +f/2*absorbpg*.5*(1.-absorbta)*qdir*sin(fpi*theta)*a5
     &     +f/2*absorbpg*qreflin(4,iperiod)*sin(fpi*theta)*a3
     &     +f/2*absorbpg*qscabsin(4,iperiod)*lfuselg*wfuselg
     &     *a3/(absorbpg*a3+absorfbt*a4))
       endif
c
c next for the roof structure and the rest
c
c first three temperatures of roof structure:
          qnetsky=(emisrftp*sig*t(1)**4-emisrftp*qsky)
          newt(1)=t(1)+deltime/(dens(1)*shc(1)*f/2*th(1))*
     &       (absorftp*qdir*sin(fpi*theta)-qnetsky-hhf*(t(1)-ta)-
     &       (t(1)-t(2))/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
          newt(2)=t(2)+deltime/(dens(1)*shc(1)*(1-f)*th(1))*
     &       ((t(1)-t(2))/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1))-
     &       (t(2)-t(3))/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
          newt(3)=t(3)+deltime/(dens(1)*shc(1)*f/2*th(1))*
     &       ((t(2)-t(3))/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1))-
     &       (t(3)-t(4))/(f/4*th(1)/k(1)+f/4*th(2)/k(2)))
c internal nodes: t4-t36:
          do 20 i=1,nlayer
          if(i.eq.layair1.or.i.eq.layair2)goto 20
          if(i.eq.1.or.i.eq.nlayer)goto 20
          ii=(i-1)*3
c beginning element within layer i: t4,t7,t10,t16,t19,t22,t25,t31,t34:
          if(i.eq.layair1+1)then
            qnetcab=(sig*t(ii+1)**4-jj(11))/((1.-emisfl)/emisfl)
            if(icool.eq.1)then
              newt(ii+1)=t(ii+1)+deltime/(dens(i)*shc(i)*f/2*th(i))*
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```
     &       (-(t(ii+1)-t(ii+2))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &       hhc*(t(ii+1)-ta)-
     &       qnetcab+absorbfl*qreflin(2,iperiod)*sin(fpi*theta)+
     &       qscabsin(2,iperiod))
            elseif(icool.eq.2)then
              newt(ii+1)=t(ii+1)+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &       ((tpgrf-t(ii+1))/(th(i-1)/(nusselt1*k(i-1)))-
     &       (t(ii+1)-t(ii+2))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &       qnetcab+
     &       (absorbfl*qreflin(2,iperiod)*sin(fpi*theta)+
     &       qscabsin(2,iperiod))*sunfact2)
            endif
           elseif(i.eq.layair2+1)then
            newt(ii+1)=t(ii+1)+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &      ((t(ii-3)-t(ii+1))/(f/4*th(i-2)/k(i-2)+th(i-1)/k(i-1)+
     &                                              f/4*th(i)/k(i))-
     &      (t(ii+1)-t(ii+2))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
           else
            newt(ii+1)=t(ii+1)+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &      ((t(ii)-t(ii+1))/(f/4*th(i-1)/k(i-1)+f/4*th(i)/k(i))-
     &      (t(ii+1)-t(ii+2))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
           endif
c middle element within layer i: t5,t8,t11,t17,t20,t23,t26,t32,t35:
           newt(ii+2)=t(ii+2)+deltime/(dens(i)*shc(i)*(1-f)*th(i))*
     &     ((t(ii+1)-t(ii+2))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &     (t(ii+2)-t(ii+3))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
c ending element within layer i: t6,t9,t12,t18,t21,t24,t27,t33,t36:
        if(i.eq.layair1-1)then
        qrfbt=emisrfbt*sig*t(ii+3)**4-emisrfbt/(a3*emispg+a4*emisrfbt)*
     &(a3*emispg*sig*tpg3**4+a4*emisrfbt*sig*t(ii+3)**4-qnet*(a3+a4))
           if(icool.eq.1)then
              newt(ii+3)=t(ii+3)+deltime/(a2*dens(i)*shc(i)*f/2*th(i))*
     &       ((t(ii+2)-t(ii+3))/((1-f)/2*th(i)/k(i)+f/4*th(i)/k(i))*a2-
     &        hhc*(t(ii+3)-ta)*a2
     &        -qrfbt*a4
     &        +absorfbt*qreflin(4,iperiod)*sin(fpi*theta)*a4
     &        +absorfbt*qscabsin(4,iperiod)*lfuselg*wfuselg*a4/
     &        (absorbpg*a3+absorfbt*a4))
            elseif(icool.eq.2)then
              newt(ii+3)=t(ii+3)+deltime/(a2*dens(i)*shc(i)*f/2*th(i))*
     &       ((t(ii+2)-t(ii+3))/((1-f)/2*th(i)/k(i)+f/4*th(i)/k(i))*a2-
     &        (tpgrf-t(ii+7))/(th(i+1)/(nusselt1*k(i+1)))*a4
     &        -qrfbt*a4
     &        +(absorfbt*qreflin(4,iperiod)*sin(fpi*theta)*a4
     &        +absorfbt*qscabsin(4,iperiod)*lfuselg*wfuselg*a4/
     &        (absorbpg*a3+absorfbt*a4))*sunfact2)
            endif
           elseif(i.eq.layair2-1)then
           newt(ii+3)=t(ii+3)+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &     ((t(ii+2)-t(ii+3))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &     (t(ii+3)-t(ii+7))/(f/4*th(i)/k(i)+th(i+1)/k(i+1)+
```

```
     &                                f/4*th(i+2)/k(i+2)))
           else
           newt(ii+3)=t(ii+3)+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &     ((t(ii+2)-t(ii+3))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &     (t(ii+3)-t(ii+4))/(f/4*th(i)/k(i)+f/4*th(i+1)/k(i+1)))
           endif
  20       continue
c belly-pan temp (t39), as well as internal temp t37 and t38:
           newt(lend-2)=t(lend-2)+
     &        deltime/(dens(nlayer)*shc(nlayer)*f/2*th(nlayer))*
     &        ((t(lend-3)-t(lend-2))/
     &        (f/4*th(nlayer-1)/k(nlayer-1)+f/4*th(nlayer)/k(nlayer))-
     &        (t(lend-2)-t(lend-1))/
     &        (f/4*th(nlayer)/k(nlayer)+(1-f)/2*th(nlayer)/k(nlayer)))
           newt(lend-1)=t(lend-1)+
     &        deltime/(dens(nlayer)*shc(nlayer)*(1-f)*th(nlayer))*
     &        ((t(lend-2)-t(lend-1))/
     &        (f/4*th(nlayer)/k(nlayer)+(1-f)/2*th(nlayer)/k(nlayer))-
     &        (t(lend-1)-t(lend))/
     &        (f/4*th(nlayer)/k(nlayer)+(1-f)/2*th(nlayer)/k(nlayer)))
           qnetsky=(sig*t(lend)**4-jj(7))/((1.-emisfb)/emisfb)
           newt(lend)=t(lend)+
     &        deltime/(dens(nlayer)*shc(nlayer)*f/2*th(nlayer))*
     &        (qabstwb(3,iperiod)-qnetsky-hhf*(t(lend)-ta)+
     &        (t(lend-1)-t(lend))/
     &        (f/4*th(nlayer)/k(nlayer)+(1-f)/2*th(nlayer)/k(nlayer)))
        tpg1=newtpg1
        tpg2=newtpg2
        tpg3=newtpg3
        do 60 i=1,lend
  60    t(i)=newt(i)
       temptrn(21)=t(1)-459.67
       temptrn(22)=(t(3)+t(4))/2.-459.67
       temptrn(23)=(t(6)+t(7))/2.-459.67
       temptrn(24)=(t(9)+t(10))/2.-459.67
       temptrn(25)=t(12)-459.67
       temptrn(26)=t(16)-459.67
       temptrn(27)=(t(18)+t(19))/2.-459.67
       temptrn(28)=(t(21)+t(22))/2.-459.67
       temptrn(29)=(t(24)+t(25))/2.-459.67
       temptrn(30)=t(27)-459.67
       temptrn(31)=(t(27)+t(31))/2.-459.67
       temptrn(32)=(t(27)+t(31))/2.-459.67
       temptrn(33)=(t(27)+t(31))/2.-459.67
       temptrn(34)=(t(27)+t(31))/2.-459.67
       temptrn(35)=t(31)-459.67
       temptrn(36)=(t(33)+t(34))/2.-459.67
       temptrn(37)=(t(36)+t(37))/2.-459.67
       temptrn(38)=t(39)-459.67
       temptrn(49)=tpg1-459.67
       temptrn(50)=tpg3-459.67
```

```
      return
      end
c
      subroutine tarmac1(itotitr,icool,iperiod,istep,ta,ttarm,hht)
c purpose: transient analysis of the tarmac
c called from: trnsien1
c calls: none
      common/c4/widthwng,lengtwng,hwng,locwng,lplane,lfuselg,hfuselg,
     &          wfuselg
      common/c5/trnsm,absorbta,emista,tarmd,densta,conducta,shcta
      common/c2/tt(200),fn(200),jacob(200,200)
      common/c3/tth(100),kk(100)
      common/c14/thicknes(100),density(100),conductv(100),sheatcap(100)
      common/reflecq/qreflin(6,100),qscabsin(6,100),qreflfwr(6,100),
     &qreflfwl(6,100),qscabfwr(6,100),qscabfwl(6,100),qabstwa1(6,100),
     &qabstwa2(6,100),qabstwb(6,100)
      common/temp5/t(1000)
      common/data1/deltime
      common/radiosit/jj(14)
      common/facttarm/fact
      common/result/temp(200),temptrn(200)
      dimension newt(100)
      real jj,newt,lengtwng
      parameter(sig=.1714e-8)
      parameter(fpi=3.141593/180.)
      parameter(afact=1.0,bfact=0.00001)
c
c Variables:
c afact=cooling when door is opened: no motion: therefore tarmac temperature
c       underneath the wing remains very constant
c bfact=a small number to force the tarmac temperature underneath the wing
c       to be the same as the unsheltered tarmac temperature: in effect when
c       the aircraft is in motion
c
      if(itotitr.eq.1.and.istep.eq.1)then
      rlwng=(lengtwng-wfuselg)/2.
      endif
      if(istep.eq.1)then
c reference the initial temp.:
      t(51)=tt(51)
      t(52)=tt(52)
      t(53)=tt(53)
c reference the initial radiosity
      jj(12)=tt(54)
      jj(13)=tt(55)
      jj(14)=tt(56)
      return
      endif
      if(icool.eq.1)fact1=afact
      if(icool.eq.2)fact1=bfact
c
```

```
c formulate transient cooling:
c
c LHS Wing/Tarmac t(51):
          qnetsky=(sig*t(51)**4-jj(12))/((1.-emista)/emista)
          newt(51)=t(51)+deltime/(densta*rlwng*widthwng*tarmd*shcta)*
     &    ((qabstwa1(1,iperiod)-qnetsky-hht*(t(51)-ta))*rlwng*widthwng+
     &   2.*(conducta/(fact1*fact*widthwng)*(ttarm-t(51)))*tarmd*rlwng+
     &     conducta/(fact1*fact*widthwng)*(ttarm-t(51))*tarmd*widthwng-
     &     conducta/(.5*wfuselg+.5*rlwng)*(t(51)-t(52))*tarmd*widthwng)
c RHS Wing/Tarmac t(53):
          qnetsky=(sig*t(53)**4-jj(14))/((1.-emista)/emista)
          newt(53)=t(53)+deltime/(densta*rlwng*widthwng*tarmd*shcta)*
     &    ((qabstwa2(1,iperiod)-qnetsky-hht*(t(53)-ta))*rlwng*widthwng+
     &   2.*(conducta/(fact1*fact*widthwng)*(ttarm-t(53)))*tarmd*rlwng+
     &     conducta/(fact1*fact*widthwng)*(ttarm-t(53))*tarmd*widthwng-
     &     conducta/(.5*wfuselg+.5*rlwng)*(t(53)-t(52))*tarmd*widthwng)
c MIDDLE Wing/Tarmac t(52):
          qnetsky=(sig*t(52)**4-jj(13))/((1.-emista)/emista)
          newt(52)=t(52)+deltime/(densta*wfuselg*widthwng*tarmd*shcta)*
     &    ((qabstwb(1,iperiod)-qnetsky-hht*(t(52)-ta))*wfuselg*widthwng+
     &   2.*(conducta/(fact1*fact*widthwng)*(ttarm-t(51)))*tarmd*wfuselg
     &    +conducta/(.5*wfuselg+.5*rlwng)*(t(51)-t(52))*tarmd*widthwng+
     &    conducta/(.5*wfuselg+.5*rlwng)*(t(53)-t(52))*tarmd*widthwng)
      t(51)=newt(51)
      t(52)=newt(52)
      t(53)=newt(53)
      temptrn(51)=t(51)-459.67
      temptrn(52)=t(52)-459.67
      temptrn(53)=t(53)-459.67
      return
      end
c
      subroutine updradio(itotitr,iperiod,istep,qsky,qtarm,emisf,
     &                          emisw,eemisf,eemisw,rff,rfw)
c purpose: updates the radiosity (14 of them) during the cooling phase
c            ie:a*radiosity=tempfact
c called from: trnsien1 and trnsien2
c calls: ludcmp,lubksb
      common/c1/n,ntrial,tolx,tolf
      common/c2/x(200),fvec(200),a(200,200)
      common/sc1/indx(200),b(200)
      common/c4/widthwng,lengtwng,hwng,locwng,lplane,lfuselg,hfuselg,
     &          wfuselg
      common/c5/trnsm,absorbta,emista,tarmd,densta,conducta,shcta
      common/c6/absorbff,emisff,absorbww,emisww,absorbfl,emisfl,absorbfi
     &,emisfi,absorbpg,emispg,absorftp,emisrftp,absorfbt,emisrfbt
     &,absorbfb,emisfb
      common/c7/nperiods,envtdata(100,20)
      common/c12/a1,a2,a3,a4,a5,a6(100),a7(100)
      common/temp1/t1(1000)
      common/temp2/t2(1000)
```

```
      common/temp3/t3(1000)
      common/temp4/t4(1000),tpg1,tpg2,tpg3
      common/temp5/t5(1000)
      common/radiosit/radiosj(14)
      common/vf1/fbwa(6,6),fbwb(6,6)
      common/vf2/fa11,fa12,fa13,fa14,fa15,fa16,fa21,fa22,fa23,fa24,
     &           fa25,fa26,fa31,fa32,fa33,fa34,fa35,fa36,fa41,fa42,
     &           fa43,fa44,fa45,fa46,fa51,fa52,fa53,fa54,fa55,fa56,
     &           fa61,fa62,fa63,fa64,fa65,fa66
      common/vf4/fa57,fa68
      common/vf5/fc11,fc12,fc13,fc14,fc15,fc16,fc21,fc22,fc23,fc24,
     &           fc25,fc26,fc31,fc32,fc33,fc34,fc35,fc36,fc41,fc42,
     &           fc43,fc44,fc45,fc46,fc51,fc52,fc53,fc54,fc55,fc56,
     &           fc61,fc62,fc63,fc64,fc65,fc66
      common/result/temp(200),temptrn(200)
      dimension t(100),aa(14,14),iindx(14)
      dimension tempfact(14)
      parameter(sig=.1714e-8)
      real lfuselg
c
c Variables:
c tempfact()=updated term that is a function of the previous temperature
c aa(,)=matrix relating radiosity to tempfact; to be inverted
c radiosity()=updated radiosity
c
      if(iperiod.eq.1.and.istep.eq.1)then
c find the a matrix relating radiosity jj to the temperature term tempfact
c because the a matrix is a constant, you need to find it and its
c inverse only once for a given paint scheme
c
      n=14
c initialize a(i,j) to zeroes initially because most of the coefficients are
c zeroes
      do 15 i=1,n
           do 15 j=1,n
             a(i,j)=0.0
 15   continue
c
c LHS Wing/Fuselage :::Wing
c J1:::a(1,1),a(1,5),tempfact(1); from fn(24):
      a(1,1)=1/(1/fa12)+1/(1/fa13)+1/(1/fa14)+1/(1/fa15)+1/(1/fa16)
     &       +rfw/((1-rfw*eemisw)/eemisw)
      a(1,5)=-1/(1/fa12)
c LHS Wing/Fuselage :::Fuselage
c J5:::a(5,1),a(5,5),tempfact(5); from fn(28):
      a(5,1)=-1/(1/fa21)
      a(5,5)=1/(1/fa21)+1/(1/fa23)+1/(1/fa24)+1/(1/fa25)+1/(1/fa26)
     &       +rff/((1-rff*eemisf)/eemisf)
c RHS Wing/Fuselage :::Wing
c J3:::a(3,3),a(3,6),tempfact(3); from fn(26):
      a(3,3)=1/(1/fa12)+1/(1/fa13)+1/(1/fa14)+1/(1/fa15)+1/(1/fa16)
```

```
     &        +rfw/((1-rfw*eemisw)/eemisw)
      a(3,6)=-1/(1/fa12)
c RHS Wing/Fuselage :::Fuselage
c J6:::a(6,3),a(6,6),tempfact(6); from fn(30):
      a(6,3)=-1/(1/fa21)
      a(6,6)=1/(1/fa21)+1/(1/fa23)+1/(1/fa24)+1/(1/fa25)+1/(1/fa26)
     &        +rff/((1-rff*eemisf)/eemisf)
c LHS Wing/Tarmac :::Wing
c J2:::a(2,2),a(2,12),a(2,13),a(2,14),tempfact(2); from fn(20):
      a(2,2)=1/(1/fbwa(3,1))+1/(1/fbwa(3,2))+1/(1/fbwa(3,4))+
     &        1/(1/fbwa(3,5))+1/(1/fbwa(3,6))+1/((1-emisw)/emisw)
      a(2,12)=-1/(1/fbwa(3,1))
      a(2,13)=-fbwb(4,1)/(1/fbwa(3,2))
      a(2,14)=-fbwa(4,1)*fbwb(4,2)/(1/fbwa(3,2))
c RHS Wing/Tarmac :::Wing
c J4:::a(4,4),a(4,12),a(4,13),a(4,14),tempfact(4); from fn(22):
      a(4,4)=1/(1/fbwa(3,1))+1/(1/fbwa(3,2))+1/(1/fbwa(3,4))+
     &        1/(1/fbwa(3,5))+1/(1/fbwa(3,6))+1/((1-emisw)/emisw)
      a(4,12)=-fbwa(2,1)*fbwb(2,4)/(1/fbwa(3,4))
      a(4,13)=-fbwb(2,1)/(1/fbwa(3,4))
      a(4,14)=-1/(1/fbwa(3,1))
c MIDDLE Wing/Tarmac :::Wing
c J7:::a(7,7),a(7,12),a(7,13),a(7,14),tempfact(7); from fn(46):
      a(7,7)=1/(1/fbwb(3,1))+1/(1/fbwb(3,2))+1/(1/fbwb(3,4))+
     &        1/(1/fbwb(3,5))+1/(1/fbwb(3,6))+1/((1-emisfb)/emisfb)
      a(7,12)=-fbwa(2,1)/(1/fbwb(3,4))
      a(7,13)=-1/(1/fbwb(3,1))
      a(7,14)=-fbwa(4,1)/(1/fbwb(3,2))
c LHS Wing/Tarmac :::Tarmac
c J12:::a(12,2),a(12,4),a(12,7),a(12,12),tempfact(12); from fn(54):
      a(12,2)=-1/(1/fbwa(1,3))
      a(12,4)=-fbwa(4,3)*fbwb(4,2)/(1/fbwa(1,2))
      a(12,7)=-fbwb(4,3)/(1/fbwa(1,2))
      a(12,12)=1/(1/fbwa(1,2))+1/(1/fbwa(1,3))+1/(1/fbwa(1,4))+
     &        1/(1/fbwa(1,5))+1/(1/fbwa(1,6))+1/((1-emista)/emista)
c RHS Wing/Tarmac :::Tarmac
c J14:::a(14,2),a(14,4),a(14,7),a(14,14),tempfact(14); from fn(56):
      a(14,2)=-fbwa(2,3)*fbwb(2,4)/(1/fbwa(1,4))
      a(14,4)=-1/(1/fbwa(1,3))
      a(14,7)=-fbwb(2,3)/(1/fbwa(1,4))
      a(14,14)=1/(1/fbwa(1,2))+1/(1/fbwa(1,3))+1/(1/fbwa(1,4))+
     &        1/(1/fbwa(1,5))+1/(1/fbwa(1,6))+1/((1-emista)/emista)
c MIDDLE Wing/Tarmac :::Tarmac
c J13:::a(13,2),a(13,4),a(13,7),a(13,13),tempfact(13); from fn(55):
      a(13,2)=-fbwa(2,3)/(1/fbwb(1,4))
      a(13,4)=-fbwa(4,3)/(1/fbwb(1,2))
      a(13,7)=-1/(1/fbwb(1,3))
      a(13,13)=1/(1/fbwb(1,2))+1/(1/fbwb(1,3))+1/(1/fbwb(1,4))+
     &        1/(1/fbwb(1,5))+1/(1/fbwb(1,6))+1/((1-emista)/emista)
c FUSELAGE INTERIOR (CABIN)
c LHS Fuselage Interior (Cabin)
```

```
c J8:::a(8,8),a(8,9),a(8,10),a(8,11),tempfact(8); from fn(47):
      a(8,8)=1/(1/fc41)+1/(1/fc42)+1/(1/fc43)+1/(1/fc45)+1/(1/fc46)
     &         +1/((1-emisfi)/emisfi)
      a(8,9)=-1/(1/fc43)
      a(8,10)=-1/(1/fc42)
      a(8,11)=-1/(1/fc41)
c RHS Fuselage Interior (Cabin)
c J10:::a(10,8),a(10,9),a(10,10),a(10,11),tempfact(10); from fn(49):
      a(10,8)=-1/(1/fc24)
      a(10,9)=-1/(1/fc23)
      a(10,10)=1/(1/fc21)+1/(1/fc23)+1/(1/fc24)+1/(1/fc25)+1/(1/fc26)
     &         +1/((1-emisfi)/emisfi)
      a(10,11)=-1/(1/fc21)
c BOTTOM (floor) Fuselage Interior (Cabin)
c J11:::a(11,8),a(11,9),a(11,10),a(11,11),tempfact(11); from fn(50):
      a(11,8)=-1/(1/fc14)
      a(11,9)=-1/(1/fc13)
      a(11,10)=-1/(1/fc12)
      a(11,11)=1/(1/fc12)+1/(1/fc13)+1/(1/fc14)+1/(1/fc15)+1/(1/fc16)
     &         +1/((1-emisfl)/emisfl)
c TOP (combined roof and plexiglass structure) Fuselage Interior (Cabin)
c J9:::a(9,8),a(9,9),a(9,10),a(9,11),tempfact(9); from fn(48):
      c1=a1/(a1+a2)
      c2=a2/(a1+a2)
      emispgrf=c1*emispg+c2*emisrfbt
      a(9,8)=-1/(1/fc34)
      a(9,9)=1/(1/fc31)+1/(1/fc32)+1/(1/fc34)+1/(1/fc35)+1/(1/fc36)
     &         +1/((1-emispgrf)/emispgrf)
      a(9,10)=-1/(1/fc32)
      a(9,11)=-1/(1/fc31)
c      if(itotitr.le.nperiods)write(17,*)'matrix a'
c      do 10 i=1,14
c 10   if(itotitr.le.nperiods)write(17,80)(a(i,j),j=1,14)
 80   format(2x,500(1x,e10.3))
      call ludcmp
c      if(itotitr.le.nperiods)write(17,*)'decomposed matrix a'
c      do 20 i=1,14
c 20   if(itotitr.le.nperiods)write(17,80)(a(i,j),j=1,14)
c replace a(i,j) with aa(i,j), bec. a(i,j) gets changed in the steady-state
c analysis phase.  same thing for index(i)
      do 25 i=1,14
      iindx(i)=indx(i)
      do 25 j=1,14
 25   aa(i,j)=a(i,j)
      return
      endif
c
c find the updated temperature term tempfact(i)
c ie A*J=T, where T is the tempfact. then find updated J.  A is constant
c first relate t(i) to t1(i),t2(i),t3(i),tpg3,t4(i) and t5(i) obtained from
c transient analysis
```

```
      t(1)=t1(1)
      t(8)=t1(27)
      t(9)=t2(1)
      t(16)=t2(27)
      t(17)=t3(1)
      t(38)=t3(12)
      t(39)=t3(16)
      t(24)=t3(27)
      t(36)=tpg3
      t(61)=t4(12)
      t(35)=t4(16)
      t(25)=t4(39)
      t(51)=t5(51)
      t(52)=t5(52)
      t(53)=t5(53)
c LHS Wing/Fuselage :::Wing
c J1:::a(1,1),a(1,5),tempfact(1); from fn(24):
      q1=qsky+fa57*(emisf*sig*t(17)**4
     &     +(1-emisf)*(qsky+.5*qtarm+.5*(1.-emista)*qsky))
      q2=qsky+fa68*(emisf*sig*t(17)**4
     &     +(1-emisf)*(qsky+.5*qtarm+.5*(1.-emista)*qsky))
      tempfact(1)=qsky/(1/fa13)+qsky/(1/fa14)+q1/(1/fa15)+q2/(1/fa16)
     &                +sig*t(1)**4/((1-rfw*eemisw)/eemisw)
c LHS Wing/Fuselage :::Fuselage
c J5:::a(5,1),a(5,5),tempfact(5); from fn(28):
      q1=qsky+.5*qtarm+.5*(1-emista)*qsky
      tempfact(5)=qsky/(1/fa23)+q1/(1/fa24)+q1/(1/fa25)+q1/(1/fa26)
     &                +sig*t(17)**4/((1-rff*eemisf)/eemisf)
c RHS Wing/Fuselage :::Wing
c J3:::a(3,3),a(3,6),tempfact(3); from fn(26):
      q1=qsky+fa57*(emisf*sig*t(24)**4
     &     +(1-emisf)*(qsky+.5*qtarm+.5*(1.-emista)*qsky))
      q2=qsky+fa68*(emisf*sig*t(24)**4
     &     +(1-emisf)*(qsky+.5*qtarm+.5*(1.-emista)*qsky))
      tempfact(3)=qsky/(1/fa13)+qsky/(1/fa14)+q1/(1/fa15)+q2/(1/fa16)
     &                +sig*t(9)**4/((1-rfw*eemisw)/eemisw)
c RHS Wing/Fuselage :::Fuselage
c J6:::a(6,3),a(6,6),tempfact(6); from fn(30):
      q1=qsky+.5*qtarm+.5*(1-emista)*qsky
      tempfact(6)=qsky/(1/fa23)+q1/(1/fa24)+q1/(1/fa25)+q1/(1/fa26)
     &                +sig*t(24)**4/((1-rff*eemisf)/eemisf)
c LHS Wing/Tarmac :::Wing
c J2:::a(2,2),a(2,12),a(2,13),a(2,14),tempfact(2); from fn(20):
c find qskytarm first
      qskytarm=qsky+0.5*qtarm+0.5*(1.-emista)*qsky
      tempfact(2)=1/(1/fbwa(3,2))*
     & ((qskytarm*fbwa(4,2)+qskytarm*fbwa(4,5)+qskytarm*fbwa(4,6))*
     & fbwb(4,2)+qskytarm*fbwb(4,5)+qskytarm*fbwb(4,6))+
     & qskytarm/(1/fbwa(3,4))+qskytarm/(1/fbwa(3,5))+
     & qskytarm/(1/fbwa(3,6))+sig*t(8)**4/((1-emisw)/emisw)
c RHS Wing/Tarmac :::Wing
```

```
c J4:::a(4,4),a(4,12),a(4,13),a(4,14),tempfact(4); from fn(22):
      tempfact(4)=qskytarm/(1/fbwa(3,2))+1/(1/fbwa(3,4))*
     & ((qskytarm*fbwa(2,4)+qskytarm*fbwa(2,5)+qskytarm*fbwa(2,6))*
     & fbwb(2,4)+qskytarm*fbwb(2,5)+qskytarm*fbwb(2,6))+
     & qskytarm/(1/fbwa(3,5))+
     & qskytarm/(1/fbwa(3,6))+sig*t(16)**4/((1-emisw)/emisw)
c MIDDLE Wing/Tarmac :::Wing
c J7:::a(7,7),a(7,12),a(7,13),a(7,14),tempfact(7); from fn(46):
      tempfact(7)=1/(1/fbwb(3,2))*
     & (qskytarm*fbwa(4,2)+qskytarm*fbwa(4,5)+qskytarm*fbwa(4,6))+
     &                1/(1/fbwb(3,4))*
     & (qskytarm*fbwa(2,4)+qskytarm*fbwa(2,5)+qskytarm*fbwa(2,6))+
     & qskytarm/(1/fbwb(3,5))+
     & qskytarm/(1/fbwb(3,6))+
     & sig*t(25)**4/((1-emisfb)/emisfb)
c LHS Wing/Tarmac :::Tarmac
c J12:::a(12,2),a(12,4),a(12,7),a(12,12),tempfact(12); from fn(54):
      tempfact(12)=1/(1/fbwa(1,2))*
     & ((qsky*fbwa(4,2)+qsky*fbwa(4,5)+qsky*fbwa(4,6))*
     & fbwb(4,2)+qsky*fbwb(4,5)+qsky*fbwb(4,6))+
     & qsky/(1/fbwa(1,4))+qsky/(1/fbwa(1,5))+
     & qsky/(1/fbwa(1,6))+sig*t(51)**4/((1-emista)/emista)
c RHS Wing/Tarmac :::Tarmac
c J14:::a(14,2),a(14,4),a(14,7),a(14,14),tempfact(14); from fn(56):
      tempfact(14)=qsky/(1/fbwa(1,2))+1/(1/fbwa(1,4))*
     & ((qsky*fbwa(2,4)+qsky*fbwa(2,5)+qsky*fbwa(2,6))*
     & fbwb(2,4)+qsky*fbwb(2,5)+qsky*fbwb(2,6))+
     & qsky/(1/fbwa(1,5))+
     & qsky/(1/fbwa(1,6))+sig*t(53)**4/((1-emista)/emista)
c MIDDLE Wing/Tarmac :::Tarmac
c J13:::a(13,2),a(13,4),a(13,7),a(13,13),tempfact(13); from fn(55):
      tempfact(13)=1/(1/fbwb(1,2))*
     & (qsky*fbwa(4,2)+qsky*fbwa(4,5)+qsky*fbwa(4,6))+
     &                1/(1/fbwb(1,4))*
     & (qsky*fbwa(2,4)+qsky*fbwa(2,5)+qsky*fbwa(2,6))+
     & qsky/(1/fbwb(1,5))+
     & qsky/(1/fbwb(1,6))+
     & sig*t(52)**4/((1-emista)/emista)
c FUSELAGE INTERIOR (CABIN)
c find the weighted average temperatures tend and tpgrf first.
      aa1=lfuselg*wfuselg
      aa2=a1
      aa3=lfuselg*hfuselg
      aa4=aa3
      aa5=a2
      atot=aa1+aa2+aa3+aa4+aa5
      cc1=aa1/atot
      cc2=aa2/atot
      cc3=aa3/atot
      cc4=aa4/atot
      cc5=aa5/atot
```

```
      tend=cc1*t(35)+cc2*t(36)+cc3*t(38)+cc4*t(39)+cc5*t(61)
      tpgrf=c1*t(36)+c2*t(61)
c LHS Fuselage Interior (Cabin)
c J8:::a(8,8),a(8,9),a(8,10),a(8,11),tempfact(8); from fn(47):
      tempfact(8)=sig*tend**4/(1/fc45)+sig*tend**4/(1/fc46)
     &                +sig*t(38)**4/((1-emisfi)/emisfi)
c RHS Fuselage Interior (Cabin)
c J10:::a(10,8),a(10,9),a(10,10),a(10,11),tempfact(10); from fn(49):
      tempfact(10)=sig*tend**4/(1/fc25)+sig*tend**4/(1/fc26)
     &                +sig*t(39)**4/((1-emisfi)/emisfi)
c BOTTOM (floor) Fuselage Interior (Cabin)
c J11:::a(11,8),a(11,9),a(11,10),a(11,11),tempfact(11); from fn(50):
      tempfact(11)=sig*tend**4/(1/fc15)+sig*tend**4/(1/fc16)
     &                +sig*t(35)**4/((1-emisfl)/emisfl)
c TOP (combined roof and plexiglass structure) Fuselage Interior (Cabin)
c J9:::a(9,8),a(9,9),a(9,10),a(9,11),tempfact(9); from fn(48):
      tempfact(9)=sig*tend**4/(1/fc35)+sig*tend**4/(1/fc36)
     &                +sig*tpgrf**4/((1-emispgrf)/emispgrf)
c
c now find the updated radiosity
c first replace tempfact(i) with a column vector b(i) to be
c input into lubksb
      do 30 i=1,14
 30   b(i)=tempfact(i)
c      if(itotitr.eq.1)write(17,80)(b(i),i=1,14)
c put aa(i,j) into a(i,j); because a(i,j) has changed in the steady-state
c phase.  same thing for indx(i)
      do 50 i=1,14
      indx(i)=iindx(i)
      do 50 j=1,14
 50   a(i,j)=aa(i,j)
c input n (n was 67)
      n=14
      call lubksb
c lubksb now returns b(i) which is the updated radiosity
c for clarity transfer b(i) to radiosj(i)
      do 40 i=1,14
 40   radiosj(i)=b(i)
c      if(itotitr.eq.1)write(17,80)(radiosj(i),i=1,14)
      do 45 i=1,14
 45   temptrn(53+i)=radiosj(i)
      return
      end
c
      subroutine hcoolcon(itotitr,l,v,h)
c purpose: determines the convective coefficient according to the flight
c            speed
c called from: trnsien1 and trnsien2
c calls: none
      common/c7/nperiods,envtdata(100,20)
      common/c10/k,thdiffus,visckine,prandtl
```

```
      real l,llamn,nusllamn,k
      parameter(rellamn=5.e5)
c
c Variables:
c nusllamn=Nusselt number in the laminar zone
c rellamn=Reynold's number for laminar flow
c
           rel=v*l/visckine
c          if(itotitr.le.nperiods)write(12,*)'coolingneg,l,v,h',l,v,h
           if(rel.le.rellamn)then
             nusllamn=0.664*rel**(1./2)*prandtl**(1./3)
             h=k*nusllamn/l
           elseif(rel.gt.rellamn)then
             llamn=rellamn*visckine/v
             nusllamn=0.664*rellamn**(1./2)*prandtl**(1./3)
             hlamn=k*nusllamn/llamn
             hturb=0.0296*k/(l-llamn)*prandtl**(1./3)*(v/visckine)**(4./5)
     &          *(5./4)*(l**(4./5)-llamn**(4./5))
             h=1./l*(llamn*hlamn+(l-llamn)*hturb)
           endif
c          if(itotitr.le.nperiods)write(12,*)'cooling,v,h',v,h
      return
      end
c
c
c
      subroutine lhswng2(ithtrial,itotitr,iperiod,istep,theta,ta,hhw,
     &                   rfw,absorbw,emisw,eemisw,sunfact,isolfoun)
c purpose: transient analysis of the left wing (the wing that is not under
c            shade)
c called from: newraph2
c calls: none
      common/c2/tt(200),ffn(200),jacob(200,200)
      common/c3/tth(100),kk(100)
      common/c6/absorbff,emisff,absorbww,emisww,absorbfl,emisfl,absorbfi
     &,emisfi,absorbpg,emispg,absorftp,emisrftp,absorfbt,emisrfbt
     &,absorbfb,emisfb
      common/c10/aircondc,thdiffus,visckine,prandtl
      common/c14/thicknes(100),density(100),conductv(100),sheatcap(100)
      common/reflecq/qreflin(6,100),qscabsin(6,100),qreflfwr(6,100),
     &qreflfwl(6,100),qscabfwr(6,100),qscabfwl(6,100),qabstwa1(6,100),
     &qabstwa2(6,100),qabstwb(6,100)
      common/temp1/t(1000)
      common/data1/deltime
      common/radiosit/jj(14)
      common/result/temp(200),temptrn(200)
      dimension newt(100),k(100),th(100),dens(100),shc(100),fn(100)
      dimension tjacob(27,27)
      real kk,k,jj,newt,jacob
      parameter(sig=.1714e-8)
      parameter(fpi=3.141593/180.)
```

```
      parameter(f=0.2)
c
c Variables:
c f=fraction of an element thickness
c
c Note:
c A total of 9 layers are used to model the wing.  the fifth layer is usually either
c air or fuel or a combination of both
c
      if(itotitr.eq.1.and.istep.eq.1)then
c reference thickness (th):
      th(1)=tth(1)
      th(2)=tth(2)
      th(3)=tth(3)
      th(4)=tth(4)
      th(5)=tth(29)
      th(6)=tth(30)
      th(7)=tth(5)
      th(8)=tth(6)
      th(9)=tth(7)
c reference conductivity (k):
      k(1)=kk(1)
      k(2)=kk(2)
      k(3)=kk(3)
      k(4)=kk(4)
      k(5)=kk(29)
      k(6)=kk(30)
      k(7)=kk(5)
      k(8)=kk(6)
      k(9)=kk(7)
c reference density (dens):
      dens(1)=density(1)
      dens(2)=density(2)
      dens(3)=density(3)
      dens(4)=density(4)
      dens(5)=density(5)
      dens(6)=density(6)
      dens(7)=density(7)
      dens(8)=density(8)
      dens(9)=density(9)
c reference specific heat capacity (shc):
      shc(1)=sheatcap(1)
      shc(2)=sheatcap(2)
      shc(3)=sheatcap(3)
      shc(4)=sheatcap(4)
      shc(5)=sheatcap(5)
      shc(6)=sheatcap(6)
      shc(7)=sheatcap(7)
      shc(8)=sheatcap(8)
      shc(9)=sheatcap(9)
      endif
```

```
      if(istep.eq.1)then
c reference the initial temp. (t): each layer is partitioned into 3 control volumes.
c so the total number of temperatures = (nlayer=9)*3=27.  note that after step 1, ie at
c step 2 and beyond the steady state temperature tt(i) is replaced with newt(i).  so
c all steady state temperatures are lost.  they can be retrieved, however from
c the /result/temp(i) variable in the form of degrees Farenheit.
      t(1)=tt(1)
      t(2)=(tt(1)+tt(2))/2.
      t(3)=tt(2)
      t(4)=tt(2)
      t(5)=(tt(2)+tt(3))/2.
      t(6)=tt(3)
      t(7)=tt(3)
      t(8)=(tt(3)+tt(4))/2.
      t(9)=tt(4)
      t(10)=tt(4)
      t(11)=(tt(4)+tt(62))/2.
      t(12)=tt(62)
      t(13)=tt(62)
      t(14)=(tt(62)+tt(63))/2.
      t(15)=tt(63)
      t(16)=tt(63)
      t(17)=(tt(63)+tt(5))/2.
      t(18)=tt(5)
      t(19)=tt(5)
      t(20)=(tt(5)+tt(6))/2.
      t(21)=tt(6)
      t(22)=tt(6)
      t(23)=(tt(6)+tt(7))/2.
      t(24)=tt(7)
      t(25)=tt(7)
      t(26)=(tt(7)+tt(8))/2.
      t(27)=tt(8)
c for the nonlinear solution of the new transient temperatures newt, one needs an
c initial guess for the set of newt's.  what better guess than the steady state
c temperatures (as above) prior to the start of the transient analysis
      do 10 i=1,27
   10 newt(i)=t(i)
c reference the initial radiosity (jj)
      jj(1)=tt(40)
      jj(2)=tt(41)
      return
      endif
c
c formulate transient cooling: develop the function ffn(i), which is the fvec
c in the non-linear transient solution process.
c
c first need to replace newt(i) with the incoming tt(i), where tt(i) is
c the solution from newraph2 subroutine for step=istep and at iteration=ithtrial.
c note that the original tt(i), ie the steady state temperatures are all destroyed
c after step 1, ie at step 2 and greater.
```

```
c
      if(ithtrial.eq.1)go to 65
           do 50 i=1,27
       newt(i)=tt(i)
 50   continue
c
 65   if(isolfoun.eq.1)then
       if(ithtrial.eq.1)then
            do 55 i=1,27
         newt(i)=tt(i)
 55      continue
       endif
       do 60 i=1,27
 60    t(i)=newt(i)
       temptrn(1)=t(1)-459.67
       temptrn(2)=(t(3)+t(4))/2.-459.67
       temptrn(3)=(t(6)+t(7))/2.-459.67
       temptrn(4)=(t(9)+t(10))/2.-459.67
       temptrn(5)=(t(12)+t(13))/2.-459.67
       temptrn(6)=(t(15)+t(16))/2.-459.67
       temptrn(7)=(t(18)+t(19))/2.-459.67
       temptrn(8)=(t(21)+t(22))/2.-459.67
       temptrn(9)=(t(24)+t(25))/2.-459.67
       temptrn(10)=t(27)-459.67
           return
      endif
c
c upper wing surface temp (newt1), as well as internal temp newt2 and newt3: and fn(1),
c fn(2) and fn(3).
c
           qnetsky=(sig*newt(1)**4-rfw*jj(1))/((1.-rfw*eemisw)/eemisw)
           fn(1)=-newt(1)+t(1)+deltime/(dens(1)*shc(1)*f/2*th(1))*
     &        ((absorbw*qreflfwl(1,iperiod)*sin(fpi*theta)+
     &          qscabfwl(1,iperiod))*sunfact+
     &         (absorbw*qreflfwr(1,iperiod)*sin(fpi*theta)+
     &          qscabfwr(1,iperiod))*(1-sunfact)
     &        -qnetsky-hhw*(newt(1)-ta)-
     &        (newt(1)-newt(2))/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
           fn(2)=-newt(2)+t(2)+deltime/(dens(1)*shc(1)*(1-f)*th(1))*
     &        ((newt(1)-newt(2))/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1))-
     &        (newt(2)-newt(3))/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
           fn(3)=-newt(3)+t(3)+deltime/(dens(1)*shc(1)*f/2*th(1))*
     &        ((newt(2)-newt(3))/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1))-
     &        (newt(3)-newt(4))/(f/4*th(1)/k(1)+f/4*th(2)/k(2)))
c
c internal nodes (all conduction): newt4-newt24: fn(4)-fn(24): layers 2 to 8.
c
           do 20 i=2,8
           ii=(i-1)*3
c
c beginning element within layer i: newt4,newt7,newt10,newt13,newt16,newt19,newt22:
```

```
c
            fn(ii+1)=
     &   -newt(ii+1)+t(ii+1)+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &      ((newt(ii)-newt(ii+1))/(f/4*th(i-1)/k(i-1)+f/4*th(i)/k(i))-
     &      (newt(ii+1)-newt(ii+2))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
c
c middle element within layer i: newt5,newt8,newt11,newt14,newt17,newt20,newt23:
c
          fn(ii+2)=
     &    -newt(ii+2)+t(ii+2)+deltime/(dens(i)*shc(i)*(1-f)*th(i))*
     &    ((newt(ii+1)-newt(ii+2))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &    (newt(ii+2)-newt(ii+3))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
c
c ending element within layer i: newt6,newt9,newt12,newt15,newt18,newt21,newt24:
c
          fn(ii+3)=
     &    -newt(ii+3)+t(ii+3)+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &    ((newt(ii+2)-newt(ii+3))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &    (newt(ii+3)-newt(ii+4))/(f/4*th(i)/k(i)+f/4*th(i+1)/k(i+1)))
 20       continue
c
c lower wing surface temp newt27, as well as internal temp newt25 and newt26: fn(27),
c fn(26) and fn(25).
c
           fn(25)=-newt(25)+t(25)+
     &        deltime/(dens(9)*shc(9)*f/2*th(9))*
     &        ((newt(24)-newt(25))/
     &        (f/4*th(8)/k(8)+f/4*th(9)/k(9))-
     &        (newt(25)-newt(26))/
     &        (f/4*th(9)/k(9)+(1-f)/2*th(9)/k(9)))
          fn(26)=-newt(26)+t(26)+
     &        deltime/(dens(9)*shc(9)*(1-f)*th(9))*
     &        ((newt(25)-newt(26))/
     &        (f/4*th(9)/k(9)+(1-f)/2*th(9)/k(9))-
     &        (newt(26)-newt(27))/
     &        (f/4*th(9)/k(9)+(1-f)/2*th(9)/k(9)))
          qnetsky=(sig*newt(27)**4-jj(2))/((1.-emisw)/emisw)
          fn(27)=-newt(27)+t(27)+
     &        deltime/(dens(9)*shc(9)*f/2*th(9))*
     &        (qabstwa1(3,iperiod)-qnetsky-hhw*(newt(27)-ta)+
     &        (newt(26)-newt(27))/
     &        (f/4*th(9)/k(9)+(1-f)/2*th(9)/k(9)))
c
c transfer the fn(i) into the global ffn(i), which is used together with jacobian
c to find the p(i) and then the new tt(i) in newraph2 subroutine.
c
      do 30 i=1,27
   30 ffn(i)=fn(i)
c
c now find the jacobian, global jacob(120,120) from the partial derivative of fn(i).
c find tjacob(27,27) first.  then put it into the global jacob(120,120).
```

```
c
c first initialize tjacob(27,27) to 0.0.
c note:  most of the tjacob(27,27) are 0.0
c
      do 70 itj=1,27
       do 70 jtj=1,27
 70   tjacob(itj,jtj)=0.0
c
c first find tjacob(1,),tjacob(2,),tjacob(3,) for the upper wing surface functions
c fn(1),fn(2),fn(3)
c
c tjacob(1,1),tjacob(1,2):
c
     tjacob(1,1)=-1+deltime/(dens(1)*shc(1)*f/2*th(1))*
    &        (-(4*sig*newt(1)**3)/((1.-rfw*eemisw)/eemisw)-hhw*(1)-
    &        (1)/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
     tjacob(1,2)=deltime/(dens(1)*shc(1)*f/2*th(1))*
    &           (-(-1)/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
c
c tjacob(2,1),tjacob(2,2),tjacob(2,3):
c
     tjacob(2,1)=deltime/(dens(1)*shc(1)*(1-f)*th(1))*
    &        ((1)/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
     tjacob(2,2)=-1+deltime/(dens(1)*shc(1)*(1-f)*th(1))*
    &        ((-1)/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1))-
    &        (1)/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
     tjacob(2,3)=deltime/(dens(1)*shc(1)*(1-f)*th(1))*
    &        (-(-1)/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
c
c tjacob(3,2),tjacob(3,3),tjacob(3,4):
c
     tjacob(3,2)=deltime/(dens(1)*shc(1)*f/2*th(1))*
    &        ((1)/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
     tjacob(3,3)=-1+deltime/(dens(1)*shc(1)*f/2*th(1))*
    &        ((-1)/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1))-
    &          (1)/(f/4*th(1)/k(1)+f/4*th(2)/k(2)))
     tjacob(3,4)=deltime/(dens(1)*shc(1)*f/2*th(1))*
    &        (-(-1)/(f/4*th(1)/k(1)+f/4*th(2)/k(2)))
c
c now find jacobians for the internal conduction layers: tjacob(4,) to tjacob(24,)
c for functions fn(4) to fn (24):
c
          do 120 i=2,8
          ii=(i-1)*3
c
c find tjacob(4,),tjacob(7,),tjacob(10,),tjacob(13,),tjacob(16,),tjacob(19,)
c and tjacob(22,) for beginning element within
c layer i: from fn(4),fn(7),fn(10),fn(13),fn(16),fn(19) and fn(22):
c
     tjacob(ii+1,ii)=deltime/(dens(i)*shc(i)*f/2*th(i))*
    &      ((1)/(f/4*th(i-1)/k(i-1)+f/4*th(i)/k(i)))
```

```
      tjacob(ii+1,ii+1)=-1+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &       ((-1)/(f/4*th(i-1)/k(i-1)+f/4*th(i)/k(i))-
     &         (1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
      tjacob(ii+1,ii+2)=deltime/(dens(i)*shc(i)*f/2*th(i))*
     &       (-(-1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
c
c find tjacob(5,),tjacob(8,),tjacob(11,),tjacob(14,),tjacob(17,),tjacob(20,)
c and tjacob(23,) for middle element within
c layer i: from fn(5),fn(8),fn(11),fn(14),fn(17),fn(20) and fn(23):
c
      tjacob(ii+2,ii+1)=deltime/(dens(i)*shc(i)*(1-f)*th(i))*
     &     ((1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
      tjacob(ii+2,ii+2)=-1+deltime/(dens(i)*shc(i)*(1-f)*th(i))*
     &     ((-1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &       (1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
      tjacob(ii+2,ii+3)=deltime/(dens(i)*shc(i)*(1-f)*th(i))*
     &     (-(-1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
c
c find tjacob(6,),tjacob(9,),tjacob(12,),tjacob(15,),tjacob(18,),tjacob(21,)
c and tjacob(24,) for ending element within
c layer i: from fn(6),fn(9),fn(12),fn(15),fn(18),fn(21) and fn(24):
c
      tjacob(ii+3,ii+2)=deltime/(dens(i)*shc(i)*f/2*th(i))*
     &     ((1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
      tjacob(ii+3,ii+3)=-1+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &     ((-1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &       (1)/(f/4*th(i)/k(i)+f/4*th(i+1)/k(i+1)))
      tjacob(ii+3,ii+4)=deltime/(dens(i)*shc(i)*f/2*th(i))*
     &     (-(-1)/(f/4*th(i)/k(i)+f/4*th(i+1)/k(i+1)))
  120 continue
c
c now find tjacob(25,),tjacob(26,),tjacob(27,) for the lower wing surface functions
c fn(25),fn(26) and fn(27)
c
c tjacob(25,24),tjacob(25,25) and tjacob(25,26):
c
      tjacob(25,24)=deltime/(dens(9)*shc(9)*f/2*th(9))*
     &       ((1)/(f/4*th(8)/k(8)+f/4*th(9)/k(9)))
      tjacob(25,25)=-1+deltime/(dens(9)*shc(9)*f/2*th(9))*
     &       ((-1)/(f/4*th(8)/k(8)+f/4*th(9)/k(9))-
     &         (1)/(f/4*th(9)/k(9)+(1-f)/2*th(9)/k(9)))
      tjacob(25,26)=deltime/(dens(9)*shc(9)*f/2*th(9))*
     &       (-(-1)/(f/4*th(9)/k(9)+(1-f)/2*th(9)/k(9)))
c
c tjacob(26,25),tjacob(26,26) and tjacob(26,27):
c
      tjacob(26,25)=deltime/(dens(9)*shc(9)*(1-f)*th(9))*
     &       ((1)/(f/4*th(9)/k(9)+(1-f)/2*th(9)/k(9)))
      tjacob(26,26)=-1+deltime/(dens(9)*shc(9)*(1-f)*th(9))*
     &       ((-1)/(f/4*th(9)/k(9)+(1-f)/2*th(9)/k(9))-
     &         (1)/(f/4*th(9)/k(9)+(1-f)/2*th(9)/k(9)))
```

```
      tjacob(26,27)=deltime/(dens(9)*shc(9)*(1-f)*th(9))*
     &        (-(-1)/(f/4*th(9)/k(9)+(1-f)/2*th(9)/k(9)))
c
c tjacob(27,26) and tjacob(27,27):
c
      tjacob(27,26)=deltime/(dens(9)*shc(9)*f/2*th(9))*
     &        ((1)/(f/4*th(9)/k(9)+(1-f)/2*th(9)/k(9)))
      tjacob(27,27)=-1+deltime/(dens(9)*shc(9)*f/2*th(9))*
     &        (-(4*sig*newt(27)**3)/((1.-emisw)/emisw)-hhw*(1)+
     &        (-1)/(f/4*th(9)/k(9)+(1-f)/2*th(9)/k(9)))
c
c jacobian analysis is done.  now put tjacob(i,j) into the global jacobian matrix
c jacob(ijacob,jjacob), where ijacob starts and ends at 1 and 27,
c and jjacob starts and ends at 1 and 27.  note:  most jacob values are 0's
c
      do 130 i=1,27
       do 130 j=1,27
        jacob(i,j)=tjacob(i,j)
  130 continue
      return
      end
c
c
      subroutine rhswng2(ithtrial,itotitr,iperiod,istep,theta,ta,hhw,
     &                   rfw,absorbw,emisw,eemisw,sunfact,isolfoun)
c purpose: transient analysis of the right wing (the wing that is under
c            shade)
c called from: newraph2
c calls: none
      common/c2/tt(200),ffn(200),jacob(200,200)
      common/c3/tth(100),kk(100)
      common/c6/absorbff,emisff,absorbww,emisww,absorbfl,emisfl,absorbfi
     &,emisfi,absorbpg,emispg,absorftp,emisrftp,absorfbt,emisrfbt
     &,absorbfb,emisfb
      common/c10/aircondc,thdiffus,visckine,prandtl
      common/c14/thicknes(100),density(100),conductv(100),sheatcap(100)
      common/reflecq/qreflin(6,100),qscabsin(6,100),qreflfwr(6,100),
     &qreflfwl(6,100),qscabfwr(6,100),qscabfwl(6,100),qabstwa1(6,100),
     &qabstwa2(6,100),qabstwb(6,100)
      common/temp2/t(1000)
      common/data1/deltime
      common/radiosit/jj(14)
      common/result/temp(200),temptrn(200)
      dimension newt(100),k(100),th(100),dens(100),shc(100),fn(100)
      dimension tjacob(27,27)
      real kk,k,jj,newt,jacob
      parameter(sig=.1714e-8)
      parameter(fpi=3.141593/180.)
      parameter(f=0.2)
c
```

```
c Variables:
c f=fraction of an element thickness
c
c Note:
c A total of 9 layers are used to model the wing.  the fifth layer is usually either
c air or fuel or a combination of both
c
      if(itotitr.eq.1.and.istep.eq.1)then
c reference thickness (th):
      th(1)=tth(1)
      th(2)=tth(2)
      th(3)=tth(3)
      th(4)=tth(4)
      th(5)=tth(29)
      th(6)=tth(30)
      th(7)=tth(5)
      th(8)=tth(6)
      th(9)=tth(7)
c reference conductivity (k):
      k(1)=kk(1)
      k(2)=kk(2)
      k(3)=kk(3)
      k(4)=kk(4)
      k(5)=kk(29)
      k(6)=kk(30)
      k(7)=kk(5)
      k(8)=kk(6)
      k(9)=kk(7)
c reference density (dens):
      dens(1)=density(1)
      dens(2)=density(2)
      dens(3)=density(3)
      dens(4)=density(4)
      dens(5)=density(5)
      dens(6)=density(6)
      dens(7)=density(7)
      dens(8)=density(8)
      dens(9)=density(9)
c reference specific heat capacity (shc):
      shc(1)=sheatcap(1)
      shc(2)=sheatcap(2)
      shc(3)=sheatcap(3)
      shc(4)=sheatcap(4)
      shc(5)=sheatcap(5)
      shc(6)=sheatcap(6)
      shc(7)=sheatcap(7)
      shc(8)=sheatcap(8)
      shc(9)=sheatcap(9)
      endif
      if(istep.eq.1)then
c reference the initial temp. (t): each layer is partitioned into 3 control volumes.
```

```
c so the total number of temperatures = (nlayer=9)*3=27.  note that after step 1, ie at
c step 2 and beyond the steady state temperature tt(i) is replaced with newt(i).  so
c all steady state temperatures are lost.  they can be retrieved, however from
c the /result/temp(i) variable in the form of degrees Fahrenheit.
      t(1)=tt(9)
      t(2)=(tt(9)+tt(10))/2.
      t(3)=tt(10)
      t(4)=tt(10)
      t(5)=(tt(10)+tt(11))/2.
      t(6)=tt(11)
      t(7)=tt(11)
      t(8)=(tt(11)+tt(12))/2.
      t(9)=tt(12)
      t(10)=tt(12)
      t(11)=(tt(12)+tt(64))/2.
      t(12)=tt(64)
      t(13)=tt(64)
      t(14)=(tt(64)+tt(65))/2.
      t(15)=tt(65)
      t(16)=tt(65)
      t(17)=(tt(65)+tt(13))/2.
      t(18)=tt(13)
      t(19)=tt(13)
      t(20)=(tt(13)+tt(14))/2.
      t(21)=tt(14)
      t(22)=tt(14)
      t(23)=(tt(14)+tt(15))/2.
      t(24)=tt(15)
      t(25)=tt(15)
      t(26)=(tt(15)+tt(16))/2.
      t(27)=tt(16)
c for the nonlinear solution of the new transient temperatures newt, one needs an
c initial guess for the set of newt's.  what better guess than the steady state
c temperatures (as above) prior to the start of the transient analysis
      do 10 i=1,27
   10 newt(i)=t(i)
c reference the initial radiosity (jj):
      jj(3)=tt(42)
      jj(4)=tt(43)
      return
      endif
c
c formulate transient cooling: develop the function fn(i), which is the fvec
c in the non-linear transient solution process.
c
c first need to replace newt(i) with the incoming tt(i), where tt(i) is
c the solution from newraph2 subroutine for step=istep and at iteration=ithtrial.
c note that the original tt(i), ie the steady state temperatures are all destroyed
c after step 1, ie at step 2 and greater.
c
      if(ithtrial.eq.1)go to 65
```

```
          do 50 i=1,27
       newt(i)=tt(27+i)
 50   continue
c
 65   if(isolfoun.eq.1)then
       if(ithtrial.eq.1)then
            do 55 i=1,27
         newt(i)=tt(27+i)
 55      continue
       endif
       do 60 i=1,27
 60    t(i)=newt(i)
       temptrn(11)=t(1)-459.67
       temptrn(12)=(t(3)+t(4))/2.-459.67
       temptrn(13)=(t(6)+t(7))/2.-459.67
       temptrn(14)=(t(9)+t(10))/2.-459.67
       temptrn(15)=(t(12)+t(13))/2.-459.67
       temptrn(16)=(t(15)+t(16))/2.-459.67
       temptrn(17)=(t(18)+t(19))/2.-459.67
       temptrn(18)=(t(21)+t(22))/2.-459.67
       temptrn(19)=(t(24)+t(25))/2.-459.67
       temptrn(20)=t(27)-459.67
          return
      endif
c
c upper wing surface temp (newt1), as well as internal temp newt2 and newt3: and fn(1),
c fn(2) and fn(3).
c
          qnetsky=(sig*newt(1)**4-rfw*jj(3))/((1.-rfw*eemisw)/eemisw)
          fn(1)=-newt(1)+t(1)+deltime/(dens(1)*shc(1)*f/2*th(1))*
     &        ((absorbw*qreflfwr(1,iperiod)*sin(fpi*theta)+
     &          qscabfwr(1,iperiod))*sunfact+
     &         (absorbw*qreflfwl(1,iperiod)*sin(fpi*theta)+
     &          qscabfwl(1,iperiod))*(1-sunfact)
     &        -qnetsky-hhw*(newt(1)-ta)-
     &        (newt(1)-newt(2))/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
          fn(2)=-newt(2)+t(2)+deltime/(dens(1)*shc(1)*(1-f)*th(1))*
     &        ((newt(1)-newt(2))/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1))-
     &        (newt(2)-newt(3))/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
          fn(3)=-newt(3)+t(3)+deltime/(dens(1)*shc(1)*f/2*th(1))*
     &        ((newt(2)-newt(3))/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1))-
     &        (newt(3)-newt(4))/(f/4*th(1)/k(1)+f/4*th(2)/k(2)))
c
c internal nodes (all conduction): newt4-newt24: fn(4)-fn(24): layers 2 to 8.
c
          do 20 i=2,8
          ii=(i-1)*3
c
c beginning element within layer i: newt4,newt7,newt10,newt13,newt16,newt19,newt22:
c
         fn(ii+1)=
```

```
     &      -newt(ii+1)+t(ii+1)+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &      ((newt(ii)-newt(ii+1))/(f/4*th(i-1)/k(i-1)+f/4*th(i)/k(i))-
     &      (newt(ii+1)-newt(ii+2))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
c
c middle element within layer i: newt5,newt8,newt11,newt14,newt17,newt20,newt23:
c
          fn(ii+2)=
     &    -newt(ii+2)+t(ii+2)+deltime/(dens(i)*shc(i)*(1-f)*th(i))*
     &    ((newt(ii+1)-newt(ii+2))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &    (newt(ii+2)-newt(ii+3))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
c
c ending element within layer i: newt6,newt9,newt12,newt15,newt18,newt21,newt24:
c
          fn(ii+3)=
     &    -newt(ii+3)+t(ii+3)+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &    ((newt(ii+2)-newt(ii+3))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &    (newt(ii+3)-newt(ii+4))/(f/4*th(i)/k(i)+f/4*th(i+1)/k(i+1)))
 20       continue
c
c lower wing surface temp newt27, as well as internal temp newt25 and newt26: fn(27),
c fn(26) and fn(25).
c
          fn(25)=-newt(25)+t(25)+
     &       deltime/(dens(9)*shc(9)*f/2*th(9))*
     &       ((newt(24)-newt(25))/
     &       (f/4*th(8)/k(8)+f/4*th(9)/k(9))-
     &       (newt(25)-newt(26))/
     &       (f/4*th(9)/k(9)+(1-f)/2*th(9)/k(9)))
          fn(26)=-newt(26)+t(26)+
     &       deltime/(dens(9)*shc(9)*(1-f)*th(9))*
     &       ((newt(25)-newt(26))/
     &       (f/4*th(9)/k(9)+(1-f)/2*th(9)/k(9))-
     &       (newt(26)-newt(27))/
     &       (f/4*th(9)/k(9)+(1-f)/2*th(9)/k(9)))
          qnetsky=(sig*newt(27)**4-jj(4))/((1.-emisw)/emisw)
          fn(27)=-newt(27)+t(27)+
     &       deltime/(dens(9)*shc(9)*f/2*th(9))*
     &       (qabstwa2(3,iperiod)-qnetsky-hhw*(newt(27)-ta)+
     &       (newt(26)-newt(27))/
     &       (f/4*th(9)/k(9)+(1-f)/2*th(9)/k(9)))
c
c transfer the fn(i) into the global ffn(i), which is used together with jacobian
c to find the p(i) and then the new tt(i) in newraph2 subroutine.
c
      do 30 i=1,27
   30 ffn(27+i)=fn(i)
c
c now find the jacobian, global jacob(120,120) from the partial derivative of fn(i).
c find tjacob(27,27) first.  then put it into the global jacob(120,120).
c
c first initialize tjacob(27,27) to 0.0.
```

```
c note:  most of the tjacob(27,27) are 0.0
c
      do 70 itj=1,27
       do 70 jtj=1,27
  70   tjacob(itj,jtj)=0.0
c
c first find tjacob(1,),tjacob(2,),tjacob(3,) for the upper wing surface functions
c fn(1),fn(2),fn(3)
c
c tjacob(1,1),tjacob(1,2):
c
     tjacob(1,1)=-1+deltime/(dens(1)*shc(1)*f/2*th(1))*
    &        (-(4*sig*newt(1)**3)/((1.-rfw*eemisw)/eemisw)-hhw*(1)-
    &        (1)/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
     tjacob(1,2)=deltime/(dens(1)*shc(1)*f/2*th(1))*
    &           (-(-1)/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
c
c tjacob(2,1),tjacob(2,2),tjacob(2,3):
c
     tjacob(2,1)=deltime/(dens(1)*shc(1)*(1-f)*th(1))*
    &        ((1)/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
     tjacob(2,2)=-1+deltime/(dens(1)*shc(1)*(1-f)*th(1))*
    &        ((-1)/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1))-
    &        (1)/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
     tjacob(2,3)=deltime/(dens(1)*shc(1)*(1-f)*th(1))*
    &        (-(-1)/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
c
c tjacob(3,2),tjacob(3,3),tjacob(3,4):
c
     tjacob(3,2)=deltime/(dens(1)*shc(1)*f/2*th(1))*
    &        ((1)/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
     tjacob(3,3)=-1+deltime/(dens(1)*shc(1)*f/2*th(1))*
    &        ((-1)/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1))-
    &          (1)/(f/4*th(1)/k(1)+f/4*th(2)/k(2)))
     tjacob(3,4)=deltime/(dens(1)*shc(1)*f/2*th(1))*
    &        (-(-1)/(f/4*th(1)/k(1)+f/4*th(2)/k(2)))
c
c now find jacobians for the internal conduction layers: tjacob(4,) to tjacob(24,)
c for functions fn(4) to fn (24):
c
          do 120 i=2,8
          ii=(i-1)*3
c
c find tjacob(4,),tjacob(7,),tjacob(10,),tjacob(13,),tjacob(16,),tjacob(19,)
c and tjacob(22,) for beginning element within
c layer i: from fn(4),fn(7),fn(10),fn(13),fn(16),fn(19) and fn(22):
c
     tjacob(ii+1,ii)=deltime/(dens(i)*shc(i)*f/2*th(i))*
    &      ((1)/(f/4*th(i-1)/k(i-1)+f/4*th(i)/k(i)))
     tjacob(ii+1,ii+1)=-1+deltime/(dens(i)*shc(i)*f/2*th(i))*
    &      ((-1)/(f/4*th(i-1)/k(i-1)+f/4*th(i)/k(i))-
```

```
     &        (1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
      tjacob(ii+1,ii+2)=deltime/(dens(i)*shc(i)*f/2*th(i))*
     &       (-(-1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
c
c find tjacob(5,),tjacob(8,),tjacob(11,),tjacob(14,),tjacob(17,),tjacob(20,)
c and tjacob(23,) for middle element within
c layer i: from fn(5),fn(8),fn(11),fn(14),fn(17),fn(20) and fn(23):
c
      tjacob(ii+2,ii+1)=deltime/(dens(i)*shc(i)*(1-f)*th(i))*
     &     ((1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
      tjacob(ii+2,ii+2)=-1+deltime/(dens(i)*shc(i)*(1-f)*th(i))*
     &     ((-1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &       (1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
      tjacob(ii+2,ii+3)=deltime/(dens(i)*shc(i)*(1-f)*th(i))*
     &     (-(-1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
c
c find tjacob(6,),tjacob(9,),tjacob(12,),tjacob(15,),tjacob(18,),tjacob(21,)
c and tjacob(24,) for ending element within
c layer i: from fn(6),fn(9),fn(12),fn(15),fn(18),fn(21) and fn(24):
c
      tjacob(ii+3,ii+2)=deltime/(dens(i)*shc(i)*f/2*th(i))*
     &     ((1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
      tjacob(ii+3,ii+3)=-1+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &     ((-1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &       (1)/(f/4*th(i)/k(i)+f/4*th(i+1)/k(i+1)))
      tjacob(ii+3,ii+4)=deltime/(dens(i)*shc(i)*f/2*th(i))*
     &     (-(-1)/(f/4*th(i)/k(i)+f/4*th(i+1)/k(i+1)))
  120 continue
c
c now find tjacob(25,),tjacob(26,),tjacob(27,) for the lower wing surface functions
c fn(25),fn(26) and fn(27)
c
c tjacob(25,24),tjacob(25,25) and tjacob(25,26):
c
      tjacob(25,24)=deltime/(dens(9)*shc(9)*f/2*th(9))*
     &        ((1)/(f/4*th(8)/k(8)+f/4*th(9)/k(9)))
      tjacob(25,25)=-1+deltime/(dens(9)*shc(9)*f/2*th(9))*
     &        ((-1)/(f/4*th(8)/k(8)+f/4*th(9)/k(9))-
     &          (1)/(f/4*th(9)/k(9)+(1-f)/2*th(9)/k(9)))
      tjacob(25,26)=deltime/(dens(9)*shc(9)*f/2*th(9))*
     &        (-(-1)/(f/4*th(9)/k(9)+(1-f)/2*th(9)/k(9)))
c
c tjacob(26,25),tjacob(26,26) and tjacob(26,27):
c
      tjacob(26,25)=deltime/(dens(9)*shc(9)*(1-f)*th(9))*
     &        ((1)/(f/4*th(9)/k(9)+(1-f)/2*th(9)/k(9)))
      tjacob(26,26)=-1+deltime/(dens(9)*shc(9)*(1-f)*th(9))*
     &        ((-1)/(f/4*th(9)/k(9)+(1-f)/2*th(9)/k(9))-
     &          (1)/(f/4*th(9)/k(9)+(1-f)/2*th(9)/k(9)))

      tjacob(26,27)=deltime/(dens(9)*shc(9)*(1-f)*th(9))*
```

```
     &        (-(-1)/(f/4*th(9)/k(9)+(1-f)/2*th(9)/k(9)))
c
c tjacob(27,26) and tjacob(27,27):
c
      tjacob(27,26)=deltime/(dens(9)*shc(9)*f/2*th(9))*
     &        ((1)/(f/4*th(9)/k(9)+(1-f)/2*th(9)/k(9)))
      tjacob(27,27)=-1+deltime/(dens(9)*shc(9)*f/2*th(9))*
     &        (-(4*sig*newt(27)**3)/((1.-emisw)/emisw)-hhw+
     &        (-1)/(f/4*th(9)/k(9)+(1-f)/2*th(9)/k(9)))
c
c jacobian analysis is done.  now put tjacob(i,j) into the global jacobian matrix
c jacob(ijacob,jjacob), where ijacob starts and ends at 28 and 54,
c and jjacob starts and ends at 28 and 54.  note:  most jacob values are 0's
c
      do 130 i=1,27
       do 130 j=1,27
        jacob(27+i,27+j)=tjacob(i,j)
  130 continue
      return
      end
c
c
      subroutine fuslglr2(ithtrial,itotitr,icool,iperiod,istep,theta,ta,
     &             hhf,hhc,rff,absorbf,eemisf,sunfact,sunfact2,isolfoun)
c purpose: transient analysis of the fuselage (left to right)
c called from: newraph2
c calls: none
      common/c2/tt(200),ffn(200),jacob(200,200)
      common/c3/tth(100),kk(100)
      common/c6/absorbff,emisff,absorbww,emisww,absorbfl,emisfl,absorbfi
     &,emisfi,absorbpg,emispg,absorftp,emisrftp,absorfbt,emisrfbt
     &,absorbfb,emisfb
      common/c10/aircondc,thdiffus,visckine,prandtl
      common/c14/thicknes(100),density(100),conductv(100),sheatcap(100)
      common/reflecq/qreflin(6,100),qscabsin(6,100),qreflfwr(6,100),
     &qreflfwl(6,100),qscabfwr(6,100),qscabfwl(6,100),qabstwa1(6,100),
     &qabstwa2(6,100),qabstwb(6,100)
      common/temp3/t(1000)
      common/data1/deltime
      common/radiosit/jj(14)
      common/result/temp(200),temptrn(200)
      dimension newt(100),k(100),th(100),dens(100),shc(100),fn(100)
      dimension tfn(100),tjacob(27,27),ttjacob(27,27)
      real kk,k,jj,newt,nusselt2,jacob
      parameter(sig=.1714e-8,gravity=32.2)
      parameter(fpi=3.141593/180.)
      parameter(f=0.2)
c
c Variables:
c f=fraction of an element thickness
c
```

```
c Note:
c A total of 9 layers are used to model the fuselage cabin (widthwise).
c the fifth layer is air space (maybe in turbulence).  the fifth layer is
c not modelled because of its complexity.  any reference to the 13,14 and 15
c control volume is only a dummy.
c
      if(itotitr.eq.1.and.istep.eq.1)then
c reference thickness (th):
      th(1)=tth(8)
      th(2)=tth(9)
      th(3)=tth(10)
      th(4)=tth(23)
      th(5)=tth(11)
      th(6)=tth(23)
      th(7)=tth(10)
      th(8)=tth(9)
      th(9)=tth(8)
c reference conductivity (k):
      k(1)=kk(8)
      k(2)=kk(9)
      k(3)=kk(10)
      k(4)=kk(23)
      k(5)=kk(11)
      k(6)=kk(23)
      k(7)=kk(10)
      k(8)=kk(9)
      k(9)=kk(8)
c reference density (dens):
      dens(1)=density(10)
      dens(2)=density(11)
      dens(3)=density(12)
      dens(4)=density(13)
      dens(5)=density(14)
      dens(6)=density(13)
      dens(7)=density(12)
      dens(8)=density(11)
      dens(9)=density(10)
c reference specific heat capacity (shc):
      shc(1)=sheatcap(10)
      shc(2)=sheatcap(11)
      shc(3)=sheatcap(12)
      shc(4)=sheatcap(13)
      shc(5)=sheatcap(14)
      shc(6)=sheatcap(13)
      shc(7)=sheatcap(12)
      shc(8)=sheatcap(11)
      shc(9)=sheatcap(10)
      endif
      if(istep.eq.1)then
c reference the initial temp. (t): each layer is partitioned into 3 control volumes.
c so the total number of temperatures = (nlayer=9)*3=27.  note that after step 1, ie at
```

```
c step 2 and beyond the steady state temperature tt(i) is replaced with newt(i).  so
c all steady state temperatures are lost.  they can be retrieved, however from
c the /result/temp(i) variable in the form of degrees Fahrenheit.
      t(1)=tt(17)
      t(2)=(tt(17)+tt(18))/2.
      t(3)=tt(18)
      t(4)=tt(18)
      t(5)=(tt(18)+tt(19))/2.
      t(6)=tt(19)
      t(7)=tt(19)
      t(8)=(tt(19)+tt(20))/2.
      t(9)=tt(20)
      t(10)=tt(20)
      t(11)=(tt(20)+tt(38))/2.
      t(12)=tt(38)
      t(13)=tt(38)
      t(14)=(tt(38)+tt(39))/2.
      t(15)=tt(39)
      t(16)=tt(39)
      t(17)=(tt(39)+tt(21))/2.
      t(18)=tt(21)
      t(19)=tt(21)
      t(20)=(tt(21)+tt(22))/2.
      t(21)=tt(22)
      t(22)=tt(22)
      t(23)=(tt(22)+tt(23))/2.
      t(24)=tt(23)
      t(25)=tt(23)
      t(26)=(tt(23)+tt(24))/2.
      t(27)=tt(24)
c for the nonlinear solution of the new transient temperatures newt, one needs an
c initial guess for the set of newt's.  what better guess than the steady state
c temperatures (as above) prior to the start of the transient analysis
      do 10 i=1,27
   10 newt(i)=t(i)
c reference the initial radiosity (jj)
      jj(5)=tt(44)
      jj(6)=tt(45)
      jj(8)=tt(47)
      jj(10)=tt(49)
      return
      endif
c
c formulate transient cooling: develop the function ffn(i), which is the fvec
c in the non-linear transient solution process.
c
c first need to replace newt(i) with the incoming tt(i), where tt(i) is
c the solution from newraph2 subroutine for step=istep and at iteration=ithtrial.
c note that the original tt(i), ie the steady state temperatures are all destroyed
c after step 1, ie at step 2 and greater.
c note that the internal layer (cabin air) is not modelled due to its complexity.
```

```
c result should be ok. so there are (27-3) control volumes = 24, rearranged as
c shown here and at the end of this subroutine.
c
      if(ithtrial.eq.1)go to 65
       isum=0
           do 50 i=1,27
       if(i.eq.13.or.i.eq.14.or.i.eq.15)goto 50
       isum=isum+1
       newt(i)=tt(54+isum)
 50   continue
c
 65   if(isolfoun.eq.1)then
       if(ithtrial.eq.1)then
        isum=0
             do 55 i=1,27
          if(i.eq.13.or.i.eq.14.or.i.eq.15)goto 55
          isum=isum+1
          newt(i)=tt(54+isum)
 55       continue
       endif
       do 60 i=1,27
 60    t(i)=newt(i)
       temptrn(39)=t(1)-459.67
       temptrn(40)=(t(3)+t(4))/2.-459.67
       temptrn(41)=(t(6)+t(7))/2.-459.67
       temptrn(42)=(t(9)+t(10))/2.-459.67
       temptrn(43)=t(12)-459.67
       temptrn(44)=t(16)-459.67
       temptrn(45)=(t(18)+t(19))/2.-459.67
       temptrn(46)=(t(21)+t(22))/2.-459.67
       temptrn(47)=(t(24)+t(25))/2.-459.67
       temptrn(48)=t(27)-459.67
           return
      endif
c
c find the rayleigh and nusselt number within the cabin when it is closed (icool=2)
c and perhaps turbulence is present.  these numbers are required to find the convective
c coefficient within the cabin.  note that when the cabin door is opened (icool=1)
c the convective coefficient is hhc, coming from trnsien2 subroutine.
c
      if(icool.eq.2)then
           rayleig2=gravity*1./((newt(12)+newt(16))/2.)*abs(newt(12)-newt(16))*
     &          th(5)**3/(thdiffus*visckine)
           if(rayleig2.le.(1e3*(0.2+prandtl)/prandtl))then
             nusselt2=1.0
           elseif(rayleig2.gt.(1e3*(0.2+prandtl)/prandtl).and.rayleig2.lt.
     &        1.0e9)then
             nusselt2=0.18*((prandtl/(0.2+prandtl))*rayleig2)**0.29
           endif
      endif
c
```

```
c formulate transient cooling:
c
c LHS surface temp of fuselage (newt1), as well as internal temp newt2 and newt3: as well
c as functions fn(1), fn(2) and fn(3).
c
          qnetsky=(sig*newt(1)**4-rff*jj(5))/((1.-rff*eemisf)/eemisf)
          fn(1)=-newt(1)+t(1)+deltime/(dens(1)*shc(1)*f/2*th(1))*
     &       ((absorbf*qreflfwl(2,iperiod)*cos(fpi*theta)+
     &       qscabfwl(2,iperiod))*sunfact+
     &       qscabfwr(2,iperiod)*(1-sunfact)
     &       -qnetsky-hhf*(newt(1)-ta)-
     &       (newt(1)-newt(2))/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
          fn(2)=-newt(2)+t(2)+deltime/(dens(1)*shc(1)*(1-f)*th(1))*
     &       ((newt(1)-newt(2))/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1))-
     &       (newt(2)-newt(3))/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
          fn(3)=-newt(3)+t(3)+deltime/(dens(1)*shc(1)*f/2*th(1))*
     &       ((newt(2)-newt(3))/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1))-
     &       (newt(3)-newt(4))/(f/4*th(1)/k(1)+f/4*th(2)/k(2)))
c
c internal nodes::: for layers 2 to 8
c internal nodes::: beginning of control volume: newt(4,7,10,16,19,22): same as fn()
c                   middle of control volume: newt(5,8,11,17,20,23): same as fn()
c                   ending of control volume: newt(6,9,12,18,21,24): same as fn()
c newt(13,14 and 16) for cabin air neglected: ie layer 5
c
          do 20 i=2,8
        if(i.eq.5)goto 20
          ii=(i-1)*3
c
c beginning element within layer 2,3,4,6,7,8:
c newt4,newt7,newt10,newt16,newt19,newt22: fn(4),fn(7),fn(10),fn(16),fn(19),fn(22)
c
          if(i.eq.6)then
            qnetcab=(sig*newt(ii+1)**4-jj(10))/((1.-emisfi)/emisfi)
            if(icool.eq.1)then
          fn(ii+1)=
     &       -newt(ii+1)+t(ii+1)+deltime/(dens(i)*shc(i)*f/2*th(i))*
     & (-(newt(ii+1)-newt(ii+2))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &       qnetcab+absorbfi*qreflin(1,iperiod)*cos(fpi*theta)+
     &       qscabsin(1,iperiod)-hhc*(newt(ii+1)-ta))
            elseif(icool.eq.2)then
          fn(ii+1)=
     &       -newt(ii+1)+t(ii+1)+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &       ((newt(ii-3)-newt(ii+1))/(f/4*th(i-2)/k(i-2)+
     &                  th(i-1)/(nusselt2*k(i-1))+f/4*th(i)/k(i))-
     &   (newt(ii+1)-newt(ii+2))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &       qnetcab+
     &       (absorbfi*qreflin(1,iperiod)*cos(fpi*theta)+
     &       qscabsin(1,iperiod))*sunfact2)
c    &       (absorbfi*qreflin(3,iperiod)*cos(fpi*theta)+
c    &       qscabsin(3,iperiod))*(1-sunfact))
```

```
            endif
           else
          fn(ii+1)=
     &      -newt(ii+1)+t(ii+1)+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &      ((newt(ii)-newt(ii+1))/(f/4*th(i-1)/k(i-1)+f/4*th(i)/k(i))-
     &      (newt(ii+1)-newt(ii+2))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
           endif
c
c middle element within layer 2,3,4,6,7,8:
c newt5,newt8,newt11,newt17,newt20,newt23: fn(5),fn(8),fn(11),fn(17),fn(20),fn(23)
c
        fn(ii+2)=
     &    -newt(ii+2)+t(ii+2)+deltime/(dens(i)*shc(i)*(1-f)*th(i))*
     &    ((newt(ii+1)-newt(ii+2))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &    (newt(ii+2)-newt(ii+3))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
c
c ending element within layer 2,3,4,6,7,8:
c newt6,newt9,newt12,newt18,newt21,newt24: fn(6),fn(9),fn(12),fn(18),fn(21),fn(24)
c
           if(i.eq.4)then
           qnetcab=(sig*newt(ii+3)**4-jj(8))/((1.-emisfi)/emisfi)
           if(icool.eq.1)then
          fn(ii+3)=
     &      -newt(ii+3)+t(ii+3)+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &    ((newt(ii+2)-newt(ii+3))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &      qnetcab+absorbfi*qreflin(3,iperiod)*cos(fpi*theta)+
     &      qscabsin(3,iperiod)-hhc*(newt(ii+3)-ta))
           elseif(icool.eq.2)then
          fn(ii+3)=
     &      -newt(ii+3)+t(ii+3)+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &    ((newt(ii+2)-newt(ii+3))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &       (newt(ii+3)-newt(ii+7))/(f/4*th(i)/k(i)+
     &                        th(i+1)/(nusselt2*k(i+1))+f/4*th(i+2)/k(i+2))-
     &      qnetcab+
     &      (absorbfi*qreflin(3,iperiod)*cos(fpi*theta)+
     &      qscabsin(3,iperiod))*sunfact2)
c    &    (absorbfi*qreflin(1,iperiod)*cos(fpi*theta)+
c    &    qscabsin(1,iperiod))*(1-sunfact))
           endif
           else
        fn(ii+3)=
     &    -newt(ii+3)+t(ii+3)+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &    ((newt(ii+2)-newt(ii+3))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &    (newt(ii+3)-newt(ii+4))/(f/4*th(i)/k(i)+f/4*th(i+1)/k(i+1)))
           endif
 20        continue
c
c RHS surface temp of fuselage (newt27), as well as internal temp
c newt25 and newt26: functions fn(27), fn(25) and fn(26).
c
           fn(25)=-newt(25)+t(25)+
```

```
     &        deltime/(dens(9)*shc(9)*f/2*th(9))*
     &        ((newt(24)-newt(25))/
     &        (f/4*th(8)/k(8)+f/4*th(9)/k(9))-
     &        (newt(25)-newt(26))/
     &        (f/4*th(9)/k(9)+(1-f)/2*th(9)/k(9)))
          fn(26)=-newt(26)+t(26)+
     &        deltime/(dens(9)*shc(9)*(1-f)*th(9))*
     &        ((newt(25)-newt(26))/
     &        (f/4*th(9)/k(9)+(1-f)/2*th(9)/k(9))-
     &        (newt(26)-newt(27))/
     &        (f/4*th(9)/k(9)+(1-f)/2*th(9)/k(9)))
          qnetsky=(sig*newt(27)**4-rff*jj(6))/((1.-rff*eemisf)/eemisf)
          fn(27)=-newt(27)+t(27)+
     &        deltime/(dens(9)*shc(9)*f/2*th(9))*
     &        (qscabfwr(2,iperiod)*sunfact+
     &         (absorbf*qreflfwl(2,iperiod)*cos(fpi*theta)+
     &          qscabfwl(2,iperiod))*(1-sunfact)
     &        -qnetsky-hhf*(newt(27)-ta)+
     &        (newt(26)-newt(27))/
     &        (f/4*th(9)/k(9)+(1-f)/2*th(9)/k(9)))
c
c transfer fn(i) into tfn(i) so that fn(13),fn(14) and fn(15) are removed
c and thus tfn(i) begins at tfn(1) and ends at tfn(24).  fn(13),fn(14) and fn(15)
c are dummies for the layer 5 (air in the cabin).
c
      isum=0
      do 100 i=1,27
       if(i.eq.13.or.i.eq.14.or.i.eq.15)goto 100
       isum=isum+1
       tfn(isum)=fn(i)
 100  continue
c
c transfer the tfn(i) into the global ffn(i), which is used together with jacobian
c to find the p(i) and then the new tt(i) in newraph2 subroutine.
c
      do 30 i=1,24
   30 ffn(54+i)=tfn(i)
c
c now find the jacobian, global jacob(120,120) from the partial derivative of fn(i).
c find tjacob(27,27) first.  then put it into the global jacob(55..78,55..78).
c note: tjacob(13,),tjacob(14,) and tjacob(15,) are just dummies to be removed later.
c
c first initialize tjacob(27,27) to 0.0.
c note:  most of the tjacob(27,27) are 0.0
c
       do 70 itj=1,27
        do 70 jtj=1,27
  70   tjacob(itj,jtj)=0.0
c
c first find tjacob(1,),tjacob(2,),tjacob(3,) for the LHS first layer functions
c fn(1),fn(2),fn(3)
```

```
c
c tjacob(1,1) and tjacob(1,2):
c
     tjacob(1,1)=-1+deltime/(dens(1)*shc(1)*f/2*th(1))*
    &        (-(4*sig*newt(1)**3)/((1.-rff*eemisf)/eemisf)-hhf*(1)-
    &        (1)/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
     tjacob(1,2)=deltime/(dens(1)*shc(1)*f/2*th(1))*
    &        (-(-1)/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
c
c tjacob(2,1),tjacob(2,2) and tjacob(2,3):
c
     tjacob(2,1)=deltime/(dens(1)*shc(1)*(1-f)*th(1))*
    &        ((1)/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
     tjacob(2,2)=-1+deltime/(dens(1)*shc(1)*(1-f)*th(1))*
    &        ((-1)/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1))-
    &        (1)/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
     tjacob(2,3)=deltime/(dens(1)*shc(1)*(1-f)*th(1))*
    &        (-(-1)/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
c
c tjacob(3,2),tjacob(3,3) and tjacob(3,4):
c
     tjacob(3,2)=deltime/(dens(1)*shc(1)*f/2*th(1))*
    &        ((1)/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
     tjacob(3,3)=-1+deltime/(dens(1)*shc(1)*f/2*th(1))*
    &        ((-1)/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1))-
    &        (1)/(f/4*th(1)/k(1)+f/4*th(2)/k(2)))
     tjacob(3,4)=deltime/(dens(1)*shc(1)*f/2*th(1))*
    &        (-(-1)/(f/4*th(1)/k(1)+f/4*th(2)/k(2)))
c
c now find jacobians for the internal conduction layers: tjacob(4,) to tjacob(24,)
c for functions fn(4) to fn (24):
c
          do 120 i=2,8
       if(i.eq.5)goto 120
          ii=(i-1)*3
c
c find tjacob(4,),tjacob(7,),tjacob(10,),tjacob(16,),tjacob(19,)
c and tjacob(22,) for beginning element within
c layer i: from fn(4),fn(7),fn(10),fn(16),fn(19) and fn(22):
c note: tjacob(13) is skipped
          if(i.eq.6)then
            if(icool.eq.1)then
c tjacob(16,16),tjacob(16,17):
          tjacob(ii+1,ii+1)=-1+deltime/(dens(i)*shc(i)*f/2*th(i))*
    &        (-(1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
    &        (4*sig*newt(ii+1)**3)/((1.-emisfi)/emisfi)-hhc*(1))
          tjacob(ii+1,ii+2)=deltime/(dens(i)*shc(i)*f/2*th(i))*
    &        (-(-1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
            elseif(icool.eq.2)then
c tjacob(16,12),tjacob(16,16),tjacob(16,17):
          if(nusselt2.eq.1.0)then
```

```
            tjacob(ii+1,ii-3)=deltime/(dens(i)*shc(i)*f/2*th(i))*
     &         ((1)/(f/4*th(i-2)/k(i-2)+
     &                  th(i-1)/(nusselt2*k(i-1))+f/4*th(i)/k(i)))
            tjacob(ii+1,ii+1)=-1+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &         ((-1)/(f/4*th(i-2)/k(i-2)+
     &                  th(i-1)/(nusselt2*k(i-1))+f/4*th(i)/k(i))-
     &         (1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &         (4*sig*newt(ii+1)**3)/((1.-emisfi)/emisfi))
            tjacob(ii+1,ii+2)=deltime/(dens(i)*shc(i)*f/2*th(i))*
     &         (-(-1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
          else
            const=0.18*( prandtl/(0.2+prandtl)*gravity*th(5)**3/
     &              (0.5*(thdiffus*visckine)) )**0.29
            dndt12=const*( ((newt(12)+newt(16))**(-0.29)*(0.29)*
     &           abs(newt(12)-newt(16))**(-0.71)*(1.0)) +
     &           (abs(newt(12)-newt(16))**0.29*(-0.29)*
     &           (newt(12)+newt(16))**(-1.29)*(1.0)) )
            dndt16=const*( ((newt(12)+newt(16))**(-0.29)*(0.29)*
     &           abs(newt(12)-newt(16))**(-0.71)*(-1.0)) +
     &           (abs(newt(12)-newt(16))**0.29*(-0.29)*
     &           (newt(12)+newt(16))**(-1.29)*(1.0)) )
            dcdt12=th(i-1)/k(i-1)*(-1.0)*nusselt2**(-2.0)*dndt12
            dcdt16=th(i-1)/k(i-1)*(-1.0)*nusselt2**(-2.0)*dndt16
            abcd=(f/4*th(i-2)/k(i-2)+
     &                  th(i-1)/(nusselt2*k(i-1))+f/4*th(i)/k(i))
            dydt12=abcd**(-1.0)*(1.0) +
     &           (newt(12)-newt(16))*( (-1.0)*abcd**(-2.0)*dcdt12  )
            dydt16=abcd**(-1.0)*(-1.0) +
     &           (newt(12)-newt(16))*( (-1.0)*abcd**(-2.0)*dcdt16  )
c
            tjacob(ii+1,ii-3)=deltime/(dens(i)*shc(i)*f/2*th(i))*
     &                     (dydt12)
            tjacob(ii+1,ii+1)=-1+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &         ( dydt16-
     &         (1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &         (4*sig*newt(ii+1)**3)/((1.-emisfi)/emisfi) )
            tjacob(ii+1,ii+2)=deltime/(dens(i)*shc(i)*f/2*th(i))*
     &         ( -(-1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)) )
          endif
           endif
          else
         tjacob(ii+1,ii)=deltime/(dens(i)*shc(i)*f/2*th(i))*
     &      ((1)/(f/4*th(i-1)/k(i-1)+f/4*th(i)/k(i)))
         tjacob(ii+1,ii+1)=-1+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &      ((-1)/(f/4*th(i-1)/k(i-1)+f/4*th(i)/k(i))-
     &      (1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
         tjacob(ii+1,ii+2)=deltime/(dens(i)*shc(i)*f/2*th(i))*
     &      (-(-1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
          endif
c
c find tjacob(5,),tjacob(8,),tjacob(11,),tjacob(17,),tjacob(20,)
```

```
c and tjacob(23,) for middle element within
c layer i: from fn(5),fn(8),fn(11),fn(17),fn(20) and fn(23):
c note: tjacob(14) is skipped
c
       tjacob(ii+2,ii+1)=deltime/(dens(i)*shc(i)*(1-f)*th(i))*
     &    ((1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
       tjacob(ii+2,ii+2)=-1+deltime/(dens(i)*shc(i)*(1-f)*th(i))*
     &    ((-1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &    (1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
       tjacob(ii+2,ii+3)=deltime/(dens(i)*shc(i)*(1-f)*th(i))*
     &    (-(-1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
c
c find tjacob(6,),tjacob(9,),tjacob(12,),tjacob(18,),tjacob(21,)
c and tjacob(24,) for ending element within
c layer i: from fn(6),fn(9),fn(12),fn(18),fn(21) and fn(24):
c note: tjacob(15) is skipped
c
          if(i.eq.4)then
          if(icool.eq.1)then
c tjacob(12,11),tjacob(12,12):
         tjacob(ii+3,ii+2)=deltime/(dens(i)*shc(i)*f/2*th(i))*
     &      ((1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
         tjacob(ii+3,ii+3)=-1+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &      ((-1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &      (4*sig*newt(ii+3)**3)/((1.-emisfi)/emisfi)-hhc*(1))
          elseif(icool.eq.2)then
c tjacob(12,11),tjacob(12,12), tjacob(12,16):
         if(nusselt2.eq.1.0)then
          tjacob(ii+3,ii+2)=deltime/(dens(i)*shc(i)*f/2*th(i))*
     &      ( (1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)) )
          tjacob(ii+3,ii+3)=-1+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &      ( (-1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &       (1)/(f/4*th(i)/k(i)+
     &                    th(i+1)/(nusselt2*k(i+1))+f/4*th(i+2)/k(i+2))-
     &      (4*sig*newt(ii+3)**3)/((1.-emisfi)/emisfi) )
          tjacob(ii+3,ii+7)=deltime/(dens(i)*shc(i)*f/2*th(i))*
     &      ( -(-1)/(f/4*th(i)/k(i)+
     &                    th(i+1)/(nusselt2*k(i+1))+f/4*th(i+2)/k(i+2)))
         else
            const=0.18*( prandtl/(0.2+prandtl)*gravity*th(5)**3/
     &                (0.5*(thdiffus*visckine)) )**0.29
            dndt12=const*( ((newt(12)+newt(16))**(-0.29)*(0.29)*
     &           abs(newt(12)-newt(16))**(-0.71)*(1.0)) +
     &           (abs(newt(12)-newt(16))**0.29*(-0.29)*
     &           (newt(12)+newt(16))**(-1.29)*(1.0)) )
            dndt16=const*( ((newt(12)+newt(16))**(-0.29)*(0.29)*
     &           abs(newt(12)-newt(16))**(-0.71)*(-1.0)) +
     &           (abs(newt(12)-newt(16))**0.29*(-0.29)*
     &           (newt(12)+newt(16))**(-1.29)*(1.0)) )
            dcdt12=th(i+1)/k(i+1)*(-1.0)*nusselt2**(-2.0)*dndt12
            dcdt16=th(i+1)/k(i+1)*(-1.0)*nusselt2**(-2.0)*dndt16
```

```
            abcd=(f/4*th(i)/k(i)+
     &                    th(i+1)/(nusselt2*k(i+1))+f/4*th(i+2)/k(i+2))
            dydt12=abcd**(-1.0)*(1.0) +
     &           (newt(12)-newt(16))*( (-1.0)*abcd**(-2.0)*dcdt12  )
            dydt16=abcd**(-1.0)*(-1.0) +
     &           (newt(12)-newt(16))*( (-1.0)*abcd**(-2.0)*dcdt16  )
c
            tjacob(ii+3,ii+2)=deltime/(dens(i)*shc(i)*f/2*th(i))*
     &          ( (1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)) )
            tjacob(ii+3,ii+3)=-1+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &           ( (-1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &             (dydt12)-
     &            (4*sig*newt(ii+3)**3)/((1.-emisfi)/emisfi) )
            tjacob(ii+3,ii+7)=deltime/(dens(i)*shc(i)*f/2*th(i))*
     &           (-(dydt16))
          endif
           endif
           else
        tjacob(ii+3,ii+2)=deltime/(dens(i)*shc(i)*f/2*th(i))*
     &     ((1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
        tjacob(ii+3,ii+3)=-1+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &     ((-1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &     (1)/(f/4*th(i)/k(i)+f/4*th(i+1)/k(i+1)))
        tjacob(ii+3,ii+4)=deltime/(dens(i)*shc(i)*f/2*th(i))*
     &     (-(-1)/(f/4*th(i)/k(i)+f/4*th(i+1)/k(i+1)))
           endif
 120    continue
c
c
c now find tjacob(25,),tjacob(26,),tjacob(27,) for the RHS last layer surface functions
c fn(25),fn(26) and fn(27)
c
c tjacob(25,24),tjacob(25,25) and tjacob(25,26):
c
      tjacob(25,24)=deltime/(dens(9)*shc(9)*f/2*th(9))*
     &        ((1)/(f/4*th(8)/k(8)+f/4*th(9)/k(9)))
      tjacob(25,25)=-1+deltime/(dens(9)*shc(9)*f/2*th(9))*
     &        ((-1)/(f/4*th(8)/k(8)+f/4*th(9)/k(9))-
     &        (1)/(f/4*th(9)/k(9)+(1-f)/2*th(9)/k(9)))
      tjacob(25,26)=deltime/(dens(9)*shc(9)*f/2*th(9))*
     &        (-(-1)/(f/4*th(9)/k(9)+(1-f)/2*th(9)/k(9)))
c
c tjacob(26,25),tjacob(26,26) and tjacob(26,27):
c
      tjacob(26,25)=deltime/(dens(9)*shc(9)*(1-f)*th(9))*
     &        ((1)/(f/4*th(9)/k(9)+(1-f)/2*th(9)/k(9)))
      tjacob(26,26)=-1+deltime/(dens(9)*shc(9)*(1-f)*th(9))*
     &        ((-1)/(f/4*th(9)/k(9)+(1-f)/2*th(9)/k(9))-
     &        (1)/(f/4*th(9)/k(9)+(1-f)/2*th(9)/k(9)))
      tjacob(26,27)=deltime/(dens(9)*shc(9)*(1-f)*th(9))*
     &        (-(-1)/(f/4*th(9)/k(9)+(1-f)/2*th(9)/k(9)))
```

```
c
c tjacob(27,26) and tjacob(27,27): outer most control volume
c
      tjacob(27,26)=deltime/(dens(9)*shc(9)*f/2*th(9))*
     &        ((1)/(f/4*th(9)/k(9)+(1-f)/2*th(9)/k(9)))
      tjacob(27,27)=-1+deltime/(dens(9)*shc(9)*f/2*th(9))*
     &        (-(4*sig*newt(27)**3)/((1.-rff*eemisf)/eemisf)-hhf*(1)+
     &        (-1)/(f/4*th(9)/k(9)+(1-f)/2*th(9)/k(9)))
c
c jacobian analysis is done.  now put tjacob(i,j) into the global jacobian matrix
c jacob(ijacob,jjacob), where ijacob starts and ends at 55 and 78,
c and jjacob starts and ends at 55 and 78.  note:  most jacob values are 0's
c
c
c first transfer jacob(27,27) into ttjacob(24,24) so that rows and columns
c 13, 14 and 15 are removed.
c
      isum1=0
      do 140 i=1,27
       if(i.eq.13.or.i.eq.14.or.i.eq.15)goto 140
       isum1=isum1+1
       isum2=0
       do 125 j=1,27
        if(j.eq.13.or.j.eq.14.or.j.eq.15)goto 125
        isum2=isum2+1
        ttjacob(isum1,isum2)=tjacob(i,j)
 125   continue
 140  continue
c
c now put ttjacob into the global jacob
c
      do 130 i=1,24
       do 130 j=1,24
        jacob(54+i,54+j)=ttjacob(i,j)
  130 continue
      return
      end
c
c
      subroutine fuslgrf2(ithtrial,itotitr,icool,iperiod,istep,theta,ta,
     &                hhf,hhc,qdir,qsky,qtarm,sunfact2,isolfoun)
c purpose: transient analysis of the fuselage (top to bottom)
c called from: newraph2
c calls: none
      common/c2/tt(200),ffn(200),jacob(200,200)
      common/c3/tth(100),kk(100)
      common/c4/widthwng,lengtwng,hwng,locwng,lplane,lfuselg,hfuselg,
     &                wfuselg
      common/c6/absorbff,emisff,absorbww,emisww,absorbfl,emisfl,absorbfi
     &,emisfi,absorbpg,emispg,absorftp,emisrftp,absorfbt,emisrfbt
     &,absorbfb,emisfb
```

```
      common/c5/trnsm,absorbta,emista,tarmd,densta,conducta,shcta
      common/c10/aircondc,thdiffus,visckine,prandtl
      common/c12/a1,a2,a3,a4,a5,a6(100),a7(100)
      common/c14/thicknes(100),density(100),conductv(100),sheatcap(100)
      common/reflecq/qreflin(6,100),qscabsin(6,100),qreflfwr(6,100),
     &qreflfwl(6,100),qscabfwr(6,100),qscabfwl(6,100),qabstwa1(6,100),
     &qabstwa2(6,100),qabstwb(6,100)
      common/temp4/t(1000),tpg1,tpg2,tpg3
      common/data1/deltime
      common/radiosit/jj(14)
      common/result/temp(200),temptrn(200)
      dimension newt(100),k(100),th(100),dens(100),shc(100),fn(100)
      dimension tfn(100),tjacob(42,42),ttjacob(42,42)
      real kk,k,jj,newt,nusselt1,lfuselg,kpg,newtpg1,newtpg2,newtpg3
      real jacob
      parameter(sig=.1714e-8,gravity=32.2)
      parameter(fpi=3.141593/180.)
      parameter(f=0.2)
c
c Variables:
c f=fraction of an element thickness
c
c Note:
c A total of 13 layers are used to model the fuselage cabin (heightwise),
c the space between floor bottom and belly-pan top, and the belly itself.
c the fifth layer is air space (maybe in turbulence).  the fifth layer is
c not modelled because of its complexity.  any reference to the 13,14 and 15
c control volume is only a dummy.
c the tenth layer (or element) is air space (in between the floor bottom
c and belly-pan top).  it may be filled with fuel or just air
c or both.  this layer is modelled as conduction element using control volumes
c 28, 29 and 30.
      if(itotitr.eq.1.and. istep.eq.1)then
c reference thickness (th):
      th(1)=tth(27)
      th(2)=tth(26)
      th(3)=tth(25)
      th(4)=tth(28)
      th(5)=tth(24)
      th(6)=tth(21)
      th(7)=tth(20)
      th(8)=tth(19)
      th(9)=tth(18)
      th(10)=tth(31)
      th(11)=tth(14)
      th(12)=tth(13)
      th(13)=tth(12)
c reference conductivity (k):
      k(1)=kk(27)
      k(2)=kk(26)
      k(3)=kk(25)
```

```
      k(4)=kk(28)
      k(5)=kk(24)
      k(6)=kk(21)
      k(7)=kk(20)
      k(8)=kk(19)
      k(9)=kk(18)
      k(10)=kk(31)
      k(11)=kk(14)
      k(12)=kk(13)
      k(13)=kk(12)
c reference density (dens):
      dens(1)=density(15)
      dens(2)=density(16)
      dens(3)=density(17)
      dens(4)=density(18)
      dens(5)=density(19)
      dens(6)=density(20)
      dens(7)=density(21)
      dens(8)=density(22)
      dens(9)=density(23)
      dens(10)=density(24)
      dens(11)=density(25)
      dens(12)=density(26)
      dens(13)=density(27)
c reference specific heat capacity:
      shc(1)=sheatcap(15)
      shc(2)=sheatcap(16)
      shc(3)=sheatcap(17)
      shc(4)=sheatcap(18)
      shc(5)=sheatcap(19)
      shc(6)=sheatcap(20)
      shc(7)=sheatcap(21)
      shc(8)=sheatcap(22)
      shc(9)=sheatcap(23)
      shc(10)=sheatcap(24)
      shc(11)=sheatcap(25)
      shc(12)=sheatcap(26)
      shc(13)=sheatcap(27)
c also reference plexiglass thickness, conductivity, density
c and specific heat capacity:
      thpg=tth(22)
      kpg=kk(22)
      denspg=density(28)
      shcpg=sheatcap(28)
c also find these values:
      c1=a1/(a1+a2)
      c2=a2/(a1+a2)
      emispgrf=c1*emispg+c2*emisrfbt
      endif
      if(istep.eq.1)then
c reference the initial temp. (t):
```

```
      t(1)=tt(59)
      t(2)=(tt(59)+tt(58))/2.
      t(3)=tt(58)
      t(4)=tt(58)
      t(5)=(tt(58)+tt(57))/2.
      t(6)=tt(57)
      t(7)=tt(57)
      t(8)=(tt(57)+tt(60))/2.
      t(9)=tt(60)
      t(10)=tt(60)
      t(11)=(tt(60)+tt(61))/2.
      t(12)=tt(61)
      t(13)=tt(61)
      t(14)=(tt(61)+tt(35))/2.
      t(15)=tt(35)
      t(16)=tt(35)
      t(17)=(tt(35)+tt(34))/2.
      t(18)=tt(34)
      t(19)=tt(34)
      t(20)=(tt(34)+tt(33))/2.
      t(21)=tt(33)
      t(22)=tt(33)
      t(23)=(tt(33)+tt(32))/2.
      t(24)=tt(32)
      t(25)=tt(32)
      t(26)=(tt(32)+tt(31))/2.
      t(27)=tt(31)
      t(28)=tt(31)
      t(29)=(tt(31)+tt(28))/2.
      t(30)=tt(28)
      t(31)=tt(28)
      t(32)=(tt(28)+tt(27))/2.
      t(33)=tt(27)
      t(34)=tt(27)
      t(35)=(tt(27)+tt(26))/2.
      t(36)=tt(26)
      t(37)=tt(26)
      t(38)=(tt(26)+tt(25))/2.
      t(39)=tt(25)
c also reference the intial plexiglass temp.
      tpg1=tt(37)
      tpg2=(tt(37)+tt(36))/2.
      tpg3=tt(36)
c for the nonlinear solution of the new transient temperatures newt, one needs an
c initial guess for the set of newt's.  what better guess than the steady state
c temperatures (as above) prior to the start of the transient analysis.  also
c assign initial guesses for newtpg's.
      do 10 i=1,39
   10 newt(i)=t(i)
      newtpg1=tpg1
      newtpg2=tpg2
```

```
      newtpg3=tpg3
c reference the initial radiosity
      jj(7)=tt(46)
      jj(9)=tt(48)
      jj(11)=tt(50)
      return
      endif
c
c formulate transient cooling: develop the function ffn(i), which is the fvec
c in the non-linear transient solution process.
c
c first need to replace newt(i) with the incoming tt(i), where tt(i) is
c the solution from newraph2 subroutine for step=istep and at iteration=ithtrial.
c note that the original tt(i), ie the steady state temperatures are all destroyed
c after step 1, ie at step 2 and greater.
c note that the internal layer (cabin air) is not modelled due to its complexity.
c result should be ok. so there are (39-3) control volumes = 36, plus the
c three plexiglass control volumes with temperatures tpg1,tpg2 and tpg3.
c the plexiglass fvec are placed at the end of
c fn ie: fn(40), fn(41) and fn(42).
c
      if(ithtrial.eq.1)go to 65
       isum=0
           do 50 i=1,39
       if(i.eq.13.or.i.eq.14.or.i.eq.15)goto 50
       isum=isum+1
       newt(i)=tt(78+isum)
 50   continue
      newtpg1=tt(78+36+1)
      newtpg2=tt(78+36+2)
      newtpg3=tt(78+36+3)
c
 65   if(isolfoun.eq.1)then
       if(ithtrial.eq.1)then
        isum=0
            do 55 i=1,39
         if(i.eq.13.or.i.eq.14.or.i.eq.15)goto 55
         isum=isum+1
         newt(i)=tt(78+isum)
 55      continue
        newtpg1=tt(78+36+1)
        newtpg2=tt(78+36+2)
        newtpg3=tt(78+36+3)
       endif
       do 60 i=1,39
 60     t(i)=newt(i)
       tpg1=newtpg1
       tpg2=newtpg2
       tpg3=newtpg3
      temptrn(21)=t(1)-459.67
      temptrn(22)=(t(3)+t(4))/2.-459.67
```

```
      temptrn(23)=(t(6)+t(7))/2.-459.67
      temptrn(24)=(t(9)+t(10))/2.-459.67
      temptrn(25)=t(12)-459.67
      temptrn(26)=t(16)-459.67
      temptrn(27)=(t(18)+t(19))/2.-459.67
      temptrn(28)=(t(21)+t(22))/2.-459.67
      temptrn(29)=(t(24)+t(25))/2.-459.67
      temptrn(30)=(t(27)+t(28))/2.-459.67
      temptrn(31)=(t(27)+t(31))/2.-459.67
      temptrn(32)=(t(27)+t(31))/2.-459.67
      temptrn(33)=(t(27)+t(31))/2.-459.67
      temptrn(34)=(t(27)+t(31))/2.-459.67
      temptrn(35)=(t(30)+t(31))/2.-459.67
      temptrn(36)=(t(33)+t(34))/2.-459.67
      temptrn(37)=(t(36)+t(37))/2.-459.67
      temptrn(38)=t(39)-459.67
      temptrn(49)=tpg1-459.67
      temptrn(50)=tpg3-459.67
      return
      endif
c
      tpgrf=c1*newtpg3+c2*newt(12)
      qnet=(sig*tpgrf**4-jj(9))/((1.-emispgrf)/emispgrf)
c
      if(icool.eq.2)then
           rayleig1=gravity*1./((tpgrf+newt(16))/2.)*(newt(16)-tpgrf)*
     &          th(5)**3/(thdiffus*visckine)
           if(rayleig1.le.3e5)then
             nusselt1=1.0
           elseif(rayleig1.gt.3e5.and.rayleig1.le.7e9)then
             nusselt1=0.069*rayleig1**(1./3.)*prandtl**.074
           endif
      endif
c
c formulate transient cooling:
c
c first for the only three temperatures of plexiglass:
c fn(40),fn(41),fn(42): newtpg1,newtpg2,newtpg3.
c note: newtpg1=outermost plexiglas temperature
c note: newtpg3=innermost plexiglas temperature
c note: newtpg2=middle plexiglas temperature
c regard newtpg1,newtpg2 and newtpg3 as newt(40),newt(41) and newt(42) in the
c jacobian tjacob matrix.
c
c
       fn(40)=-newtpg1+tpg1+deltime/(a1*denspg*shcpg*f/2*thpg)*
     & (emispg*qsky*a1+emispg*.5*(1.-emista)*qsky*a5
     &    +emispg*.5*qtarm*a5
     &    +f/2*absorbpg*qdir*cos(fpi*theta)*a6(iperiod)
     &    +f/2*absorbpg*qdir*sin(fpi*theta)*a7(iperiod)
     &    +f/2*absorbpg*.5*(1.-absorbta)*qdir*sin(fpi*theta)*a5
```

```
     &    +f/2*absorbpg*qreflin(4,iperiod)*sin(fpi*theta)*a3
     &    +f/2*absorbpg*qscabsin(4,iperiod)*lfuselg*wfuselg
     &    *a3/(absorbpg*a3+absorfbt*a4)
     &    -emispg*sig*newtpg1**4*a1
     &    -hhf*(newtpg1-ta)*a1
     &    -(newtpg1-newtpg2)/(f/4*thpg/kpg+(1-f)/2*thpg/kpg)*a1)
       fn(41)=-newtpg2+tpg2+deltime/(a1*denspg*shcpg*(1-f)*thpg)*
     & ((newtpg1-newtpg2)/(f/4*thpg/kpg+(1-f)/2*thpg/kpg)*a1
     &    -(newtpg2-newtpg3)/((1-f)/2*thpg/kpg+f/4*thpg/kpg)*a1
     &    +(1-f)*absorbpg*qdir*cos(fpi*theta)*a6(iperiod)
     &    +(1-f)*absorbpg*qdir*sin(fpi*theta)*a7(iperiod)
     &    +(1-f)*absorbpg*.5*(1.-absorbta)*qdir*sin(fpi*theta)*a5
     &    +(1-f)*absorbpg*qreflin(4,iperiod)*sin(fpi*theta)*a3
     &    +(1-f)*absorbpg*qscabsin(4,iperiod)*lfuselg*wfuselg
     &    *a3/(absorbpg*a3+absorfbt*a4))
       qpg=emispg*sig*newtpg3**4-emispg/(a3*emispg+a4*emisrfbt)*
     &    (a3*emispg*sig*newtpg3**4+a4*emisrfbt*sig*newt(12)**4-qnet*
     &    (a3+a4))
       if(icool.eq.1)then
            fn(42)=-newtpg3+tpg3+deltime/(a1*denspg*shcpg*f/2*thpg)*
     &    ((newtpg2-newtpg3)/((1-f)/2*thpg/kpg+f/4*thpg/kpg)*a1
     &    -hhc*(newtpg3-ta)*a1
     &    -qpg*a3
     &    +f/2*absorbpg*qdir*cos(fpi*theta)*a6(iperiod)
     &    +f/2*absorbpg*qdir*sin(fpi*theta)*a7(iperiod)
     &    +f/2*absorbpg*.5*(1.-absorbta)*qdir*sin(fpi*theta)*a5
     &    +f/2*absorbpg*qreflin(4,iperiod)*sin(fpi*theta)*a3
     &    +f/2*absorbpg*qscabsin(4,iperiod)*lfuselg*wfuselg
     &    *a3/(absorbpg*a3+absorfbt*a4))
       elseif(icool.eq.2)then
c there is a problem here. correct the tpg2-tpg3 resistance
            fn(42)=-newtpg3+tpg3+deltime/(a1*denspg*shcpg*f/2*thpg)*
     &    ((newtpg2-newtpg3)/((1-f)/2*thpg/kpg+f/4*thpg/kpg)*a1
     &     -(tpgrf-newt(16))/(th(5)/(nusselt1*k(5)))*a3
     &    -qpg*a3
     &    +f/2*absorbpg*qdir*cos(fpi*theta)*a6(iperiod)
     &    +f/2*absorbpg*qdir*sin(fpi*theta)*a7(iperiod)
     &    +f/2*absorbpg*.5*(1.-absorbta)*qdir*sin(fpi*theta)*a5
     &    +f/2*absorbpg*qreflin(4,iperiod)*sin(fpi*theta)*a3
     &    +f/2*absorbpg*qscabsin(4,iperiod)*lfuselg*wfuselg
     &    *a3/(absorbpg*a3+absorfbt*a4))
       endif
c
c next for the roof structure and the rest:
c
c first three temperatures of roof structure: fn(1),fn(2,fn(3):
c newt(1),newt(2),newt(3).
c
          qnetsky=(emisrftp*sig*newt(1)**4-emisrftp*qsky)
          fn(1)=-newt(1)+t(1)+deltime/(dens(1)*shc(1)*f/2*th(1))*
     &       (absorftp*qdir*sin(fpi*theta)-qnetsky-hhf*(newt(1)-ta)-
```

```
     &        (newt(1)-newt(2))/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
          fn(2)=-newt(2)+t(2)+deltime/(dens(1)*shc(1)*(1-f)*th(1))*
     &        ((newt(1)-newt(2))/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1))-
     &        (newt(2)-newt(3))/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
          fn(3)=-newt(3)+t(3)+deltime/(dens(1)*shc(1)*f/2*th(1))*
     &        ((newt(2)-newt(3))/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1))-
     &        (newt(3)-newt(4))/(f/4*th(1)/k(1)+f/4*th(2)/k(2)))
c
c internal nodes::: for layers 2 to 12: newt4 to newt36: also fn(4) to fn(36)
c where newt(13,14 and 16) and fn(13),fn(14) and fn(15) for cabin air (layer 5) neglected
c internal nodes: beginning of control volume: newt(4,7,10,16,19,22,25,28,31,34): fn()
c                 middle of control volume: newt(5,8,11,17,20,23,26,29,32,35): fn()
c                 ending of control volume: newt(6,9,12,18,21,24,27,30,33,36): fn()
c note: newt13,newt14 and newt15 are dummies: and so are fn(13),fn(14),fn(15).
c
          do 20 i=2,12
          if(i.eq.5)goto 20
          ii=(i-1)*3
c
c beginning element within layer 2,3,4,6,7,8,9,10,11 and 12:
c newt4,newt7,newt10,newt16,newt19,newt22,newt25,newt28,newt31,newt34:
c fn(4),fn(7),fn(10),fn(16),fn(19),fn(22),fn(25),fn(28),fn(31),fn(34):
c
          if(i.eq.6)then
            qnetcab=(sig*newt(ii+1)**4-jj(11))/((1.-emisfl)/emisfl)
            if(icool.eq.1)then
           fn(ii+1)=-newt(ii+1)+t(ii+1)+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &   (-(newt(ii+1)-newt(ii+2))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &        hhc*(newt(ii+1)-ta)-
     &        qnetcab+absorbfl*qreflin(2,iperiod)*sin(fpi*theta)+
     &        qscabsin(2,iperiod))
            elseif(icool.eq.2)then
           fn(ii+1)=-newt(ii+1)+t(ii+1)+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &        ((tpgrf-newt(ii+1))/(th(i-1)/(nusselt1*k(i-1)))-
     &     (newt(ii+1)-newt(ii+2))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &        qnetcab+
     &        (absorbfl*qreflin(2,iperiod)*sin(fpi*theta)+
     &        qscabsin(2,iperiod))*sunfact2)
            endif
          else
           fn(ii+1)=-newt(ii+1)+t(ii+1)+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &      ((newt(ii)-newt(ii+1))/(f/4*th(i-1)/k(i-1)+f/4*th(i)/k(i))-
     &     (newt(ii+1)-newt(ii+2))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
          endif
c
c middle element within layer 2,3,4,6,7,8,9,10,11 and 12:
c newt5,newt8,newt11,newt17,newt20,newt23,newt26,newt29,newt32,newt35:
c fn(5),fn(8),fn(11),fn(17),fn(20),fn(23),fn(26),fn(29),fn(32),fn(35):
c
c234567812345678123456781234567812345678123456781234567812345678123456781234
5678
```

```
          fn(ii+2)=-newt(ii+2)+t(ii+2)+deltime/(dens(i)*shc(i)*(1-f)*th(i))*
     &    ((newt(ii+1)-newt(ii+2))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &    (newt(ii+2)-newt(ii+3))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
c
c ending element within layer 2,3,4,6,7,8,9,10,11 and 12:
c newt6,newt9,newt12,newt18,newt21,newt24,newt27,newt30,newt33,newt36:
c fn(6),fn(9),fn(12),fn(18),fn(21),fn(24),fn(27),fn(30),fn(33),fn(36):
c
      if(i.eq.4)then
      qrfbt=emisrfbt*sig*newt(ii+3)**4-emisrfbt/(a3*emispg+a4*emisrfbt)*
     &(a3*emispg*sig*newtpg3**4+a4*emisrfbt*sig*newt(ii+3)**4-qnet*
     &(a3+a4))
          if(icool.eq.1)then
c2345678123456781234567812345678123456781234567812345678123456781234567812345678123456781234
5678
           fn(ii+3)=-newt(ii+3)+t(ii+3)+
     &          deltime/(a2*dens(i)*shc(i)*f/2*th(i))*
     &  ((newt(ii+2)-newt(ii+3))/((1-f)/2*th(i)/k(i)+f/4*th(i)/k(i))*a2-
     &         hhc*(newt(ii+3)-ta)*a2
     &         -qrfbt*a4
     &         +absorfbt*qreflin(4,iperiod)*sin(fpi*theta)*a4
     &         +absorfbt*qscabsin(4,iperiod)*lfuselg*wfuselg*a4/
     &         (absorbpg*a3+absorfbt*a4))
          elseif(icool.eq.2)then
           fn(ii+3)=-newt(ii+3)+t(ii+3)+
     &          deltime/(a2*dens(i)*shc(i)*f/2*th(i))*
     &  ((newt(ii+2)-newt(ii+3))/((1-f)/2*th(i)/k(i)+f/4*th(i)/k(i))*a2-
     &         (tpgrf-newt(ii+7))/(th(i+1)/(nusselt1*k(i+1)))*a4
     &         -qrfbt*a4
     &         +(absorfbt*qreflin(4,iperiod)*sin(fpi*theta)*a4
     &         +absorfbt*qscabsin(4,iperiod)*lfuselg*wfuselg*a4/
     &         (absorbpg*a3+absorfbt*a4))*sunfact2)
          endif
      else
          fn(ii+3)=-newt(ii+3)+t(ii+3)+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &    ((newt(ii+2)-newt(ii+3))/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &    (newt(ii+3)-newt(ii+4))/(f/4*th(i)/k(i)+f/4*th(i+1)/k(i+1)))
      endif
 20       continue
c
c belly-pan external temp (t39), as well as internal temp t37 and t38:
c
          fn(37)=-newt(37)+t(37)+
     &       deltime/(dens(13)*shc(13)*f/2*th(13))*
     &       ((newt(36)-newt(37))/
     &       (f/4*th(12)/k(12)+f/4*th(13)/k(13))-
     &       (newt(37)-newt(38))/
     &       (f/4*th(13)/k(13)+(1-f)/2*th(13)/k(13)))
          fn(38)=-newt(38)+t(38)+
     &       deltime/(dens(13)*shc(13)*(1-f)*th(13))*
     &       ((newt(37)-newt(38))/
```

```
     &       (f/4*th(13)/k(13)+(1-f)/2*th(13)/k(13))-
     &       (newt(38)-newt(39))/
     &       (f/4*th(13)/k(13)+(1-f)/2*th(13)/k(13)))
          qnetsky=(sig*newt(39)**4-jj(7))/((1.-emisfb)/emisfb)
          fn(39)=-newt(39)+t(39)+
     &       deltime/(dens(13)*shc(13)*f/2*th(13))*
     &       (qabstwb(3,iperiod)-qnetsky-hhf*(newt(39)-ta)+
     &       (newt(38)-newt(39))/
     &       (f/4*th(13)/k(13)+(1-f)/2*th(13)/k(13)))
c
c transfer fn(i) into tfn(i) so that fn(13),fn(14) and fn(15) are removed
c and thus tfn(i) begins at tfn(1) and ends at tfn(39).  fn(13),fn(14) and fn(15)
c are dummies for the layer 5 (air in the cabin).  and fn(40),fn(41),fn(42)
c are equations for plexiglass
c
      isum=0
      do 100 i=1,42
       if(i.eq.13.or.i.eq.14.or.i.eq.15)goto 100
       isum=isum+1
       tfn(isum)=fn(i)
 100  continue
c
c transfer the tfn(i) into the global ffn(i), which is used together with jacobian
c to find the p(i) and then the new tt(i) in newraph2 subroutine.
c
      do 30 i=1,39
   30 ffn(78+i)=tfn(i)
c
c now find the jacobian, global jacob(120,120) from the partial derivative of fn(i).
c find tjacob(42,42) first.  then put it into the global jacob(79..117,79..117).
c note: tjacob(13,),tjacob(14,) and tjacob(15,) are just dummies to be removed later.
c
c first initialize tjacob(42,42) to 0.0.
c note:  most of the tjacob(42,42) are 0.0
c
       do 70 itj=1,42
        do 70 jtj=1,42
  70    tjacob(itj,jtj)=0.0
c
c first find tjacob for the only three temperatures of plexiglass:
c tjacob(40,),tjacob(41,),tjacob(42,)
c for fn(40),fn(41),fn(42): newtpg1,newtpg2,newtpg3.
c note: newtpg1=outermost plexiglas temperature
c note: newtpg3=innermost plexiglas temperature
c note: newtpg2=middle plexiglas temperature
c regard newtpg1,newtpg2 and newtpg3 as newt(40),newt(41) and newt(42) in the
c jacobian tjacob matrix.
c
c jacobians tjacob(40,40) and tjacob(40,41):
c
       tjacob(40,40)=-1+deltime/(a1*denspg*shcpg*f/2*thpg)*
```

```
     & (-4*emispg*sig*newtpg1**3*a1
     &    -hhf*(1)*a1
     &    -(1)/(f/4*thpg/kpg+(1-f)/2*thpg/kpg)*a1)
       tjacob(40,41)=deltime/(a1*denspg*shcpg*f/2*thpg)*
     & (-(-1)/(f/4*thpg/kpg+(1-f)/2*thpg/kpg)*a1)
c
c jacobians tjacob(41,40),tjacob(41,41), tjacob(41,42):
c
       tjacob(41,40)=deltime/(a1*denspg*shcpg*(1-f)*thpg)*
     & ((1)/(f/4*thpg/kpg+(1-f)/2*thpg/kpg)*a1)
       tjacob(41,41)=-1+deltime/(a1*denspg*shcpg*(1-f)*thpg)*
     & ((-1)/(f/4*thpg/kpg+(1-f)/2*thpg/kpg)*a1
     &    -(1)/((1-f)/2*thpg/kpg+f/4*thpg/kpg)*a1)
       tjacob(41,42)=deltime/(a1*denspg*shcpg*(1-f)*thpg)*
     & (-(-1)/((1-f)/2*thpg/kpg+f/4*thpg/kpg)*a1)
c
       if(icool.eq.1)then
c jacobians tjacob(42,12), tjacob(42,41) tjacob(42,42):
        tjacob(42,12)=deltime/(a1*denspg*shcpg*f/2*thpg)*
     &     (-(-emispg/(a3*emispg+a4*emisrfbt)*
     &    (4*a4*emisrfbt*sig*newt(12)**3-(4*sig*(c1*newtpg3+
     &  c2*newt(12))**3*(c2*(1)))/((1.-emispgrf)/emispgrf)*(a3+a4)))*a3)
        tjacob(42,41)=deltime/(a1*denspg*shcpg*f/2*thpg)*
     &     ((1)/((1-f)/2*thpg/kpg+f/4*thpg/kpg)*a1)
        tjacob(42,42)=-1+deltime/(a1*denspg*shcpg*f/2*thpg)*
     &     ((-1)/((1-f)/2*thpg/kpg+f/4*thpg/kpg)*a1
     &     -hhc*(1)*a1
     &     -(4*emispg*sig*newtpg3**3-emispg/(a3*emispg+a4*emisrfbt)*
     &    (4*a3*emispg*sig*newtpg3**3-(4*sig*(c1*newtpg3+
     &  c2*newt(12))**3*(c1*(1)))/((1.-emispgrf)/emispgrf)*(a3+a4)))*a3)
       elseif(icool.eq.2)then
c jacobians tjacob(42,12),tjacob(42,16),tjacob(42,41) tjacob(42,42):
        if(nusselt1.eq.1.0)then
         tjacob(42,12)=deltime/(a1*denspg*shcpg*f/2*thpg)*
     &       ( -(c2)/(th(5)/(nusselt1*k(5)))*a3
     &       -(-emispg/(a3*emispg+a4*emisrfbt)*
     &       (4*a4*emisrfbt*sig*newt(12)**3-(4*sig*tpgrf**3*c2)/
     &     ((1.-emispgrf)/emispgrf)*(a3+a4)))*a3 )
         tjacob(42,16)=deltime/(a1*denspg*shcpg*f/2*thpg)*
     &       ( -(-1)/(th(5)/(nusselt1*k(5)))*a3 )
         tjacob(42,41)=deltime/(a1*denspg*shcpg*f/2*thpg)*
     &       ( (1)/((1-f)/2*thpg/kpg+f/4*thpg/kpg)*a1 )
         tjacob(42,42)=-1+deltime/(a1*denspg*shcpg*f/2*thpg)*
     &       ( (-1)/((1-f)/2*thpg/kpg+f/4*thpg/kpg)*a1
     &        -(c1)/(th(5)/(nusselt1*k(5)))*a3
     &        -(4*emispg*sig*newtpg3**3-emispg/(a3*emispg+a4*emisrfbt)*
     &       (4*a3*emispg*sig*newtpg3**3-(4*sig*tpgrf**3*c1)/
     &     ((1.-emispgrf)/emispgrf)*(a3+a4)))*a3 )
         else
          const=0.069*prandtl**.074*(gravity*th(5)**3/
     &             (0.5*(thdiffus*visckine)))**(1./3.)
```

```
          dndt12=const*(  (tpgrf+newt(16))**(-1./3.)*
     &                  ((1./3.)*(newt(16)-tpgrf)**(-2./3.)*(-c2)) +
     &                  (newt(16)-tpgrf)**(1./3.)*
     &                  ((-1./3.)*(tpgrf+newt(16))**(-4./3.)*(c2))  )
          dndt16=const*(  (tpgrf+newt(16))**(-1./3.)*
     &                  ((1./3.)*(newt(16)-tpgrf)**(-2./3.)*(1)) +
     &                  (newt(16)-tpgrf)**(1./3.)*
     &                  ((-1./3.)*(tpgrf+newt(16))**(-4./3.)*(1))   )
          dndt42=const*(  (tpgrf+newt(16))**(-1./3.)*
     &                  ((1./3.)*(newt(16)-tpgrf)**(-2./3.)*(-c1)) +
     &                  (newt(16)-tpgrf)**(1./3.)*
     &                  ((-1./3.)*(tpgrf+newt(16))**(-4./3.)*(c1))  )
          dcdt12=(-1.0)*(th(5)/k(5))*nusselt1**(-2.0)*dndt12
          dcdt16=(-1.0)*(th(5)/k(5))*nusselt1**(-2.0)*dndt16
          dcdt42=(-1.0)*(th(5)/k(5))*nusselt1**(-2.0)*dndt42
          abcd=(th(5)/(nusselt1*k(5)))
          dydt12=abcd**(-1.0)*(c2) +
     &           (tpgrf-newt(16))*((-1.0)*abcd**(-2.0)*dcdt12)
          dydt16=abcd**(-1.0)*(-1.0) +
     &           (tpgrf-newt(16))*((-1.0)*abcd**(-2.0)*dcdt16)
          dydt42=abcd**(-1.0)*(c1) +
     &           (tpgrf-newt(16))*((-1.0)*abcd**(-2.0)*dcdt42)
c
          tjacob(42,12)=deltime/(a1*denspg*shcpg*f/2*thpg)*
     &        ( -(dydt12)*a3
     &        -(-emispg/(a3*emispg+a4*emisrfbt)*
     &        (4*a4*emisrfbt*sig*newt(12)**3-(4*sig*tpgrf**3*c2)/
     &      ((1.-emispgrf)/emispgrf)*(a3+a4)))*a3 )
          tjacob(42,16)=deltime/(a1*denspg*shcpg*f/2*thpg)*
     &         (  -(dydt16)*a3 )
          tjacob(42,41)=deltime/(a1*denspg*shcpg*f/2*thpg)*
     &         ( (1)/((1-f)/2*thpg/kpg+f/4*thpg/kpg)*a1 )
          tjacob(42,42)=-1+deltime/(a1*denspg*shcpg*f/2*thpg)*
     &        ( (-1)/((1-f)/2*thpg/kpg+f/4*thpg/kpg)*a1
     &        -(dydt42)*a3
     &        -(4*emispg*sig*newtpg3**3-emispg/(a3*emispg+a4*emisrfbt)*
     &        (4*a3*emispg*sig*newtpg3**3-(4*sig*tpgrf**3*c1)/
     &      ((1.-emispgrf)/emispgrf)*(a3+a4)))*a3 )
        endif
      endif
c
c jacobians for the roof structure tjacob(1,),tjacob(2,),tjacob(3,):
c from the three temperatures and functions of roof structure: fn(1),fn(2,fn(3):
c newt(1),newt(2),newt(3).
c
c
c tjacob(1,1) and tjacob(1,2):
c
      tjacob(1,1)=-1+deltime/(dens(1)*shc(1)*f/2*th(1))*
     &        (-(4*emisrftp*sig*newt(1)**3)-hhf*(1)-
     &        (1)/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
```

```
      tjacob(1,2)=deltime/(dens(1)*shc(1)*f/2*th(1))*
     &        (-(-1)/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
c
c tjacob(2,1), tjacob(2,2) and tjacob(2,3):
c
      tjacob(2,1)=deltime/(dens(1)*shc(1)*(1-f)*th(1))*
     &        ((1)/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
      tjacob(2,2)=-1+deltime/(dens(1)*shc(1)*(1-f)*th(1))*
     &        ((-1)/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1))-
     &        (1)/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
      tjacob(2,3)=deltime/(dens(1)*shc(1)*(1-f)*th(1))*
     &        (-(-1)/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
c
c tjacob(3,2), tjacob(3,3) and tjacob(3,4):
c
      tjacob(3,2)=deltime/(dens(1)*shc(1)*f/2*th(1))*
     &        ((1)/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1)))
      tjacob(3,3)=-1+deltime/(dens(1)*shc(1)*f/2*th(1))*
     &        ((-1)/(f/4*th(1)/k(1)+(1-f)/2*th(1)/k(1))-
     &        (1)/(f/4*th(1)/k(1)+f/4*th(2)/k(2)))
      tjacob(3,4)=deltime/(dens(1)*shc(1)*f/2*th(1))*
     &        (-(-1)/(f/4*th(1)/k(1)+f/4*th(2)/k(2)))
c
c now find jacobians tjacob(4) to tjacob(36) within layers 2 to 12.
c note that tjacob(13,) tjacob(14,) and tjacob(15,) are skipped and are just dummies.
c
          do 120 i=2,12
          if(i.eq.5)goto 120
          ii=(i-1)*3
c
c find tjacob(4),tjacob(7),tjacob(10),tjacob(16),tjacob(19),tjacob(22)
c and tjacob(25),tjacob(28),tjacob(31) and tjacob(34) for:
c beginning element within layer 2,3,4,6,7,8,9,10,11 and 12:
c newt4,newt7,newt10,newt16,newt19,newt22,newt25,newt28,newt31,newt34:
c fn(4),fn(7),fn(10),fn(16),fn(19),fn(22),fn(25),fn(28),fn(31),fn(34):
c
          if(i.eq.6)then
            if(icool.eq.1)then
c tjacob(16,16),tjacob(16,17):
          tjacob(ii+1,ii+1)=-1+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &        (-(1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &        hhc*(1)-
     &        (4*sig*newt(ii+1)**3)/((1.-emisfl)/emisfl))
          tjacob(ii+1,ii+2)=deltime/(dens(i)*shc(i)*f/2*th(i))*
     &        (-(-1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
            elseif(icool.eq.2)then
c tjacob(16,12),tjacob(16,16),tjacob(16,17),tjacob(16,42)
          if(nusselt1.eq.1.0)then
           tjacob(ii+1,ii-3)=deltime/(dens(i)*shc(i)*f/2*th(i))*
     &           ( (c2)/(th(i-1)/(nusselt1*k(i-1))) )
           tjacob(ii+1,ii+1)=-1+deltime/(dens(i)*shc(i)*f/2*th(i))*
```

```
     &          ( (-1)/(th(i-1)/(nusselt1*k(i-1)))-
     &          (1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &          (4*sig*newt(ii+1)**3)/((1.-emisfl)/emisfl) )
            tjacob(ii+1,ii+2)=deltime/(dens(i)*shc(i)*f/2*th(i))*
     &          ( -(-1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)) )
            tjacob(ii+1,42)=deltime/(dens(i)*shc(i)*f/2*th(i))*
     &          ( (c1)/(th(i-1)/(nusselt1*k(i-1))) )
           else
            const=0.069*prandtl**.074*(gravity*th(5)**3/
     &           (0.5*(thdiffus*visckine)))**(1./3.)
            dndt12=const*(  (tpgrf+newt(16))**(-1./3.)*
     &                  ((1./3.)*(newt(16)-tpgrf)**(-2./3.)*(-c2)) +
     &                  (newt(16)-tpgrf)**(1./3.)*
     &                  ((-1./3.)*(tpgrf+newt(16))**(-4./3.)*(c2))  )
            dndt16=const*(  (tpgrf+newt(16))**(-1./3.)*
     &                  ((1./3.)*(newt(16)-tpgrf)**(-2./3.)*(1)) +
     &                  (newt(16)-tpgrf)**(1./3.)*
     &                  ((-1./3.)*(tpgrf+newt(16))**(-4./3.)*(1))   )
            dndt42=const*(  (tpgrf+newt(16))**(-1./3.)*
     &                  ((1./3.)*(newt(16)-tpgrf)**(-2./3.)*(-c1)) +
     &                  (newt(16)-tpgrf)**(1./3.)*
     &                  ((-1./3.)*(tpgrf+newt(16))**(-4./3.)*(c1))  )
            dcdt12=(-1.0)*(th(5)/k(5))*nusselt1**(-2.0)*dndt12
            dcdt16=(-1.0)*(th(5)/k(5))*nusselt1**(-2.0)*dndt16
            dcdt42=(-1.0)*(th(5)/k(5))*nusselt1**(-2.0)*dndt42
            abcd=(th(5)/(nusselt1*k(5)))
            dydt12=abcd**(-1.0)*(c2) +
     &          (tpgrf-newt(16))*((-1.0)*abcd**(-2.0)*dcdt12)
            dydt16=abcd**(-1.0)*(-1.0) +
     &          (tpgrf-newt(16))*((-1.0)*abcd**(-2.0)*dcdt16)
            dydt42=abcd**(-1.0)*(c1) +
     &          (tpgrf-newt(16))*((-1.0)*abcd**(-2.0)*dcdt42)
c
            tjacob(ii+1,ii-3)=deltime/(dens(i)*shc(i)*f/2*th(i))*
     &          ( (dydt12) )
            tjacob(ii+1,ii+1)=-1+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &          ( (dydt16)-
     &           (1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &           (4*sig*newt(ii+1)**3)/((1.-emisfl)/emisfl) )
            tjacob(ii+1,ii+2)=deltime/(dens(i)*shc(i)*f/2*th(i))*
     &           ( -(-1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)) )
            tjacob(ii+1,42)=deltime/(dens(i)*shc(i)*f/2*th(i))*
     &           ( (dydt42) )
           endif
            endif
           else
          tjacob(ii+1,ii)=deltime/(dens(i)*shc(i)*f/2*th(i))*
     &      ((1)/(f/4*th(i-1)/k(i-1)+f/4*th(i)/k(i)))
          tjacob(ii+1,ii+1)=-1+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &      ((-1)/(f/4*th(i-1)/k(i-1)+f/4*th(i)/k(i))-
     &      (1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
```

```
          tjacob(ii+1,ii+2)=deltime/(dens(i)*shc(i)*f/2*th(i))*
     &       (-(-1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
           endif
c
c find tjacob(5),tjacob(8),tjacob(11),tjacob(17),tjacob(20),tjacob(23)
c and tjacob(26),tjacob(29),tjacob(32) and tjacob(35) for:
c middle element within layer 2,3,4,6,7,8,9,10,11 and 12:
c newt5,newt8,newt11,newt17,newt20,newt23,newt26,newt29,newt32,newt35:
c fn(5),fn(8),fn(11),fn(17),fn(20),fn(23),fn(26),fn(29),fn(32),fn(35):
c
        tjacob(ii+2,ii+1)=deltime/(dens(i)*shc(i)*(1-f)*th(i))*
     &     ((1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
        tjacob(ii+2,ii+2)=-1+deltime/(dens(i)*shc(i)*(1-f)*th(i))*
     &     ((-1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &     (1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
        tjacob(ii+2,ii+3)=deltime/(dens(i)*shc(i)*(1-f)*th(i))*
     &     (-(-1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
c
c find tjacob(6),tjacob(9),tjacob(12),tjacob(18),tjacob(21),tjacob(24)
c and tjacob(27),tjacob(30),tjacob(33) and tjacob(36) for:
c ending element within layer 2,3,4,6,7,8,9,10,11 and 12:
c newt6,newt9,newt12,newt18,newt21,newt24,newt27,newt30,newt33,newt36:
c fn(6),fn(9),fn(12),fn(18),fn(21),fn(24),fn(27),fn(30),fn(33),fn(36):
c
      if(i.eq.4)then
           if(icool.eq.1)then
c tjacob(12,11),tjacob(12,12),tjacob(12,42)
         tjacob(ii+3,ii+2)=deltime/(a2*dens(i)*shc(i)*f/2*th(i))*
     &        ((1)/((1-f)/2*th(i)/k(i)+f/4*th(i)/k(i))*a2)
         tjacob(ii+3,ii+3)=-1+deltime/(a2*dens(i)*shc(i)*f/2*th(i))*
     &        ((-1)/((1-f)/2*th(i)/k(i)+f/4*th(i)/k(i))*a2-
     &         hhc*(1)*a2
     &  -(4*emisrfbt*sig*newt(ii+3)**3-emisrfbt/(a3*emispg+a4*emisrfbt)*
     &       (4*a4*emisrfbt*sig*newt(ii+3)**3-(4*sig*tpgrf**3*(c2*(1)))/
     &        ((1.-emispgrf)/emispgrf)*(a3+a4)))*a4)
         tjacob(ii+3,42)=deltime/(a2*dens(i)*shc(i)*f/2*th(i))*
     &        (-(-emisrfbt/(a3*emispg+a4*emisrfbt)*
     &      (4*a3*emispg*sig*newtpg3**3-(4*sig*tpgrf**3*(c1*(1)))/
     &      ((1.-emispgrf)/emispgrf)*(a3+a4)))*a4)
           elseif(icool.eq.2)then
c tjacob(12,11),tjacob(12,12),tjacob(12,16),tjacob(12,42)
         if(nusselt1.eq.1.0)then
          tjacob(ii+3,ii+2)=deltime/(a2*dens(i)*shc(i)*f/2*th(i))*
     &        ( (1)/((1-f)/2*th(i)/k(i)+f/4*th(i)/k(i))*a2  )
          tjacob(ii+3,ii+3)=-1+deltime/(a2*dens(i)*shc(i)*f/2*th(i))*
     &        ( (-1)/((1-f)/2*th(i)/k(i)+f/4*th(i)/k(i))*a2-
     &         (c2)/(th(i+1)/(nusselt1*k(i+1)))*a4
     &  -(4*emisrfbt*sig*newt(ii+3)**3-emisrfbt/(a3*emispg+a4*emisrfbt)*
     &       (4*a4*emisrfbt*sig*newt(ii+3)**3-(4*sig*tpgrf**3*c2)/
     &       ((1.-emispgrf)/emispgrf)*(a3+a4)))*a4 )
          tjacob(ii+3,ii+7)=deltime/(a2*dens(i)*shc(i)*f/2*th(i))*
```

```
     &        ( -(-1)/(th(i+1)/(nusselt1*k(i+1)))*a4 )
           tjacob(ii+3,42)=deltime/(a2*dens(i)*shc(i)*f/2*th(i))*
     &        ( -(c1)/(th(i+1)/(nusselt1*k(i+1)))*a4
     &         -(-emisrfbt/(a3*emispg+a4*emisrfbt)*
     &       (4*a3*emispg*sig*newtpg3**3-(4*sig*tpgrf**3*c1)/
     &       ((1.-emispgrf)/emispgrf)*(a3+a4)))*a4 )
           else
              const=0.069*prandtl**.074*(gravity*th(5)**3/
     &             (0.5*(thdiffus*visckine)))**(1./3.)
              dndt12=const*(  (tpgrf+newt(16))**(-1./3.)*
     &                  ((1./3.)*(newt(16)-tpgrf)**(-2./3.)*(-c2)) +
     &                  (newt(16)-tpgrf)**(1./3.)*
     &                  ((-1./3.)*(tpgrf+newt(16))**(-4./3.)*(c2))  )
              dndt16=const*(  (tpgrf+newt(16))**(-1./3.)*
     &                  ((1./3.)*(newt(16)-tpgrf)**(-2./3.)*(1)) +
     &                  (newt(16)-tpgrf)**(1./3.)*
     &                  ((-1./3.)*(tpgrf+newt(16))**(-4./3.)*(1))   )
              dndt42=const*(  (tpgrf+newt(16))**(-1./3.)*
     &                  ((1./3.)*(newt(16)-tpgrf)**(-2./3.)*(-c1)) +
     &                  (newt(16)-tpgrf)**(1./3.)*
     &                  ((-1./3.)*(tpgrf+newt(16))**(-4./3.)*(c1))  )
              dcdt12=(-1.0)*(th(5)/k(5))*nusselt1**(-2.0)*dndt12
              dcdt16=(-1.0)*(th(5)/k(5))*nusselt1**(-2.0)*dndt16
              dcdt42=(-1.0)*(th(5)/k(5))*nusselt1**(-2.0)*dndt42
              abcd=(th(5)/(nusselt1*k(5)))
              dydt12=abcd**(-1.0)*(c2) +
     &           (tpgrf-newt(16))*((-1.0)*abcd**(-2.0)*dcdt12)
              dydt16=abcd**(-1.0)*(-1.0) +
     &           (tpgrf-newt(16))*((-1.0)*abcd**(-2.0)*dcdt16)
              dydt42=abcd**(-1.0)*(c1) +
     &           (tpgrf-newt(16))*((-1.0)*abcd**(-2.0)*dcdt42)
c
           tjacob(ii+3,ii+2)=deltime/(a2*dens(i)*shc(i)*f/2*th(i))*
     &        ( (1)/((1-f)/2*th(i)/k(i)+f/4*th(i)/k(i))*a2 )
           tjacob(ii+3,ii+3)=-1+deltime/(a2*dens(i)*shc(i)*f/2*th(i))*
     &        ( (-1)/((1-f)/2*th(i)/k(i)+f/4*th(i)/k(i))*a2-
     &         (dydt12)*a4
     &  -(4*emisrfbt*sig*newt(ii+3)**3-emisrfbt/(a3*emispg+a4*emisrfbt)*
     &       (4*a4*emisrfbt*sig*newt(ii+3)**3-(4*sig*tpgrf**3*c2)/
     &       ((1.-emispgrf)/emispgrf)*(a3+a4)))*a4 )
           tjacob(ii+3,ii+7)=deltime/(a2*dens(i)*shc(i)*f/2*th(i))*
     &        ( -(dydt16)*a4 )
           tjacob(ii+3,42)=deltime/(a2*dens(i)*shc(i)*f/2*th(i))*
     &        ( -(dydt42)*a4
     &         -(-emisrfbt/(a3*emispg+a4*emisrfbt)*
     &       (4*a3*emispg*sig*newtpg3**3-(4*sig*tpgrf**3*c1)/
     &       ((1.-emispgrf)/emispgrf)*(a3+a4)))*a4 )
           endif
             endif
         else
          tjacob(ii+3,ii+2)=deltime/(dens(i)*shc(i)*f/2*th(i))*
```

```
     &    ((1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i)))
          tjacob(ii+3,ii+3)=-1+deltime/(dens(i)*shc(i)*f/2*th(i))*
     &    ((-1)/(f/4*th(i)/k(i)+(1-f)/2*th(i)/k(i))-
     &    (1)/(f/4*th(i)/k(i)+f/4*th(i+1)/k(i+1)))
          tjacob(ii+3,ii+4)=deltime/(dens(i)*shc(i)*f/2*th(i))*
     &    (-(-1)/(f/4*th(i)/k(i)+f/4*th(i+1)/k(i+1)))
         endif
 120  continue
c
c belly-pan external temp (t39), as well as internal temp t37 and t38:
c
c find tjacob(37,),tjacob(38,) and tjacob(39,) for:
c belly-pan elements within layer 13:
c newt37,newt38 and newt39:
c from fn(37),fn(38) and fn(39):
c
c
c tjacob(37,36) and tjacob(37,37) and tjacob(37,38):
c
          tjacob(37,36)=deltime/(dens(13)*shc(13)*f/2*th(13))*
     &       ( (1)/(f/4*th(12)/k(12)+f/4*th(13)/k(13)) )
          tjacob(37,37)=-1+deltime/(dens(13)*shc(13)*f/2*th(13))*
     &       ( (-1)/(f/4*th(12)/k(12)+f/4*th(13)/k(13))-
     &       (1)/(f/4*th(13)/k(13)+(1-f)/2*th(13)/k(13)) )
          tjacob(37,38)=deltime/(dens(13)*shc(13)*f/2*th(13))*
     &       ( -(-1)/(f/4*th(13)/k(13)+(1-f)/2*th(13)/k(13)) )
c
c tjacob(38,37) and tjacob(38,38) and tjacob(38,39):
c
          tjacob(38,37)=deltime/(dens(13)*shc(13)*(1-f)*th(13))*
     &       ( (1)/(f/4*th(13)/k(13)+(1-f)/2*th(13)/k(13)) )
          tjacob(38,38)=-1+deltime/(dens(13)*shc(13)*(1-f)*th(13))*
     &       ( (-1)/(f/4*th(13)/k(13)+(1-f)/2*th(13)/k(13))-
     &       (1)/(f/4*th(13)/k(13)+(1-f)/2*th(13)/k(13)) )
          tjacob(38,39)=deltime/(dens(13)*shc(13)*(1-f)*th(13))*
     &       ( -(-1)/(f/4*th(13)/k(13)+(1-f)/2*th(13)/k(13)) )
c
c tjacob(39,38) and tjacob(39,39):
c
          tjacob(39,38)=deltime/(dens(13)*shc(13)*f/2*th(13))*
     &       ( (1)/(f/4*th(13)/k(13)+(1-f)/2*th(13)/k(13)) )
          tjacob(39,39)=-1+deltime/(dens(13)*shc(13)*f/2*th(13))*
     &       ( -(4*sig*newt(39)**3)/((1.-emisfb)/emisfb)
     &                                -hhf*(1)+
     &       (-1)/(f/4*th(13)/k(13)+(1-f)/2*th(13)/k(13)) )
c
c
c jacobian analysis is done.  now put tjacob(i,j) into the global jacobian matrix
c jacob(ijacob,jjacob), where ijacob starts and ends at 79 and 117,
c and jjacob starts and ends at 79 and 117.  note:  most jacob values are 0's
c
```

```
c
c first transfer tjacob(42,42) into ttjacob(39,39) so that rows and columns
c 13, 14 and 15 are removed.
c
      isum1=0
      do 140 i=1,42
       if(i.eq.13.or.i.eq.14.or.i.eq.15)goto 140
       isum1=isum1+1
       isum2=0
       do 125 j=1,42
        if(j.eq.13.or.j.eq.14.or.j.eq.15)goto 125
        isum2=isum2+1
        ttjacob(isum1,isum2)=tjacob(i,j)
 125   continue
 140  continue
c
c now put ttjacob into the global jacob
c
      do 130 i=1,39
       do 130 j=1,39
        jacob(78+i,78+j)=ttjacob(i,j)
  130 continue
      return
      end
c
c
      subroutine tarmac2(ithtrial,itotitr,icool,iperiod,istep,ta,ttarm,
     &                                          hht,isolfoun)
c purpose: transient analysis of the tarmac
c called from: newraph2
c calls: none
      common/c4/widthwng,lengtwng,hwng,locwng,lplane,lfuselg,hfuselg,
     &          wfuselg
      common/c5/trnsm,absorbta,emista,tarmd,densta,conducta,shcta
      common/c2/tt(200),ffn(200),jacob(200,200)
      common/c3/tth(100),kk(100)
      common/c14/thicknes(100),density(100),conductv(100),sheatcap(100)
      common/reflecq/qreflin(6,100),qscabsin(6,100),qreflfwr(6,100),
     &qreflfwl(6,100),qscabfwr(6,100),qscabfwl(6,100),qabstwa1(6,100),
     &qabstwa2(6,100),qabstwb(6,100)
      common/temp5/t(1000)
      common/data1/deltime
      common/radiosit/jj(14)
      common/facttarm/fact
      common/result/temp(200),temptrn(200)
      dimension newt(100),fn(100)
      real jj,newt,lengtwng,jacob
      parameter(sig=.1714e-8)
      parameter(fpi=3.141593/180.)
      parameter(afact=1.0,bfact=0.00001)
c
```

```
c Variables:
c afact=cooling when door is opened: no motion: therefore tarmac temperature
c         underneath the wing remains very constant
c bfact=a small number to force the tarmac temperature underneath the wing
c         to be the same as the unsheltered tarmac temperature: in effect when
c         the aircraft is in motion
c
      if(itotitr.eq.1.and.istep.eq.1)then
      rlwng=(lengtwng-wfuselg)/2.
      endif
      if(istep.eq.1)then
c reference the initial temp.:
      t(51)=tt(51)
      t(52)=tt(52)
      t(53)=tt(53)
c make the initial guess for the new temperature newt(i)
      newt(51)=t(51)
      newt(52)=t(52)
      newt(53)=t(53)
c reference the initial radiosity
      jj(12)=tt(54)
      jj(13)=tt(55)
      jj(14)=tt(56)
      return
      endif
      if(ithtrial.eq.1)goto 65
       newt(51)=tt(117+1)
       newt(52)=tt(117+2)
       newt(53)=tt(117+3)
  65  if(isolfoun.eq.1)then
       if(ithtrial.eq.1)then
        newt(51)=tt(117+1)
        newt(52)=tt(117+2)
        newt(53)=tt(117+3)
            endif
       t(51)=newt(51)
       t(52)=newt(52)
       t(53)=newt(53)
       temptrn(51)=t(51)-459.67
       temptrn(52)=t(52)-459.67
       temptrn(53)=t(53)-459.67
       return
      endif
c
      if(icool.eq.1)fact1=afact
      if(icool.eq.2)fact1=bfact
c
c formulate transient cooling:
c
c LHS Wing/Tarmac t(51): global temperature tt(118): global fvec ffn(118)
c
```

```
          qnetsky=(sig*newt(51)**4-jj(12))/((1.-emista)/emista)
          fn(51)=
     &      -newt(51)+t(51)+deltime/(densta*rlwng*widthwng*tarmd*shcta)*
     &  ((qabstwa1(1,iperiod)-qnetsky-hht*(newt(51)-ta))*rlwng*widthwng+
     & 2.*(conducta/(fact1*fact*widthwng)*(ttarm-newt(51)))*tarmd*rlwng+
     &   conducta/(fact1*fact*widthwng)*(ttarm-newt(51))*tarmd*widthwng-
     &conducta/(.5*wfuselg+.5*rlwng)*(newt(51)-newt(52))*tarmd*widthwng)
c
c RHS Wing/Tarmac t(53): global temperature tt(120): global fvec ffn(120)
c
          qnetsky=(sig*newt(53)**4-jj(14))/((1.-emista)/emista)
          fn(53)=
     &      -newt(53)+t(53)+deltime/(densta*rlwng*widthwng*tarmd*shcta)*
     &  ((qabstwa2(1,iperiod)-qnetsky-hht*(newt(53)-ta))*rlwng*widthwng+
     & 2.*(conducta/(fact1*fact*widthwng)*(ttarm-newt(53)))*tarmd*rlwng+
     &   conducta/(fact1*fact*widthwng)*(ttarm-newt(53))*tarmd*widthwng-
     &conducta/(.5*wfuselg+.5*rlwng)*(newt(53)-newt(52))*tarmd*widthwng)
c
c MIDDLE Wing/Tarmac t(52): global temperature tt(119): global fvec ffn(119)
c
          qnetsky=(sig*newt(52)**4-jj(13))/((1.-emista)/emista)
          fn(52)=
     &    -newt(52)+t(52)+deltime/(densta*wfuselg*widthwng*tarmd*shcta)*
     & ((qabstwb(1,iperiod)-qnetsky-hht*(newt(52)-ta))*wfuselg*widthwng+
     &2.*(conducta/(fact1*fact*widthwng)*(ttarm-newt(51)))*tarmd*
     &                                        wfuselg+
     &conducta/(.5*wfuselg+.5*rlwng)*(newt(51)-newt(52))*tarmd*widthwng+
     &conducta/(.5*wfuselg+.5*rlwng)*(newt(53)-newt(52))*tarmd*widthwng)
c
c transfer fn(51),fn(52),fn(53) into the global vector ffn(118),ffn(119) and ffn(120)
c
      ffn(118)=fn(51)
      ffn(119)=fn(52)
      ffn(120)=fn(53)
c
c find the jacobians, tjacb and put it into the global jacobian(120,120)
c
c now find tjacb151 and tjacb152
c for LHS Wing/Tarmac t(51): global temperature tt(118): global fvec ffn(118)
c
      tjacb151=-1+deltime/(densta*rlwng*widthwng*tarmd*shcta)*
     &    ((-(4*sig*newt(51)**3)/((1.-emista)/emista)-hht*(1))*rlwng*
     &                                        widthwng+
     &     2.*(conducta/(fact1*fact*widthwng)*(-1))*tarmd*rlwng+
     &     conducta/(fact1*fact*widthwng)*(-1)*tarmd*widthwng-
     &     conducta/(.5*wfuselg+.5*rlwng)*(1)*tarmd*widthwng)
      tjacb152=deltime/(densta*rlwng*widthwng*tarmd*shcta)*
     &    (-conducta/(.5*wfuselg+.5*rlwng)*(-1)*tarmd*widthwng)
c
```

```
c now find tjacb251,tjacb252,tjacb253
c MIDDLE Wing/Tarmac t(52): global temperature tt(119): global fvec ffn(119)
c
      tjacb251=deltime/(densta*wfuselg*widthwng*tarmd*shcta)*
     &   ((2.*(conducta/(fact1*fact*widthwng)*(-1)))*tarmd*wfuselg
     &    +conducta/(.5*wfuselg+.5*rlwng)*(1)*tarmd*widthwng)
      tjacb252=-1+deltime/(densta*wfuselg*widthwng*tarmd*shcta)*
     &    ((-(4*sig*newt(52)**3)/((1.-emista)/emista)-hht*(1))*
     &                              wfuselg*widthwng
     &    +conducta/(.5*wfuselg+.5*rlwng)*(-1)*tarmd*widthwng+
     &    conducta/(.5*wfuselg+.5*rlwng)*(-1)*tarmd*widthwng)
      tjacb253=deltime/(densta*wfuselg*widthwng*tarmd*shcta)*
     &    (conducta/(.5*wfuselg+.5*rlwng)*(1)*tarmd*widthwng)
c
c now find tjacb352 and tjacb353
c RHS Wing/Tarmac t(53): global temperature tt(120): global fvec ffn(120)
c
      tjacb352=deltime/(densta*rlwng*widthwng*tarmd*shcta)*
     &    (-conducta/(.5*wfuselg+.5*rlwng)*(-1)*tarmd*widthwng)
      tjacb353=-1+deltime/(densta*rlwng*widthwng*tarmd*shcta)*
     &    ((-(4*sig*newt(53)**3)/((1.-emista)/emista)-hht*(1))*
     &                                rlwng*widthwng+
     &     2.*(conducta/(fact1*fact*widthwng)*(-1))*tarmd*rlwng+
     &     conducta/(fact1*fact*widthwng)*(-1)*tarmd*widthwng-
     &     conducta/(.5*wfuselg+.5*rlwng)*(1)*tarmd*widthwng)
c
c now put these jacobians into the global jacobian jacob(120,120)
c the jacobians are: for ffn(118):jacob(118,118);jacob(118,119);
c                 for ffn(119):jacob(119,118):jacob(119,119):jacob(119,120)
c                 for ffn(120):jacob(120,119):jacob(120,120)
c
      jacob(118,118)=tjacb151
      jacob(118,119)=tjacb152
      jacob(119,118)=tjacb251
      jacob(119,119)=tjacb252
      jacob(119,120)=tjacb253
      jacob(120,119)=tjacb352
      jacob(120,120)=tjacb353
      return
      end
c
```

A.3 REFERENCES.

A-1. Govindarajoo, N., "THERMOD, An Enhanced Thermal Model for Determining Aircraft Operational Temperatures User's Manual," FAA Report to be published.

A-2. MSC.NASTRAN 70.5, "Quick Reference Guide," MacNeal-Schwendler Corp., 815 Colorado Boulevard, Los Angeles, CA, 1998.