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Development of an Interface Program for Coupling Analysis of Thermal Transfer between Fluid and Structure

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1. INTRODUCTION

In the structural design of SSTs or spacecraft, the prediction of temperature of the structural surface is important. Coupling analysis of thermal transfer between fluid and structure is useful in this prediction. But such a coupling program has not been available commercially.

In the first year of this study, a two-dimensional coupling analysis program was developed for a structural model of the leading edge of a wing.

In the second year, a two-dimensional interface program and control program were developed. These two programs run with the fluid dynamics part of the coupling program developed in the first year, and one of the commercially available structural analysis programs.

In the final year, the transfer method of the interface program was modified. The program has been available to couple analyses between fluid and structure with the different size of boundary meshes each other.

The transfer method of the interface program was designed for extension to three-dimensional coupling analysis in the future.

2. METHOD OF DATA TRANSFER

At the boundary between fluid and structure, two types of data are transferred by the interface program. One is heat flux through the boundary from fluid to the structure, and the other is temperature through the boundary from structure to fluid.

Figure 1 shows the method for three-dimensional data transfer. The basic mechanism of the data transfer is that the value of point D is linearly interpolated or extrapolated among the values of three points A, B, C. Then points A, B, C are selected as the nearest three points to point D.

Now, 'V' in Figure 1 is assumed as the value of heat flux, point D is the center of the mass of a boundary element of the structure, and points A, B, and C are the centers of the mass of the cells of the fluid nearest to point D. The heat flux value of these points are V_D, V_A, V_B, and V_C. If the plane including points A, B, and C is defined as X-Y plane, the positions of these points are described as (X_D,Y_D), (X_A,Y_A), (X_B,Y_B), and (X_C,Y_C). But, (X_D,Y_D) is the position of point D that is projected on the X-Y plane normally.

The transfer from heat flux V_A, V_B, and V_C to V_D is

$$V_D = [C_A \ C_B \ C_C] \begin{vmatrix} V_A \\ V_B \\ V_C \end{vmatrix} \tag{1}$$

where C_A, C_B, and C_C are the coefficients of transfer and the function of position X and Y.

If the heat flux around the point is described as

$$V = [X \ Y \ 1] \begin{vmatrix} C_1 \\ C_2 \\ C_3 \end{vmatrix} . \tag{2}$$

Then, these coefficients C_1, C_2, and C_3 are obtained from the following equation.

$$\begin{vmatrix} C_1 \\ C_2 \\ C_3 \end{vmatrix} = \begin{vmatrix} X_A & Y_A & 1 \\ X_B & Y_B & 1 \\ X_C & Y_C & 1 \end{vmatrix}^{-1} \begin{vmatrix} V_A \\ V_B \\ V_C \end{vmatrix} \tag{3}$$

According to equations (2), and (3), coefficients C_A, C_B, and C_C in equation (1), which transfer the heat flux from fluid to structure, are obtained from the following equation.

$$[C_A \ C_B \ C_C] = [X_D \ Y_D \ 1] \begin{vmatrix} X_A & Y_A & 1 \\ X_B & Y_B & 1 \\ X_C & Y_C & 1 \end{vmatrix}^{-1} \tag{4}$$

Similarly to the above formulation about heat flux, if 'V' in Figure 1 is assumed as the value of temperature, the coefficients C_A, C_B, and C_C which transfer the temperature from structure to fluid, are obtained from equation(4).

Point D is the center of the mass of boundary cells of the fluid, and points A, B, and C are the centers of the mass of the element of the structure nearest to point D. And the temperature value of these points are V_D, V_A, V_B, and V_C.

3. SYSTEM OF COUPLING ANALYSIS

The system of coupling analysis consists of a fluid analysis program, a structural analysis program, interface programs, a control program, and a transfer coefficients generation program. Figure 2 shows the flow-chart of the system.

The fluid analysis program is 'HYPER-2d' which was developed in the first step of this study. The structural analysis program is 'MSC/NASTRAN-PWS' which is one of the commercially available programs.

In each step of execution of 'HYPER-2d', the temperature of the surface of the structure is assumed to be constant. And in each step of execution of 'MSC/NASTRAN-PWS', the heat flux from the fluid is assumed to be constant.

Interface programs 'HT2A3' and 'HT2B3' have been created in FORTRAN77. 'HT2A3' transfers the heat flux from fluid to structure, and 'HT2B3' transfers the temperature from structure to fluid. Figures 3 and 4 show these flow-charts.

The control program 'HEAD3' has been created in C-Shell. 'MSC/NASTRAN-PWS' exists on one engineering-work-station(EWS), and 'HYPER-2d', 'HT2A3', 'HT2B3' and 'HEAD3' exist on the other EWS. These two EWS are connected on the network. 'HEAD3' controls the loop of executions of 'HYPER-2d', 'HT2A3', 'MSC/NASTRAN-PWS', and 'HT2B3'.

The transfer coefficients generation program 'HT2C3' is created in FORTRAN77. 'HT2C3' reads the point position data on both boundary of fluid and structure, and generates the transfer coefficients by using equation (4). Figure 5 shows the flow-chart of 'HT2C3'.

4. EXAMPLE ANALYSIS

Two example analyses, (a) and (b), were executed to compare the data transfer. The difference between the two models is the meshes between the cells of the fluid and the elements of structure on the boundary.

Figure 6 shows two models. Figure 7 shows the result of the analysis. The difference in temperature was 0.11K at the end.

Conditions:

Mach number: 6.47, structure: a stainless steal column of 3.81 cm radius outside and 2.54 cm radius inside; initial temperature: 294.44K, time step: 0.1sec; end time: 2.0sec, meshes on fluid: 25 $\times$ 60, meshes on structure: (a);25$\times$ 6,(b);20$\times$ 6, number of convergence loops in a step of 'HYPER-2d': 300

5. CONCLUSIONS

The transfer method of the interface program was designed for extension to three-dimensional coupling analysis of fluid in the future. The method is also available to couple analyses between fluid and structure with the different size of boundary meshes each other.

A two-dimensional interface program was developed using the above method, and demonstrated the effectiveness of the method.

A three-dimensional coupling analysis system will be developed by using 'HYPER-3d' on the super-computer and the method designed here.

REFERENCES

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3) K.Ohtake, et al., "Management System for Coupling Analysis of Aerodynamically Heat and Structural Thermal Transfer", NAL J94004, pp.55-123, Oct.1994.

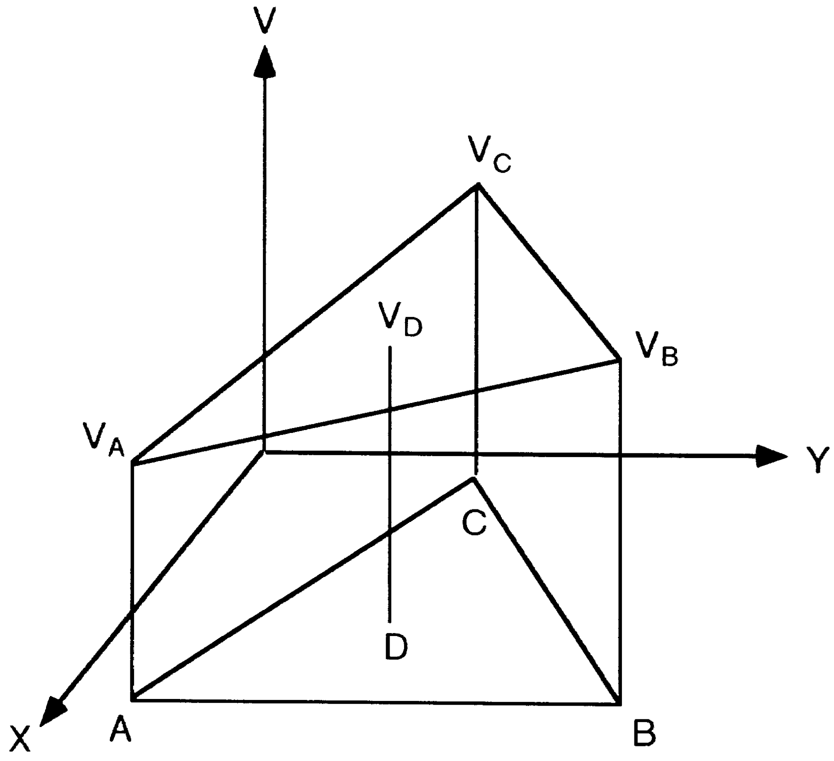

Figure 1 Method of data transfer

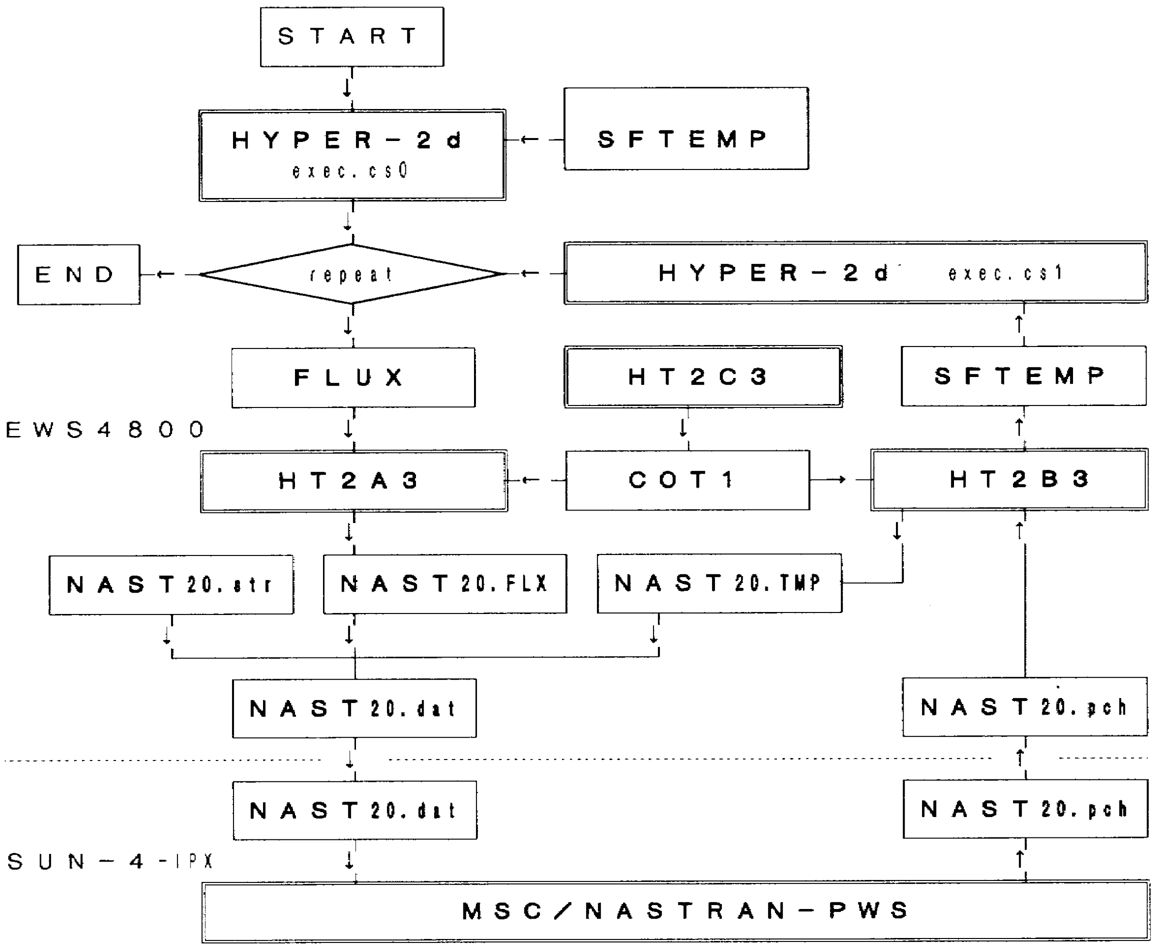

Figure 2 Flow-chart ofthe management sysytem for the two-dimensional coupling analysis

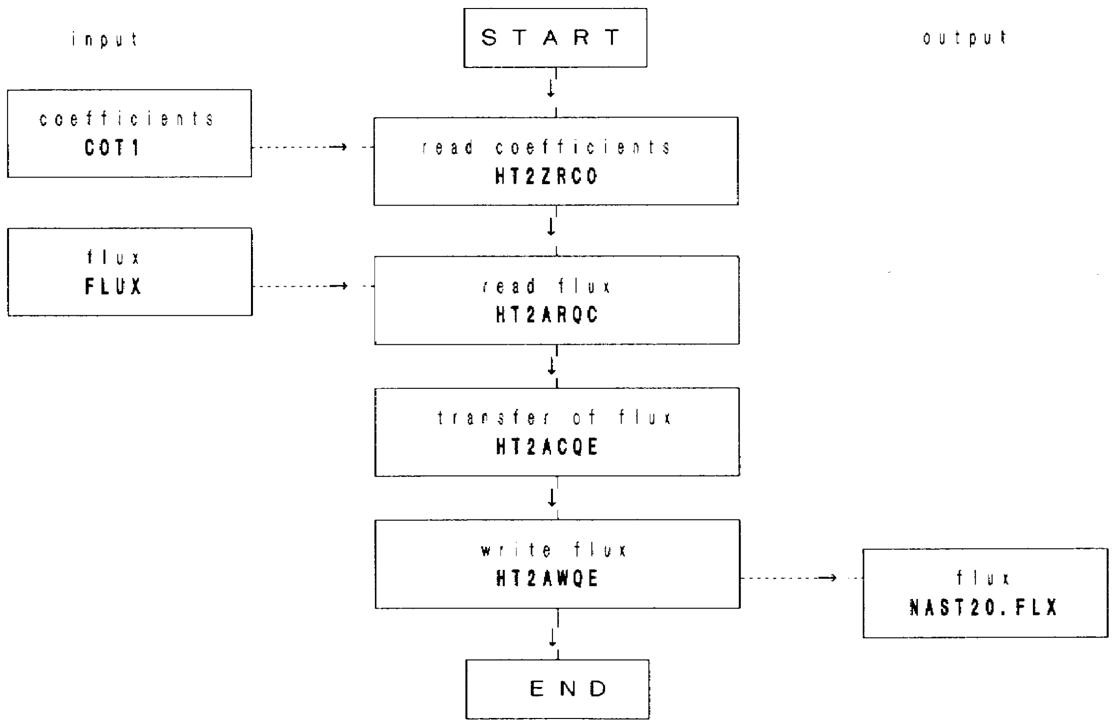

Figure 3 Flow-chart of the program(HT2A3) which transfers the heat flux from fluid to structure

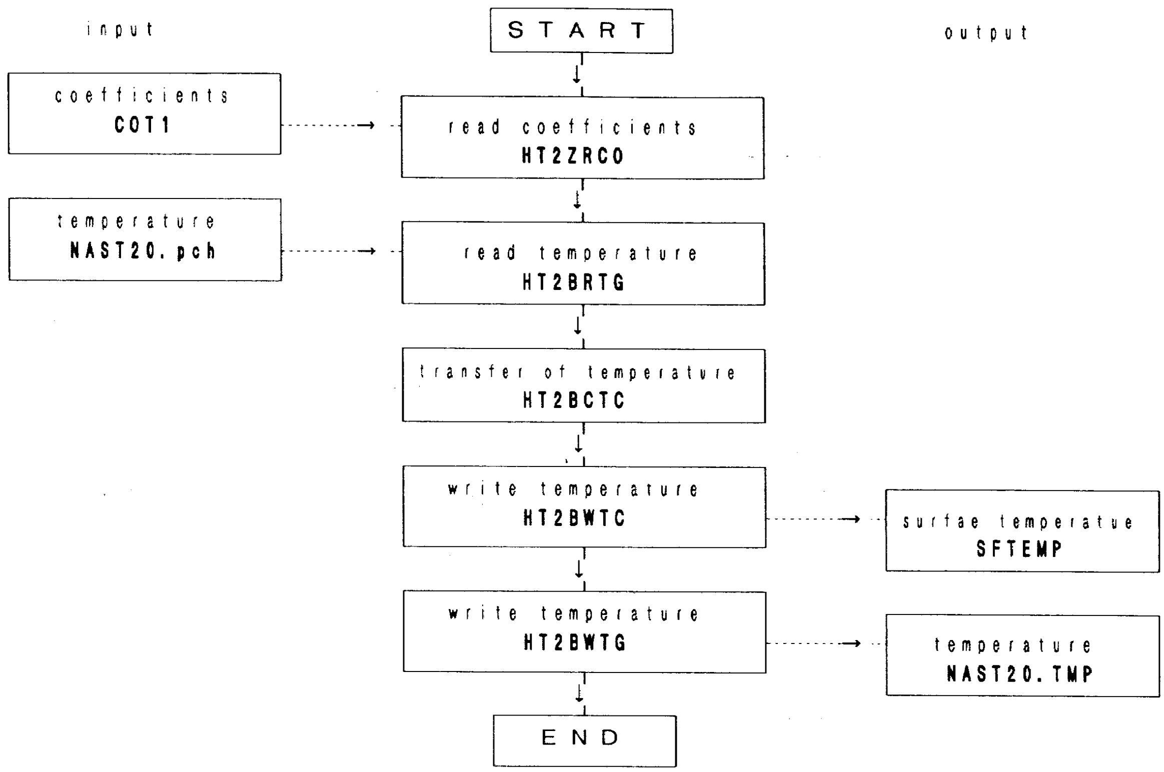

Figure 4 Flow-chart of the program which transfers the temperature from structure to fluid

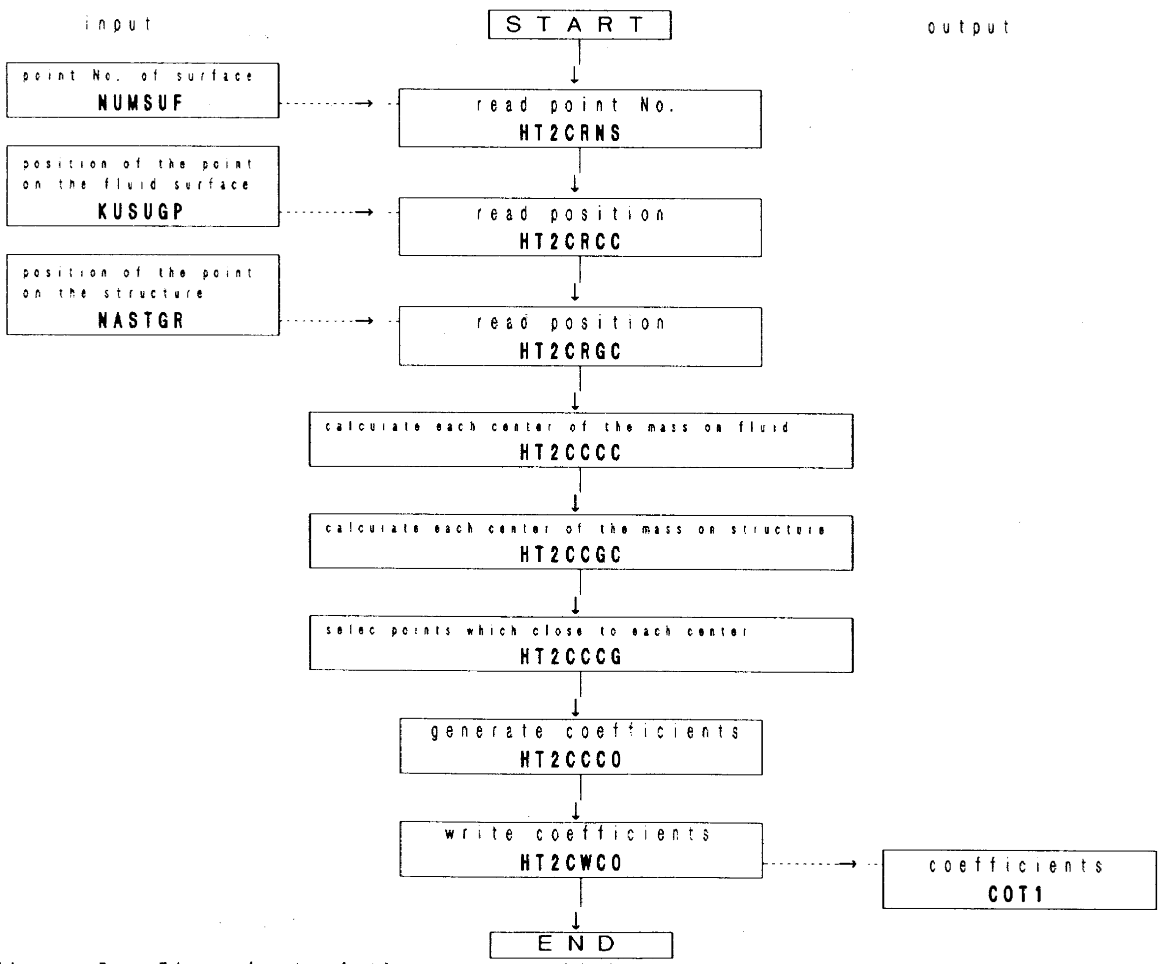

Figure 5 Flow-chart of the program which generates the transfer coefficients

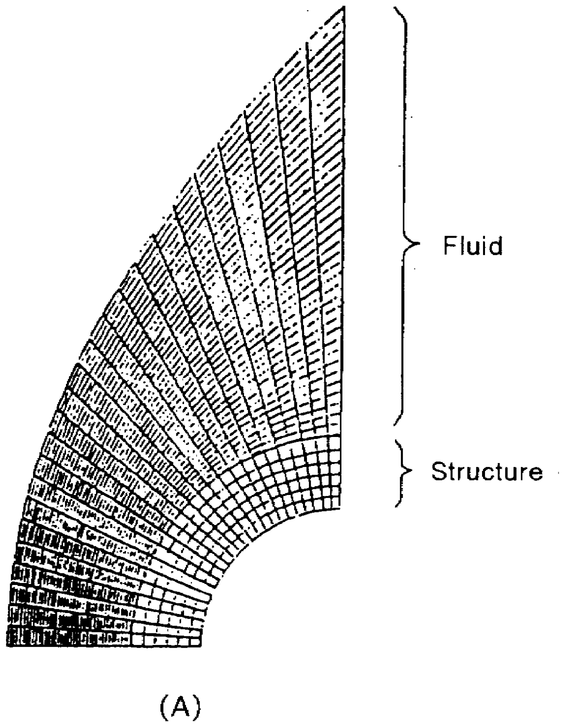

Figure 6 Analysis model

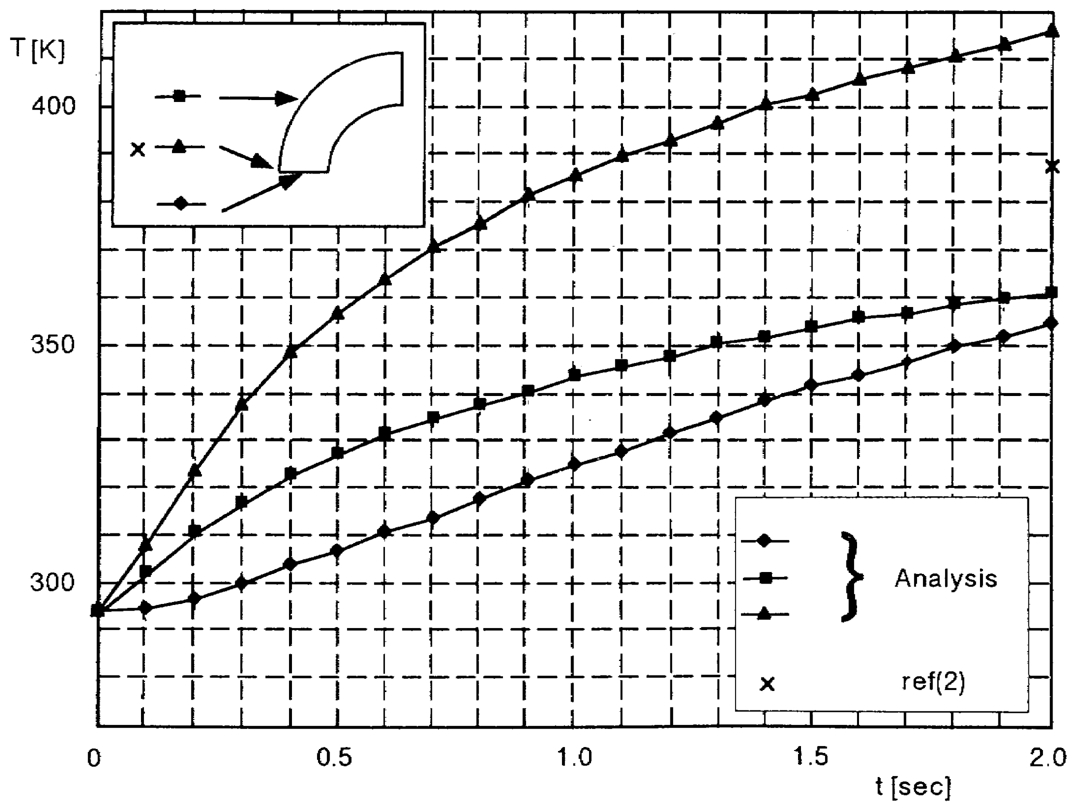

Figure 7 Time history of temperature