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## MATHEMATICAL ANALYSIS OF HEAT CONDUCTION IN A SECTOR OF A HOLLOW CIRCULAR CYLINDER

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#### FOREWORD

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This final technical report was prepared by the Martin Company, Orlando Division, Orlando, Florida, under Air Force Contract No. AF 33(615)-2385. The contract, sponsored by Technical Area 750A, Mechanics of Flight, was accomplished under Project 1467, Structural Analysis Methods. It was administered under the Structures Division, Air Force Flight Dynamics Laboratory, Deputy Commander/Technology, RTD, with Mr. T. N. Bernstein, (FDTR), acting as Project Engineer.

This report (contractor's report No. OR 8042) was completed in March 1966 and covers the work performed from March 1965 to January 1966. Mathematical analysis and development were conducted by Mr. J. G. Torian under the supervision of Mr. J. I. Gonzalez, Head of the Fluid Dynamics, Heat, and Mass Transfer Section in the Engineering Mechanics Research Laboratory, Martin Company. The digital programming was performed by Mr. V. T. Murphy under the supervision of Mr. C. J. Gentry of the Scientific Computer Applications Department.

This technical report has been reviewed and is approved.

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#### ABSTRACT

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This study was undertaken to develop an analytical method of determining temperature distribution in a sector of a hollow circular cylinder, with temperature dependent thermophysical properties, based on an exact mathematical solution. The subject non-linear differential equation is reduced to a linear differential equation by an integral transform and with the assumption that only the thermal conductivity is a function of temperature, whereas the thermal diffusivity remains constant. The solution has been programmed in FORTRAN IV for application to an IBM 7094. In addition, a successive transform applicable to the solution of similar problems involving temperature dependent thermal diffusivity is illustrated and discussed.

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### SYMBOLS

Mathematical	Program Counterpart	Use	
v		real temperature	
т		transform temperature	
r		radius	
φ		angle	
θ		time	
λ		dummy time variable	
K(v)		thermal conductivity	
ρ		density	
C(v)		specific heat	
α	ALPHØ	thermal diffusivity	
r <sub>1</sub>	ARE(1)	inner radius	
r <sub>2</sub>	ARE(2)	outer radius	
ф <sub>1</sub>	PHI(1)	lower angular boundary (equal to zero)	
ф <sub>2</sub>	PHI(2)	upper angular boundary	
ĸ	AZERØ	thermal conductivity at v equal zero	
γ	GAMMØS(i)	angular eigenvalue	
β	BAYTØS(i)	radial eigenvalue	
£	EPILØN(i)	radial eigenvalue	
Α <sub>γ</sub> β	ARBA(i,j)	arbitrary coefficient	
в <sub>у</sub>	BSUB(i)	arbitrary coefficient	
$G_{\gamma\beta}$	ARBG(i,j)	arbitrary coefficient	

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F Y	FSUB(i)	arbitrary coefficient
F <sub>e</sub>	AF(i)	arbitrary coefficient
M <sub>e</sub>	AM(i)	arbitrary coefficient
1 <sub>11</sub>	AL(1,1)	boundary condition indicator
1.12 International Internation	AL(1,2)	boundary condition indicator
<i>L</i> <sub>21</sub>	AL(2,1)	boundary condition indicator
1 <sub>22</sub>	AL(2,2)	boundary condition indicator
<sup>k</sup> 11	AK(1,1)	boundary condition indicator
<sup>k</sup> 12	AK(1,2)	boundary condition indicator
<sup>k</sup> 21	AK(2,1)	boundary condition indicator
<sup>k</sup> 22	AK(2,2)	boundary condition indicator
b	BEE	constant used in definition of K(v)
c	SEE	constant used in definition of K(v)
f <sub>r1</sub> (\$)	FARE1(i)	coordinate varying boundary condition in real temperature at r <sub>1</sub>
f <sub>r2</sub> (φ)	FARE2(i)	coordinate varying boundary condition in real temperature at r2
f <sub>q1</sub> (r)	FPHI1(i)	coordinate varying boundary condition in real temperature at $\phi_1$
f <sub>q2</sub> (r)	FPHI2(i)	coordinate varying boundary condition in real temperature at $\phi_2$
F <sub>r1</sub> (φ)	FARE1(i)	coordinate varying boundary conditions in transform variable at r <sub>1</sub>
F <sub>r2</sub> (φ)	FARE2(i)	coordinate varying boundary conditions in transform variable at $r_2$
F <sub>ф1</sub> (r)	FPHI1(i)	coordinate varying boundary conditions in transform variable at $\phi_1$
F <sub>¢2</sub> (r)	FPHI2(i)	coordinate varying boundary conditions in transform variable at $\phi_2$

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h(r,φ)	DZERØ(i,j)	initial temperature distribution in real temperature
f(r,	STEADY(i,j)	steady state solution
Υ[v]		transform of real temperature
Λ <b>[T</b> ]		inversion of transform temperature
$T_i(\theta, r, \phi)$	TERMA	initial temperature distribution solution in transform variable
$T_{s}^{(\theta,r,\phi)}$	-TERMB+ g(θ)f(r,φ)	surface effects solution in transform variable
ξ	XI	function as defined in text
Ξ(ν,θ,r,φ)		transform time function
Ω(v,ψ,r,φ)		inversion of time function
$J_{\gamma}(\beta r)$		Bessel function of first kind and order $\boldsymbol{\gamma}$
$Y_{\gamma}(\beta r)$		Bessel function of second kind and order $\boldsymbol{\gamma}$
$J'_{\gamma}(\beta r)$		$\frac{\partial}{\partial\beta} J_{\gamma} (\beta r)$
$Y'_{\gamma}(\beta r)$		$\frac{\partial}{\partial\beta} Y_{\gamma}(\beta r)$
g(θ)	GTHETA	time function
ψ		transform time

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#### SECTION I

#### INTRODUCTION

This study was undertaken to develop an analytical method for determining temperature distribution in a sector of a hollow circular cylinder, with temperature dependent thermophysical properties, based on an exact mathematical solution. The subject non-linear differential equation was reduced to a linear differential equation by an integral transform with the assumption that only the thermal conductivity is a function of temperature, whereas the thermal diffusivity remains constant.

The integral transform method used in linearizing the equations is presented in Reference 1. Carslaw and Jaeger attribute the method, as applied to transient problems, to Van Dusen (1930) and note that the method as applied to steady heat flow dates back to 1894 (Kirchhoff). The Russian authors, Kudryashev and Zhemkov (Reference 2), rediscovered the method in 1963. They present a method of solution to problems involving temperature dependent thermal diffusivity using a successive transform. The formulation of these methods to analysis of two-dimensional transient heat conduction in a segment of a hollow circular cylinder is presented in Section IIA of this report.

The resulting linear differential equation, initial temperature distribution, and coordinate and time varying boundary conditions constitute a Sturm-Liouville System in the transform variable. A series solution of the linear system, as applicable to hollow semicircular cylinders, is presented by Luzzi (Reference 3) and by Torian (Reference 4) as applicable to hollow sectors of cylinders. Section IIB of this report presents a revised solution to the linear system based on Reference 4. The revisions are directed primarily toward greater applicability to calculations on a digital computer.

The solution of the linear system is applicable to either the temperature dependent or constant thermal diffusivity case. A digital computer program was developed based on this system as applicable to the temperature dependent thermal conductivity, constant diffusivity case. Mathematical formulation is given in Section IIB. A discussion of the digital program is given in Section III. The authors' comments on mathematical formulation of the temperature dependent thermal diffusivity case are included in Section IIC and the latter part of Section IIA.

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The utilization of the computer program is given in Section IIIB. A detailed description of the program is provided in Section IIIA, and Section IV shows its application to typical sample problems.

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#### SECTION II

#### MATHEMATICAL FORMULATION

#### A. TRANSFORMATION OF THE NON-LINEAR EQUATION

The differential equation to be solved is

$$\rho C(\mathbf{v}) \frac{\partial \mathbf{v}}{\partial \theta} = K(\mathbf{v}) \left[ \frac{\partial^2 \mathbf{v}}{\partial \mathbf{r}^2} + \frac{1}{r^2} \frac{\partial^2 \mathbf{v}}{\partial \theta^2} + \frac{1}{r} \frac{\partial \mathbf{v}}{\partial \mathbf{r}} \right] + \frac{\partial K(\mathbf{v})}{\partial \mathbf{v}} \left[ \frac{1}{r^2} \left( \frac{\partial \mathbf{v}}{\partial \phi} \right)^2 + \left( \frac{\partial \mathbf{v}}{\partial \mathbf{r}} \right)^2 \right]$$
(1)

where the initial condition is

$$v(0,r,\phi) = h(r_1\phi)$$
(2)

and the coordinate and time varying surface conditions (Figure 1) are:

 $\frac{1}{-K(v)} \frac{\partial v}{\partial \phi} = r f_{\phi 1}(r) g(\theta)$ (3)

(representing a coordinate and time varying heat flux at this surface), or

$$v = f_{b1}(r) g(\theta)$$
(4)

(representing a coordinate and time varying temperature at this surface);

 $\frac{2}{2}$  At  $\phi_2$ 

$$K(v) \frac{\partial v}{\partial \phi} = r f_{\phi 2}(r) g(\theta)$$
(5)

(representing a coordinate and time varying heat flux at this surface), or

$$v = f_{\phi 2}(r) g(\theta)$$
 (6)

(representing a coordinate and time varying temperature at this surface); Contrails

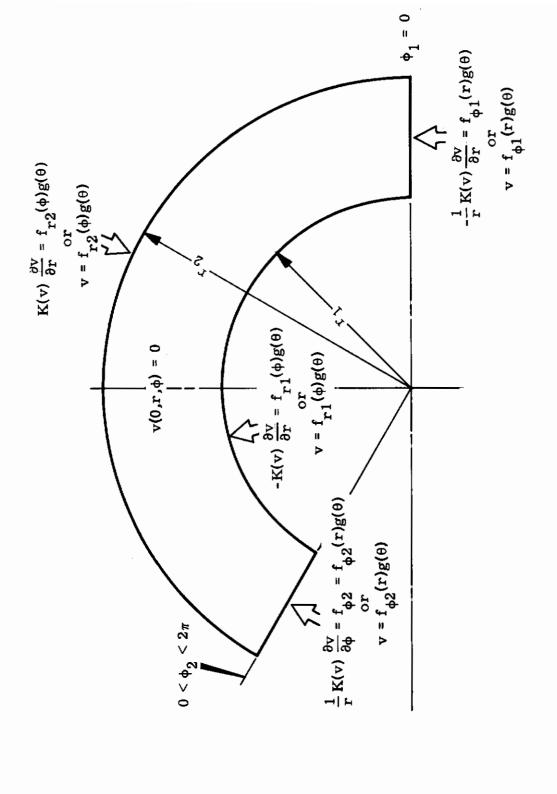


Figure 1. Mathematical Model

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 $\underline{3}$  At  $\mathbf{r}_1$ 

$$-K(v) \frac{\partial v}{\partial r} = f_{r1}(\phi) g(\theta)$$
(7)

(representing a coordinate and time varying heat flux at this surface), or

$$v = f_{p_1}(\phi) g(\theta)$$
(8)

(representing a coordinate and time varying temperature at this surface);

 $\frac{4}{2}$  At r<sub>2</sub>

$$K(v) \frac{\partial v}{\partial r} = f_{r2}(\phi) g(\theta)$$
(9)

(representing a coordinate and time varying heat flux at this surface), or

$$v = f_{r2}(\phi) g(\theta)$$
(10)

(representing a coordinate and time varying temperature at this surface).

By the methods of Reference 1, a new variable is introduced:

T = 
$$\frac{1}{K_0} \int_0^V K(v) dv$$
, (11)

where K(v) is the thermal conductivity expressed as a function of temperature v, and  $K_0$  is the value of K(v) at v equal to zero. We write

$$\mathbf{T} = \Upsilon \left[ \mathbf{v} \right] \tag{12}$$

after integrating Equation (11). The inversion may be written as

$$\mathbf{v} = \boldsymbol{\Lambda} \left[ \mathbf{T} \right] \,. \tag{13}$$

When Equation (1) is rewritten in terms of the new variable, we obtain:

$$\frac{\rho C(v)}{K(v)} \frac{\partial T}{\partial \theta} = \frac{\partial^2 T}{\partial r^2} + \frac{1}{r^2} \frac{\partial^2 T}{\partial \phi^2} + \frac{1}{r} \frac{\partial T}{\partial r}.$$
(14)

If we restrict the variation of K(v) and C(v) such that

$$\frac{\rho C(v)}{K(v)} = \text{ constant } = \frac{1}{\alpha},$$

which is indicative of constant thermal diffusivity, Equation (14) becomes

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$$\frac{1}{\alpha}\frac{\partial T}{\partial \theta} = \frac{\partial^2 T}{\partial r^2} + \frac{1}{r^2}\frac{\partial^2 T}{\partial \phi^2} + \frac{1}{r}\frac{\partial T}{\partial r}$$
(15)

and the initial condition becomes

$$T(0,r,\phi) = T[h(r,\phi)]; \qquad (16)$$

the boundary conditions, Equations (3) through (10), become:

 $\frac{1}{-K_{o}} \frac{\partial T}{\partial \phi} = r f_{\phi 1}(r) g(\theta)$ (17)

 $\mathbf{or}$ 

$$\mathbf{T} = \mathbf{T} \left[ \mathbf{f}_{\phi 1}(\mathbf{r}) \ \mathbf{g}(\theta) \right] ; \tag{18}$$

 $\frac{2}{2}$  At  $\phi_2$ 

$$K_{0} \frac{\partial T}{\partial \phi} = r f_{\phi 2}(r) g(\theta)$$
(19)

 $\mathbf{or}$ 

$$T = T \left[ f_{\phi 2}(r) g(\phi) \right]; \qquad (20)$$

 $\frac{3}{2}$  At r<sub>1</sub>

$$K_{o} \frac{\partial T}{\partial r} = f_{r1}(\phi) g(\theta)$$
(21)

 $\mathbf{or}$ 

$$T = \Upsilon \left[ f_{r1}(\phi) g(\theta) \right];$$
(22)

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 $\frac{4}{2}$  At r<sub>2</sub>

$$K_{0} \frac{\partial T}{\partial r} = f_{r2}(\phi) g(\theta)$$
(23)

 $\mathbf{or}$ 

$$T = T \left[ f_{r2}(\phi) g(\theta) \right].$$
(24)

A solution of the system of Equations (1) through (10) can be obtained for the temperature dependent thermal conductivity (constant diffusivity) case by transforming these equations to a linear system, Equations (15) through (24). When a solution to the linear system for r,  $\phi$ , and  $\theta$  in the transform temperature (T) is obtained, a solution to the non-linear system can be obtained for r,  $\phi$ , and  $\theta$  in the real temperature (v) by application of the inversion from Equation (13).

To proceed with solution of the temperature dependent thermal diffusivity case, we introduce the new variable

$$\psi = \int_{0}^{\theta} \frac{K(\mathbf{v})}{\rho C(\mathbf{v})} d\theta.$$
 (25)

Then

$$\frac{\partial T}{\partial \theta} = \frac{\partial T}{\partial \psi} \frac{\partial \psi}{\partial \theta} = \frac{K(v)}{\rho C(v)} \frac{\partial T}{\partial \psi}$$
(26)

 $\mathbf{or}$ 

$$\frac{\rho C(\mathbf{v})}{K(\mathbf{v})} \frac{\partial T}{\partial \theta} = \frac{\partial T}{\partial \psi}.$$
(27)

When Equation (27) is inserted in Equation (14), we obtain

$$\frac{\partial T}{\partial \psi} = \frac{\partial^2 T}{\partial r^2} + \frac{1}{r^2} \frac{\partial^2 T}{\partial \phi^2} + \frac{1}{r} \frac{\partial T}{\partial r}$$
(28)

which is a linear differential equation similar to Equation (15) except in a transform time variable ( $\psi$ ) rather than real time ( $\theta$ ). (The method of reducing non-linear diffusion Equation (14) to linear diffusion Equation (28) is based on the work of Kudryashev and Zhemkov in Reference 2.)

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Equation (25) may be written

$$\psi = \int_{0}^{\theta} \alpha \left[ \Lambda(\mathbf{T}) \right] d\theta = \Xi (\mathbf{v}, \theta, \mathbf{r}, \phi)$$
(29)

where

$$\frac{K(\mathbf{v})}{\rho C(\mathbf{v})} = \alpha(\mathbf{v}) = \alpha \left[ \Lambda(\mathbf{T}) \right].$$
(30)

Then

$$\theta = \int_{0}^{\psi} \frac{d\psi}{\alpha[\Lambda(T)]} = \Omega(\mathbf{v}, \psi, \mathbf{r}, \phi)$$
(31)

is the inversion to real time in the transform temperature (T).

Although the differential equation in the transform time variable is linear, the real problem can only be transformed into a complete linear system (including the boundary conditions) for certain cases of the boundary conditions. This is a result of the requirements for transformation of the time function  $g(\theta)$  into a new function in the transform time variable ( $\psi$ ). For a prescribed coordinate and time varying temperature at a surface, the transformation, Equation (29), can be accomplished since the transform temperature\* is known. A coordinate varying heat flux may be prescribed at a surface, but variation with time is disallowed since the surface temperature is not known and the transformation of the boundary conditions in terms of the new time variable cannot be accomplished.

For a typical coordinate and time varying temperature at a surface in the form

$$\mathbf{v}_{s} = \mathbf{f}_{1}(\mathbf{r}, \boldsymbol{\theta}), \tag{32}$$

\*The transforms can be made in terms of the real temperature by noting that an equivalent form of Equation (29) is

$$\psi = \int_0^{\theta} \alpha(\mathbf{v}) \, \mathrm{d}\theta \, .$$

the transformation in temperature is

$$T = T[f_1(r,\theta)].$$
(33)

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The succeeding transformation in time is

$$T = T \left[ f_2(r, \psi) \right] , \qquad (34)$$

where the functions  $f_1$  and  $f_2$  are related through Equation (29).

From the preceding, it is concluded that a solution to a system of equations similar to Equations (1) through (10) can also be solved by exact methods (excluding prescribed time varying flux at a surface) for the case of temperature dependent thermal diffusivity. The non-linear system is reduced to a linear system by two successive transformations. Obtaining a solution to the linear system at r and in terms of the transform temperature and time variable, T and  $\psi$ , successive inversions are applied to obtain the solution in the real temperature and time.

#### B. SOLUTION OF THE TEMPERATURE DEPENDENT THERMAL CONDUCTIVITY, CONSTANT DIFFUSIVITY CASE

#### 1. Transformation and Inversion

The solution of the subject problem involving temperature dependent thermal conductivity requires a transformation of the initial and boundary conditions to the transform variable and a corresponding inversion from transform temperature to real temperature. This transformation and inversion, as used in this report, is independent of the coordinate system or the form of the initial and boundary conditions. It depends only on the relationship of thermal conductivity to real temperature. This section discusses various forms of the relationship between thermal conductivity and real temperature and presents the corresponding transformation and inversion.

For various algebraic relations of thermal conductivity to real temperature, Equation (11) can be manipulated to provide an algebraic expression for the transform temperature. This equation can then be solved for real temperature to provide the inversion of Equation (13). Five such cases were prepared for incorporation in the digital computer program. The expression for thermal conductivity and the corresponding transformation and inversion expressions are given in Table I.

Data obtained from a curve of thermal conductivity versus temperature, which cannot be curve fit by one of the expressions on Table I, may be integrated numerically to obtain the relationship between real and transform



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Transform and Inversion Relations

K(v)	Ϋ́ν	Л(Т)
Case 1 K(v) = K <sub>0</sub> exp(-bv)	$T = \frac{1}{b} 1 - \exp(-bv)$	$\mathbf{v} = -\frac{1}{b}\ln\left[1 - bT\right]$
Case 2 $K(v) = \frac{K_o}{1 + bv + cv^2}$		
$q = 4c - b^2$		
A. q < 0, c > 0	$T = \frac{1}{\sqrt{-q}} \ln \left[ \frac{\frac{2cv}{b - \sqrt{-q}} + 1}{\frac{2cv}{b + \sqrt{-q}} + 1} \right]$	$v = \frac{(b + \sqrt{-q}) X - b + \sqrt{-q}}{2c \left[1 - X\right]}$ where
B. q = 0 c>0	$T = 2\left[\frac{1}{b} - \frac{1}{2cv + b}\right]$	$X = \exp(\sqrt{-q} T) \left[ \frac{b - \sqrt{-q}}{b + \sqrt{-q}} \right]$ $v = \frac{bT}{2 \left[ 2 \frac{c}{b} - cT \right]}$
C. q>0 c>0	$T = \frac{2}{\sqrt{q}} \left[ \tan^{-1} \frac{2cv + b}{\sqrt{q}} - \tan^{-1} \frac{b}{\sqrt{q}} \right]$	$v = \sqrt{\frac{q}{2c}}  Y = \frac{b}{2c}$ where
		$Y = \frac{\tan \frac{\sqrt{q} T}{2} + \frac{b}{\sqrt{q}}}{1 - \frac{b}{\sqrt{q}} \tan \frac{\sqrt{q} T}{2}}$
Case 3 $K(v) = \frac{K_o}{1+bv}$	$T = \frac{1}{b} \ln (1 + bv)$	$v = \frac{1}{b} (\exp(bT) - 1)$
Case 4 $K(v) = K_0 (1+bv)$	$T = v + \frac{b}{2} v^2$	$\mathbf{v} = -\frac{1}{b} + \frac{1}{b}\sqrt{1 + 2bT}$
Case 5 K(v) = K <sub>o</sub>	T = v	$\mathbf{v} = \mathbf{T}$

temperature. The resulting data when plotted can be used for both the transformation and inversion process.

A third form of the relationship between thermal conductivity and real temperature, which combines the input simplicity of the algebraic expressions with the flexibility of the numerical integration of data points, may be obtained by writing n exponential terms in the form

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$$K(v) = \sum_{i=1}^{n} a_{i} v^{i}; \qquad (35)$$

then

$$T = \frac{1}{K_{o}} \begin{bmatrix} n & a_{i} & b_{i}^{-1} \\ \sum_{i=1}^{o} \frac{b_{i}^{-1}}{b_{i}^{-1}} & v \end{bmatrix}.$$
 (36)

At this point a curve should be prepared based on Equation (36) and used for the inversion process, since a general expression for the inversion in Equation (13) cannot be written directly from Equation (36).

Regardless of the form of relationship of thermal conductivity to real temperature, the thermal conductivity must be greater than zero over the range of temperatures involved in the particular problem. It is obvious that no one would suggest a negative or zero thermal conductivity in a practical problem. However, when using algebraic relations of higher orders to curve fit given data on thermal conductivity, care should be taken to ensure that the function is positive over the argumented range of temperatures. Abrupt maxima or minima should also be avoided when using forms other than the algebraic cases of Table I. This is not a mathematical restriction in the strict sense; however, maxima or minima in the thermal conductivity curve produce "flat spots" in the curve of transform versus real temperature with attendant inaccuracies in the numerical inversion process.

In the preceding sections, the solution to the subject problem will be solved by the principle of superposition in two parts,  $T_i$  and  $T_s$ , where  $T_i$  is the solution resulting from the initial temperature distribution effects, and  $T_s$  is the solution resulting from the coordinate and time varying surface conditions. The inversion process is applied to the sum of  $T_i$  and  $T_s$ . That is

$$\mathbf{V} = \mathbf{\Lambda} \begin{bmatrix} \mathbf{T}_{i} + \mathbf{T}_{s} \end{bmatrix}. \tag{37}$$

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#### 2. Solution of the Transformed Equation

The solution of the linear system, Equations (15) through (24), may (by the principle of superposition) be expressed as the sum of the solution resulting from the initial temperature distribution with homogeneous boundary conditions and the solution resulting from the prescribed boundary condition with zero initial temperature distribution. These two solutions are discussed separately in the following paragraphs.

#### a. Initial Temperature Distribution Effects

The system of equations to be solved is

$$\frac{1}{\alpha}\frac{\partial T_{i}}{\partial \theta} = \frac{\partial^{2} T_{i}}{\partial r^{2}} + \frac{1}{r^{2}}\frac{\partial^{2} T}{\partial \phi^{2}} + \frac{1}{r}\frac{\partial T}{\partial r}$$
(38)

with the initial condition

$$T_{i}(0,r,\phi) = T[h(r,\phi)]$$
(39)

and the boundary conditions

$$k_{11} \frac{\partial T_i}{\partial \phi} + k_{12} T_i = 0 \quad \text{at } \phi_1, \qquad (40)$$

$$k_{21} \frac{\partial T_{i}}{\partial \phi} + k_{22} T_{i} = 0 \quad \text{at } \phi_{2}, \qquad (41)$$

$$\boldsymbol{\ell}_{11} \frac{\partial \boldsymbol{\Gamma}_{i}}{\partial \boldsymbol{r}} + \boldsymbol{\ell}_{12} \boldsymbol{T}_{i} = 0 \quad \text{at } \boldsymbol{r}_{1}, \qquad (42)$$

and

$$\boldsymbol{I}_{21} \frac{\partial \mathbf{T}_{i}}{\partial \mathbf{r}} + \boldsymbol{I}_{22} \mathbf{T}_{i} = 0 \quad \text{at } \mathbf{r}_{2}.$$
(43)

Note that the boundary conditions of Equations (40) through (43) are expressed in a general form involving constants  $k_{ij}$  and  $l_{ij}$  which may be selected as zero or unity to prescribe heat flux or temperature at the subject boundary.

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The solution to the system of Equations (38) through (43) may be written, based on the author's previous work in Reference 4, as

$$T(\theta, \mathbf{r}, \phi) = \sum_{\gamma \beta} \sum_{\beta} A_{\gamma\beta} \left[ B_{\gamma} \sin \gamma \phi + F_{\gamma} \cos \phi \right]$$
$$x \left[ C_{\gamma\beta} J_{\gamma}(\beta \mathbf{r}) + Y_{\gamma}(\beta \mathbf{r}) \right] e^{-\alpha \beta^2 \theta}$$
(44)

where  $\gamma^{\,\prime}s$  are the real positive roots of

Equation (45) may be solved to obtain an explicit expression for  $\gamma$  under various combinations of boundary conditions.

If 
$$k_{12} = k_{22} \neq 0$$
, (46)

then

$$\gamma = \frac{n\pi}{\phi_2 - \phi_1}; n = 1, 2, 3...$$
(47)

If 
$$k_{12} = k_{22} = 0$$
, (48)

then

$$\gamma = \frac{n\pi}{\phi_2 - \phi_1}; n = 0, 1, 2, \dots$$
 (49)

If 
$$k_{12} \neq k_{22}$$
, (50)

then

$$\gamma = \frac{\frac{\pi}{2}(2n+1)}{\phi_2 - \phi_1}; n = 0, 1, 2, \dots$$
 (51)

The  $\beta$ 's are the real positive roots of

$$\begin{pmatrix} \mathbf{I}_{11} \ \mathbf{J}_{\gamma}^{\dagger}(\beta\mathbf{r}_{1}) + \mathbf{I}_{12} \ \mathbf{J}_{\gamma}(\beta\mathbf{r}_{1}) \\ \mathbf{I}_{21} \ \mathbf{J}_{\gamma}^{\dagger}(\beta\mathbf{r}_{2}) + \mathbf{I}_{22} \ \mathbf{J}_{\gamma}(\beta\mathbf{r}_{2}) \\ \end{pmatrix} \begin{pmatrix} \mathbf{I}_{11} \ \mathbf{Y}_{\gamma}^{\dagger}(\beta\mathbf{r}_{1}) + \mathbf{I}_{12} \ \mathbf{Y}_{\gamma}(\beta\mathbf{r}_{1}) \\ \mathbf{I}_{21} \ \mathbf{Y}_{\gamma}^{\dagger}(\beta\mathbf{r}_{2}) + \mathbf{I}_{22} \ \mathbf{Y}_{\gamma}(\beta\mathbf{r}_{2}) \\ \end{pmatrix} = 0.$$
(52)

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Equation (52) can be solved only by numerical techniques. The numerical technique based on Newton's method requires the derivative of Equation (52) with respect to the argument  $\beta$ . The derivative can be obtained by rewriting Equation (52) in the form

$$\mathbf{F} = \begin{vmatrix} \mathbf{T}_1 & \mathbf{T}_2 \\ \mathbf{T}_3 & \mathbf{T}_4 \end{vmatrix}, \tag{53}$$

then

$$\frac{\partial F}{\partial \beta} = \begin{vmatrix} T_1 & T_2 \\ & & \\ \frac{\partial T_3}{\partial \beta} & \frac{\partial T_4}{\partial \beta} \end{vmatrix} + \begin{vmatrix} \frac{\partial T_1}{\partial \beta} & \frac{\partial T_2}{\partial \beta} \\ & & \\ T_3 & T_4 \end{vmatrix},$$
(54)

where

$$\frac{\partial \mathbf{T}_{1}}{\partial \beta} = \boldsymbol{\ell}_{11} \mathbf{J}_{\gamma}(\beta \mathbf{r}_{1}) \left[ \frac{\gamma}{\beta \mathbf{r}_{1}} - \beta \mathbf{r}_{1} \right] + \frac{\mathbf{r}_{1}}{\beta} \boldsymbol{\ell}_{12} \mathbf{J}_{\gamma}'(\beta \mathbf{r}_{1}), \qquad (55)$$

$$\frac{\partial \mathbf{T}_{2}}{\partial \beta} = \boldsymbol{I}_{11} \mathbf{Y}_{\gamma} (\beta \mathbf{r}_{1}) \left[ \frac{\gamma}{\beta \mathbf{r}_{1}} - \beta \mathbf{r}_{1} \right] + \frac{\mathbf{r}_{1}}{\beta} \boldsymbol{I}_{12} \mathbf{Y}_{\gamma} (\beta \mathbf{r}_{1}), \qquad (56)$$

$$\frac{\partial T_3}{\partial \beta} = I_{21} J_{\gamma}(\beta r_2) \left[ \frac{\gamma^2}{\beta r_2} - \beta r_2 \right] + \frac{r_2}{\beta} I_{22} J_{\gamma}(\beta r_2), \text{ and}$$
(57)

$$\frac{\partial \mathbf{T}_4}{\partial \beta} = \boldsymbol{\ell}_{21} \mathbf{Y}_{\gamma} (\beta \mathbf{r}_2) \left[ \frac{\gamma^2}{\beta \mathbf{r}_2} - \beta \mathbf{r}_2 \right] + \frac{\mathbf{r}_2}{\beta} \boldsymbol{\ell}_{22} \mathbf{Y}_{\gamma} (\beta \mathbf{r}_2).$$
(58)

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For  $\gamma$  not equal to zero,

$$F_{\gamma} = 1.0,$$
 (59)

$$B_{\gamma} = \frac{-k_{12} \cos \gamma \phi_1 + k_{11} \gamma \sin \gamma \phi_1}{k_{11} \gamma \cos \gamma \phi_1 + k_{12} \sin \gamma \phi_1}, \qquad (60)$$

$$C_{\gamma\beta} = \frac{-\ell_{11} Y_{\gamma}^{\prime}(\beta r_{1}) - \ell_{12} Y_{\gamma}(\beta r_{1})}{\ell_{11} J_{\gamma}^{\prime}(\beta r_{1}) + \ell_{12} J_{\gamma}(\beta r_{1})}, \qquad (61)$$

and

$$A_{\gamma\beta} = \frac{\int_{\phi_1}^{\phi_2} \int_{r_1}^{r_2} \mathbf{T} \left[ \mathbf{h}(\mathbf{r}, \phi) \right] \left[ \mathbf{B}_{\gamma} \sin \gamma \phi + \mathbf{F}_{\gamma} \cos \gamma \phi \right] \left[ \mathbf{C}_{\gamma\beta} J_{\gamma}(\beta \mathbf{r}) + \mathbf{Y}_{\gamma}(\beta \mathbf{r}) \right] \mathbf{r} \, d\mathbf{r} \, d\phi}{\int_{\phi_1}^{\phi_2} \left[ \mathbf{B}_{\gamma} \sin \gamma \phi + \mathbf{F}_{\gamma} \cos \gamma \phi \right]^2 \, d\phi} \int_{r_1}^{r_2} \mathbf{r} \left[ \mathbf{C}_{\gamma\beta} J_{\gamma}(\beta \mathbf{r}) + \mathbf{Y}_{\gamma}(\beta \mathbf{r}) \right]^2 \, d\mathbf{r}}$$
(62)

where

$$\int_{\phi_1}^{\phi_2} \left[ B_{\gamma} \sin \gamma \phi + F_{\gamma} \cos \gamma \phi \right]^2 d\phi = \left[ \frac{\phi}{2} (B_{\gamma}^2 + 1) - \frac{1}{4\gamma} (B_{\gamma}^2 - 1) \sin 2\gamma \phi + \frac{B_{\gamma}}{\gamma} \sin^2 \gamma \phi \right]_{\phi_1}^{\phi_2}$$
and
(63)

$$\int_{r_{1}}^{r_{2}} r \left[ C_{\gamma\beta} J_{\gamma}^{(\beta r)} + Y_{\gamma}^{(\beta r)} \right]^{2} dr = \left[ \frac{1}{2} r^{2} (1 - \frac{\gamma^{2}}{\beta^{2} r^{2}}) \left[ C_{\gamma\beta} J_{\gamma}^{(\beta r)} + Y_{\gamma}^{(\beta r)} \right]^{2} + \frac{r^{2}}{2\beta^{2}} \left[ C_{\gamma\beta} J_{\gamma}^{\dagger}^{(\beta r)} + Y_{\gamma}^{\dagger}^{(\beta r)} \right]^{2} \right]_{r_{1}}^{r_{2}}.$$
(64)

Under certain combinations of boundary conditions,  $B_{\gamma}$  is infinite for particular  $\gamma$ 's. In this case that particular term in Equation (44) is an indeterminate form. A usable form for this term can be obtained by setting

$$B_{v} = 1.0,$$
 (65)

$$\mathbf{F}_{\gamma} = \mathbf{0}, \tag{66}$$

and

$$A_{\gamma\beta} = \frac{\int_{\phi_1}^{\phi_2} \int_{r_1}^{r_2} \Upsilon[h(r,\phi)] \sin \gamma \phi \left[C_{\gamma\beta} J_{\gamma}(\beta r) + \Upsilon_{\gamma}(\beta r)\right] r \, dr \, d\phi}{\left[\frac{\phi}{2} - \frac{1}{4\gamma} \sin 2\gamma \phi\right]_{\phi_1}^{\phi_2} \int_{r_1}^{r_2} r \left[C_{\gamma\beta} J_{\gamma}(\beta r) + \Upsilon_{\gamma}(\beta r)\right]^2 \, dr} .$$
(67)

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The resulting form was obtained by division of the numerator and denominator of Equation (44) by  $B^2_{\gamma}$  and evaluating as  $B_{\gamma}$  approaches infinity.

If  $\gamma$  is equal to zero the required term can be obtained directly from Equation (44) by setting

$$\mathbf{B}_{\gamma} = 0, \tag{68}$$

$$\mathbf{F}_{\gamma} = 1.0, \qquad (69)$$

and

$$A_{\gamma\beta} = \frac{\int_{\phi_1}^{\phi_2} \int_{r_1}^{r_2} \mathbf{T}[\mathbf{h}(\mathbf{r},\phi)] [C_{\gamma\beta} J_{\gamma}(\beta \mathbf{r}) + \mathbf{Y}_{\gamma}(\beta \mathbf{r})] \mathbf{r} \, d\mathbf{r} \, d\phi}{(\phi_2 - \phi_1) \int_{r_1}^{r_2} \mathbf{r} [C_{\gamma\beta} J_{\gamma}(\beta \mathbf{r}) + \mathbf{Y}_{\gamma}(\beta \mathbf{r})]^2 \, d\mathbf{r}}$$
(70)

The series in Equation (44) converges rapidly for values of time greater than zero, since the exponential term involving time ( $\theta$ ) and  $\beta^2$ approaches zero quite rapidly for successive terms in  $\beta$ . However, for time equal to zero, this exponential term is equal to unity for all terms in Equation (44) and does not play its otherwise dominant role in the rapid convergence of the series. For a similar series, Reference 1 suggests

$$\frac{\alpha \theta}{r_2^2} > 0.02 \tag{71}$$

to ensure suitable convergence.

b. Coordinate and Time Varying Surface Effects

To obtain a solution of the coordinate and time varying surface effect in a form similar to that used in Reference 4, wherein the coordinate and time functions are separable, the following assumption is required. For a typical prescribed temperature at a boundary such as in Equation (18), we assume

$$\mathbf{T}\left[\mathbf{f}_{\phi 1}(\mathbf{r}) \ \mathbf{g}(\theta)\right] \cong \mathbf{T}\left[\mathbf{f}_{\phi 1}(\mathbf{r})\right]\mathbf{g}(\theta)$$
(72)

This is indicative of a linear transformation (constant thermal conductivity) over the range of the time function. This does not place any compromise on exactness of the solution for prescribed heat flux, zero surface temperature, or unit time function at a surface. However, Equation (72) is an approximation for a prescribed surface temperature with  $g(\theta)$ not equal to unity. (An example of transformations which do not involve this approximation is discussed in Section IIC). The magnitude of the error introduced by such an approximation will be immediately recognizable in the difference between prescribed surface temperature and the resulting solution at that surface. The magnitude of the error will increase with increased deviations in  $g(\theta)$  from unity and large variation in thermal conductivity with temperature.

The system of equations to be solved is

$$\frac{1}{\alpha} \frac{\partial T}{\partial \theta} = \frac{\partial^2 T}{\partial r^2} + \frac{1}{r^2} \frac{\partial^2 T}{\partial \phi^2} + \frac{1}{r} \frac{\partial T}{\partial r}$$
(73)

with the initial condition

$$T_{c}(0,r,\phi) = 0$$
 (74)

and the boundary conditions

$$k_{11} \frac{\partial T_{s}}{\partial \theta} + k_{12} T_{s} = \left\{ \frac{k_{11} r}{K_{o}} f_{\phi 1}(r) + k_{12} T \left[ f_{\phi 1}(r) \right] \right\} g(\theta), \quad (75)$$

$$k_{21} \frac{\partial T_{s}}{\partial \phi} + k_{22} T_{s} = \left\{ \frac{k_{21}r}{K_{o}} f_{\phi 2}(r) + k_{22} T[f_{\phi 2}(r)] \right\} g(\theta), \quad (76)$$

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$$\boldsymbol{\ell}_{11} \frac{\partial \mathbf{T}}{\partial \mathbf{r}} + \boldsymbol{\ell}_{12} \mathbf{T}_{s} = \left\{ \frac{\boldsymbol{\ell}_{11}}{\mathbf{K}_{o}} \mathbf{f}_{r1}(\boldsymbol{\phi}) + \boldsymbol{\ell}_{12} \mathbf{T} \left[ \mathbf{f}_{r1}(\boldsymbol{\phi}) \right] \right\} \mathbf{g}(\boldsymbol{\theta}), \tag{77}$$

and

$$\boldsymbol{I}_{21} \frac{\partial \mathbf{T}_{s}}{\partial \mathbf{r}} + \boldsymbol{I}_{22} \mathbf{T}_{s} = \left\{ \frac{\boldsymbol{I}_{21}}{\mathbf{K}_{o}} \mathbf{f}_{r2}(\phi) + \boldsymbol{I}_{22} \mathbf{T} \left[ \mathbf{f}_{r2}(\phi) \right] \right\} \mathbf{g}(\theta).$$
(78)

As in the previous section, the boundary conditions have been expressed in the general form involving the constants  $k_{ij}$  and  $l_{ij}$  which can be selected alternately as zero or unity for either (j) to obtain Equations (17) through (24).

By the methods of Reference 4 the solution to Equations (73) through (78) may be written\*

$$T_{g}(\theta, \mathbf{r}, \phi) = \sum_{\gamma} \sum_{\beta} G_{\gamma\beta} \left[ B_{\gamma} \sin \gamma \phi + F_{\gamma} \cos \gamma \phi \right] \left[ C_{\gamma\beta} J_{\gamma}(\beta \mathbf{r}) + Y_{\gamma}(\beta \mathbf{r}) \right]$$
$$x \left[ \alpha \beta^{2} \int_{0}^{\theta} g(\lambda) e^{-\left[ \alpha \beta^{2}(\theta - \lambda) \right]} d\lambda \right]$$
(79)

where

$$G_{\gamma\beta} = \frac{\int_{\phi_1}^{\phi_2} \int_{r_1}^{r_2} f(r,\phi) \left[ B_{\gamma} \sin \gamma \phi + F_{\gamma} \cos \gamma \phi \right] \left[ C_{\gamma\beta} J_{\gamma}(\beta r) + Y_{\gamma}(\beta r) \right] r \, dr \, d\phi}{\int_{\phi_1}^{\phi_2} \left[ B_{\gamma} \sin \gamma \phi + F_{\gamma} \cos \gamma \phi \right]^2 \, d\phi \int_{r_1}^{r_2} r \left[ C_{\gamma\beta} J_{\gamma}(\beta r) + Y_{\gamma}(\beta r) \right]^2 \, dr}$$
(80)

and  $B_{\gamma}$ ,  $F_{\gamma}$ ,  $C_{\gamma\beta}$ ,  $\gamma$  and  $\beta$  have been defined in the previous section. Here, f(r, $\phi$ ) is the steady state solution resulting from the coordinate varying boundary condition functions in Equations (75) through (78). This steady state solution is given in detail in Appendix A of this report. Equation (79) is subject to the same conditions regarding  $B_{\gamma}$  of infinity and  $\gamma$  equal to zero as discussed for Equation (44) in the previous section. Under these conditions  $G_{\gamma\beta}$ , Equation (80), is expressed in forms similar to Equations (67) and (70).

<sup>\*</sup>A more rapidly converging form will be introduced subsequently.



By adding and subtracting  $g(\theta)$  in the latter bracket, Equation (79) may be written

$$T_{g}(\theta, \mathbf{r}, \phi) = \sum_{\gamma} \sum_{\beta} G_{\gamma\beta} \left[ B_{\gamma} \sin \gamma \phi + F_{\gamma} \cos \gamma \phi \right] \left[ C_{\gamma\beta} J_{\gamma}(\beta \mathbf{r}) + Y_{\gamma}(\beta \mathbf{r}) \right]$$
$$x \left[ g(\theta) - g(\theta) + \alpha \beta^{2} \int_{0}^{\theta} g(\lambda) e^{-\alpha \beta^{2}(\theta - \lambda)} d\lambda \right]$$
(81)

and also noting that

$$f(\mathbf{r},\phi) = \sum_{\gamma} \sum_{\beta} G_{\gamma\beta} \left[ B_{\gamma} \sin \gamma \phi + F_{\gamma} \cos \gamma \phi \right] \left[ C_{\gamma\beta} J_{\gamma}^{(\beta\mathbf{r})} + Y_{\gamma}^{(\beta\mathbf{r})} \right].$$
(82)

Equation (81) becomes

$$T_{g}(\theta, \mathbf{r}, \phi) = g(\theta) f(\mathbf{r}, \phi) - \sum_{\gamma} \sum_{\beta} G_{\gamma\beta} \left[ B_{\gamma} \sin \gamma \phi + F_{\gamma} \cos \gamma \phi \right]$$
$$x \left[ C_{\gamma\beta} J_{\gamma}(\beta \mathbf{r}) + Y_{\gamma}(\beta \mathbf{r}) \right] \left[ g(\theta) - \alpha \beta^{2} \int_{0}^{\theta} g(\lambda) e^{-\alpha \beta^{2}(\theta - \lambda)} d\lambda \right]$$
(83)

Equation (83) offers several advantages in practical computation over Equation (79). The form given by Equation (83) is such that the transient series is converging toward the difference between the steady state solution that results from the boundary condition at that time and the actual temperature. As such, this series has convergence characteristics similar to the initial temperature distribution effects solution in Equation (44) of the previous section, in regards to large values of time. In contrast, the series defined by Equation (79) converges rapidly for small times, but rather slowly for large times. In addition, Equation (83) gives the proper solution at the boundaries whereas Equation (79) characteristically converges to zero at a boundary when temperature is prescribed. The form expressed by Equation (83) is used in the digital computer program.

#### C. COMMENT ON SOLUTION OF THE TEMPERATURE DEPENDENT THERMAL DIFFUSIVITY CASE

A successive transformation, Equation (25), which linearizes the temperature dependent thermal diffusivity equations was presented in Section IIA. It covers transformation of the non-linear differential equation associated with temperature dependent thermophysical properties. Since

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there are two successive transforms involved, particular attention should be given to combinations of the arbitrary functions that define the boundary conditions and the thermophysical properties in the application of this scheme to practical problems. Therefore, it is advisable to define the algebraic form of all the relationships involved and manipulate them as a set through the successive transformations.

As an example, we consider a specific set of the various arbitrary funcctions of the form

$$K(v) = K_0(1 + k_1 v),$$
 (84)

$$\alpha(\mathbf{v}) = \alpha_1 \mathbf{v}, \tag{85}$$

$$g(\theta) = g_1 \theta$$
, and (86)

with a prescribed temperature at the boundary  $\boldsymbol{\varphi}_1$  of

$$\mathbf{v}(\boldsymbol{\theta},\mathbf{r},\boldsymbol{\phi}_{1}) = \mathbf{g}(\boldsymbol{\theta}) \left[\mathbf{f}(\mathbf{r})\right]^{2}. \tag{87}$$

Then from case IV of Table I

$$T(\theta, \mathbf{r}, \phi_1) = \left\{ g_1[\mathbf{f}(\mathbf{r})]^2 \ \theta + \frac{k_1}{2} g_1^2 [\mathbf{f}(\mathbf{r})]^4 \ \theta^2 \right\}$$
(88)

from Equation (25)

$$\psi = \frac{\alpha_1 g_1}{2} [\mathbf{f}(\mathbf{r})]^2 \theta^2$$
(89)

$$\theta = \sqrt{\frac{2\Psi}{\alpha_1 g_1}} \quad \frac{1}{f(\mathbf{r})} \tag{90}$$

When Equation (90) is substituted in Equation (88), we obtain the transformed boundary condition

$$\mathbf{T}(\boldsymbol{\psi},\mathbf{r},\boldsymbol{\phi}_{1}) = \left\{ \sqrt{\frac{2\boldsymbol{\psi}\mathbf{g}_{1}}{\alpha_{1}}} \quad \mathbf{f}(\mathbf{r}) + \frac{\mathbf{k}_{1}\boldsymbol{\psi}\mathbf{g}_{1}}{\alpha_{1}} \left[\mathbf{f}(\mathbf{r})\right]^{2} \right\}.$$
(91)

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This equation is the complete transformation of the original boundary conditions in terms of both transform temperature and transform time. The two members in Equation (91) are products of a time function and a coordinate function and can be solved by methods similar to the one used in this report. Note that in this development the transform boundary condition is exact. It does not involve an approximation such as in Equation (72)\*.

Since the solution to the linear differential equation is in series form, an algebraic expression for the inversion to real time is not generally obtainable and numerical integration must be used. It is, however, under some combinations possible to obtain usable expressions for the inversion process. As an example, consider the relations

$$K(v) = K_{0}$$
(92)

and

$$\alpha(v) = \frac{1}{a_0 + a_1 v}.$$
 (93)

Here the transform temperature is

 $\mathbf{T} = \mathbf{v} \tag{94}$ 

and

$$\alpha(T) = \frac{1}{a_0 + a_1 T}.$$
 (95)

Consider a typical solution in the form

$$T(x,\psi) = \sum X(x) e^{-m^2 \psi}$$
(96)

where X(x) is the coordinate part of the product solution.

\*In place of Equation (88), the approximation defined by Equation (72) would lead to

$$T(\phi, \mathbf{r}, \phi_1) = \left\{ g_1[\mathbf{f}(\mathbf{r})]^2 \ \theta + \frac{k_1}{2} g_1[\mathbf{f}(\mathbf{r})]^4 \ \theta \right\} .$$

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Then from Equation (31), we obtain real time  $\boldsymbol{\theta}$  in the form

$$\theta = \left| a_{0} \psi + a_{1} \left[ \sum_{m} \frac{X(x)e^{-m^{2}\psi}}{-m^{2}} \right] \right|_{0}^{\psi}.$$
 (97)

The summation in Equation (97) is in the same form as the solution to Equation (96) except that each term is divided by minus  $m^2$ . In a practical solution these terms could easily be calculated parallel with the calculation of Equation (96).

#### SECTION III

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#### PROGRAMMING

#### A. PROGRAM DESCRIPTION

#### 1. Programming Philosophy

The mathematical formulation presented in the previous section is practical only when solved on a high speed computer. The temperature dependent thermal conductivity, constant thermal diffusivity, case has been developed in FORTRAN IV for application to an IBM 7094.

The computer program was developed with the view toward several objectives not usually considered in such a project. In addition to affording an analytical tool for development and study of thermal structures, the items discussed in the following paragraphs were considered.

Those familiar with mathematical texts on heat conduction such as Reference 1 will recognize that the solutions to diffusion problems have common mathematical expressions and methods of solution independent of the coordinate system. For example, the transformation and inversion used in linearizing the equations, the need for root searching techniques, the application of Duhamel's integral to incorporate time varying boundary conditions, etc., are common to many problems other than the specific problem considered in this task. Accordingly, this program was developed with these anticipated common elements as individual subroutines. This provides the user with building blocks or, as a minimum, specific guidelines for the development of similar computer programs. Detailed discussions of the subroutines are given in Appendix C.

Mathematics required to develop a program that considers temperature dependent thermal diffusivity have been discussed in preceding sections. The solution reduces to a linear system similar to that programmed in this task. Under this effort the solution of the linear system was isolated, thus providing the current program with the revision potential to incorporate temperature dependent thermal diffusivity at a later date.

For those users who are interested in the study of the characteristics of series solutions, either academically or in conjunction with development of solutions to similar problems, two control cards were incorporated as

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part of the input. These control cards, discussed subsequently, provide variation in the number of terms in the series, as well as increments used in numerical integration, and control a unique array of intermediate print options.

2. Basic Program Flow

The basic digital relationship between the MAIN routine and the subroutines of the digital program is given in Figure 2. Detailed discussions of these routines are given in Appendix C. Flow diagrams of the MAIN routine and prime subroutines are given in Appendix D.

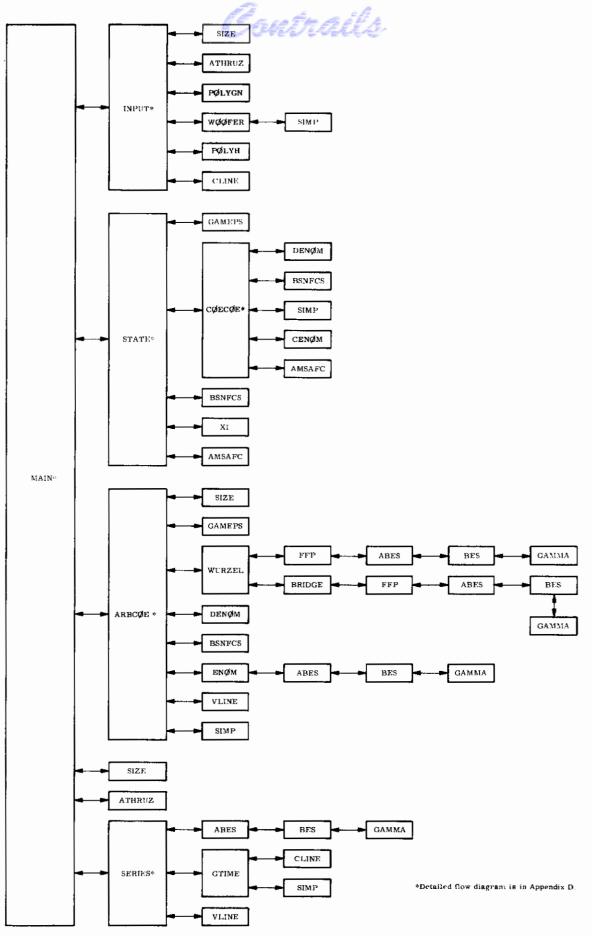
3. Output Data and Format

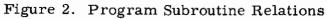
Certain intermediate print options, as discussed previously, are available for detailed study. The printout for these options is described for the individual subroutines in Appendix C. Independent of the use of these options, the standard program output is:

- 1 The problem title
- 2 All of the input problem description
- 3 The steady state solution
- 4 The times and lattice coordinates where the program is computing temperatures
- 5 The final temperatures at these coordinates.

An illustration of this output is given with the sample problems in Section IV.

In reference to 3 above, the steady state solution printout also includes a printout of the last terms in the series due to boundary condition contribution at each of the faces. The  $T_1$ ,  $T_2$ ,  $T_3$ , and  $T_4$  refer to the contribution of the boundaries  $r_1$ ,  $r_2$ ,  $\phi_1$ , and  $\phi_2$ , respectively. The IR and IP are program subscripts which locate the solution in the r and  $\phi$  directions, respectively. The latter column is the partial sum of the four series involved. With the exception of corrections at the corners in cases where temperatures are prescribed at the corresponding adjacent faces (Appendix A) this is the steady state solution  $f(r,\phi)$  used in evaluating Equation (80).







#### B. UTILIZATION OF THE COMPUTER PROGRAM

Before reading this section a review of Equations (1) through (10) and Figure 1 in Section IIA is recommended.

This section describes the utilization of the computer program via a general discussion of the input requirements followed by a detailed description of the input and output formats on Table II. Two sample problems are included in Section IV to illustrate utilization of the program.

1. Discussion of Input

It is assumed in the calculation that the physical units input for a particular problem are dimensionally compatible. That is, units of heat length, time, mass, and temperature must be consistent in a given problem. Heat flux at a surface is treated as per unit area.

a. Control (Cards A and B)

A control system, as previously mentioned, was developed to increase the flexibility of the program. Input the numbers given in the input data format, which follows for normal use of the program. See sequence line numbers 000180 through 000280 of the program listing (Appendix B) and detailed discussion of MAIN (Appendix C) for definitions if alternation to number of terms used in the series or number of increments used in numerical integration is desired.

b. Geometry (Cards D and E)

As presently programmed, the system will consider sectors between 0 and 360°, where

$$\phi_1 = 0$$
  
0 <  $\phi_2$  < 360°.

The radial boundary restrictions are

$$r_2 > r_1$$
$$r_1 \neq 0$$

### c. Thermophysical Properties (Card(s) F)

The variation of thermal conductivity with temperature may be defined by selecting any of the programmed algebraic expressions given in Table I, inputting tabular data, or defining the coefficients and exponents in an expression of the form:

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$$K(v) = \sum_{i=1}^{n} a_i v_i^{i}.$$
(35)

The latter expression is referred to as  $P \not O LY$  in the utilization instructions. The thermal diffusivity is input as a constant. Refer to Section IIB.1 (page 9) for a discussion of the associated transformation and inversion.

## d. Initial Temperature Distribution (Card(s) G)

The initial temperature distribution may be input as either a lattice array of temperatures or in polynomial form similar to Equation (35). The polynomial form is:

$$h(r,\phi) = \sum_{i=1}^{n} a_{i}r^{i}\phi^{i}.$$
(98)

e. Boundary Conditions (Card(s) H, I, J, K, and optional L)

The coordinate varying portion of the boundary conditions is incorporated in the solution via a steady state solution (see Section IIB.2.b, page 17). This steady state solution will be calculated in response to definition of the coordinate varying functions and mode (prescribed temperature or heat flux) at each surface. The solution is written such that a positive heat flux represents heat into the surface. The coordinate varying portion of a boundary condition may be input either as tabular data or by defining number of terms, coefficients, and exponents in a form similar to Equation (35).

In particular cases, the steady state solution may be known by the user either from a previous problem or because of the simplicity of the particular problem. In such cases, the steady state temperature distribution in either the real or the transform variable may be input either as a lattice array of temperatures or in polynomial form similar to the initial temperature distribution. The boundary condition mode is still required when using this option.

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### f. Time Function (Card(s) M)

The time function  $g(\theta)$  may be input as either tabulated or polynomial data. For a discussion of the approximation associated with application of this function refer to Section IIB.2.b, page 17.

### g. Output Requested (Card(s) N)

Temperature distribution data at various times may be requested either at specific values of r and  $\phi$  or in an evenly distributed lattice. It is advisable to request calculations for times in which

$$\frac{\alpha \theta}{r_2^2} > .02. \tag{71}$$

For smaller times an increased number of terms in the series may be required.

## 2. Input Data Format

All input data must contain a decimal point unless otherwise specified. If data is specified as not containing a decimal point, it must be right adjusted in its field.

When point data is furnished, the independent variable should always be supplied in monotonically increasing order. Table II presents the input data loading procedure.

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# TABLE II

# Input Data Loading Procedure

# (Note: Quotation marks indicate Hollerith terms.)

	Card Designa-	Column	
Instruction	tion	No.	Description
Control	А	5	6
		10 13-15	6 100
		18-20	100
		25	6
		29-30	10
		35	20
		39-40 44-45	30 30
	в	1-35	blank - Intermediate print options
	С	1-72	Problem title
Geometry	_		
	D	1-10 11-20	ARE(1) - the value of $r_1$ ARE(2) - the value of $r_2$
	Е	11-20	PHI(1) - the value of $\phi_1$ which must be
		-	zero
		11-20	PHI(2) - the value of φ <sub>2</sub> in degrees and fractions
Thermophysical Properties			
• To input point data			
for K(v) versus v	F	1-5	"PØINT"
	-	11-20	<ul> <li>N - the number of point pairs to be input. This number is right ad- justed with no decimal point (N≤50).</li> </ul>
		21-30	ALPHØ - the value of $\alpha$
	<b>F</b> 1	31-40 1-60	AZER $\emptyset$ - the value of K <sub>0</sub> The point pairs in ten column fields
		1.00	with the abscissa specified first in
			each case. This card (F1) is repeated
• To input K(v) as a			as necessary.
polynomial			
<b>F</b> = 5	F	1-4	"PØLY"
		11-20	N - the number of polynomial terms to be input. This number is right adjusted with no decimal point $(N \le 10)$ .
		21-30	A - the minimum value at which the polynomial is to be evaluated
		31-40	<ul> <li>B - the maximum value at which the polynomial is to be evaluated</li> </ul>

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Instruction	Card Designa- tion	Column No.	Description
<ul> <li>To input special cases of K(v) (see</li> </ul>	F1	41-50 51-60 1-10 11-20	ALPHØ - the value of $\alpha$ AZERØ - the value of K <sub>0</sub> A coefficient of the polynomial The corresponding order of the inde- pendent variable. This card (F1) is repeated as necessary.
Table I).			
	F	1-4 11-20	"CASE" N - the case number of the transform. This value is right adjusted with no decimal point (N≤7).
		21-30	BEE - the value of b in the transform equation
		31-40	SEE - the value of c in the transform equation
		41-50 51-60	ALPH $\emptyset$ - the value of $\alpha$ AZER $\emptyset$ - the value of K <sub>0</sub>
nitial Temperature Dis- ribution • To input h(r,φ) as			· · · · · · · · · · · · · · · · · · ·
point data	G	1-5 11-20	"PØINT" N - the number of points in the r direction. This value is right ad- justed with no decimal point $(N \leq 7)$ .
		21-30	M - the number of points in the $\phi$ direction. This value is right ad- justed with no decimal point (M $\leq$ 25).
To input $b(n, t)$ is	G1	1-70	( $M \ge 25$ ). The values of the dependent variable in ten column fields starting with $h(r_1, \phi_2)$ and varying (r) most rapidly with all the values for one complete cycle (r) on one card. The values of dependent variable must be evenly spaced in any given direction. This card (G1) is repeated as necessary.
<ul> <li>To input h(r,φ) in polynomial form</li> </ul>	G	1-4	"PØLY"
		11-20	N - the number of terms in the poly- nomial. This value is right ad- justed with no decimal point $(N \le 10)$ .

# Contrails

Instruction	Card Designa- tion	Column No.	Description
	G1	1-10 11-20	A - coefficient of the polynomial The corresponding order of the poly- nomial (r).
		21-30	The corresponding order of the poly- nomial (\$). This card (G1) is re- peated as necessary.
Boundary Conditions <u>1</u> Boundary conditions at r <sub>1</sub> • To input f <sub>r1</sub> (\$) as point data			
•	н	1-4	"TEMP" - for a temperature at the
	Į	1-4	boundary "FLUX" - for a flux at the boundary
		11-15	"PØINT"
		21-30	N - the number of values of the de- pendent variable to be input. This number is right adjusted with no decimal point (N≤200).
		31-32	These columns blank mean the steady state solution will be worked by the program. "NØ" - means the steady state soulution will be input. (Note: If the NØ option is used, only columns 1 through 4 of this card need to be filled in and card H1 is omitted.)
		31-34	"ØNLY" - to work the steady state solu-
<ul> <li>To input f<sub>r1</sub>(φ) as a polynomial</li> </ul>		1-70	tion and then terminate. Evenly spaced values of the dependent variable from $\phi_1$ to $\phi_2$ in ten column fields. This card (H1) is repeated as necessary.
as a polynomiai	н	1-4	"TEMP" - for a temperature at the
	ĺ	1-4	boundary "FLUX" * for a flux at the boundary
	l I	11-14	"PØLY"
		21-30	N - the number of terms in the poly- nomial. This value is right ad- justed with no decimal point $(N \le 10)$ .
		31-32	<ul> <li>Blank for the program to work the steady state solution.</li> <li>"NØ" - to input the steady state solution. (Note: If the NØ option is used, only columns 1 through 4 need to be filled in and card H1 is omitted.)</li> </ul>
		31-34	"ØNLY" - to work the steady state solution and then terminate.

Contrails

Instruction	Card Designa- tion	Column No.	Description
2 Boundary conditions	Η1	1-10 11-20	A coefficient of the polynomial The corresponding order of the poly- nomial. This card (H1) is repeated as necessary.
at $r_2$ , $\phi_1$ , and $\phi_2$	I, J, K		Cards I, J, and K follow the same form as cards H (and H1) but for the $r_2$ , $\phi_1$ , and $\phi_2$ boundaries, respectively. The options of TEMP, FLUX, PØINT, and PØLY available on card H may be used in any combination at the remaining boundaries except that the option to input or solve for the steady state solu- tion has been fixed with card H and cannot be modified thereafter.
3 Steady state solution input directly*			
	L, L1		The steady state solution card L and card(s) L1 are input in exactly the same format as the initial temperature dis- tribution (card G and card(s) G1 above) with the same restrictions and options but withe the following addition. If the steady state solution is input in the real variable (v), write "TRANSFØRM" in columns 31 through 39 of card L. (The program will perform the required transformations before proceeding with the remainder of the solution.) If the steady state solution is input in the transform variable (T) leave columns 31 through 39 blank.
<ul> <li>Time Functions</li> <li>To input the time function g(θ) as point data</li> </ul>			
	м	1-5 11-20	"PØINT" N - the number of point pairs to be input. This value is right adjusted with no decimal point (N≤50).
	M1	1-60	The point pairs in ten column fields with the time value ( $\theta$ ) given first in each case. This card (M1) is repeated as necessary.

\*All L cards are omitted if steady state solution is not input.

Contrails

Instruction	Card Designa- tion	Column No.	Description
<ul> <li>To input the time function g(θ) as a polynomial</li> </ul>			
	М	1-4	"PØLY"
		11-20	N - the number of terms in the poly- nomial. This value is right ad- justed with no decimal point (N≤10).
		21-30	<ul> <li>B - the maximum value at which the polynomial is to be evaluated.</li> <li>(The time function will be evaluated over the domain 0 to B).</li> </ul>
	<b>M</b> 1	1-10 11-20	A coefficient of the polynomial The corresponding order of the poly- nomial in $\theta$ . This card (M1) is re-
			peated as necessary.
Output Requested Individual Points			
	N	1-10	The time at which an answer is desired
		11-20	An r at which an answer is desired
		21-30	A $\phi$ in degrees and fractions at which
			an answer is desired. This card (N)
<ul> <li>Lattice Points</li> </ul>			is repeated as necessary.
Lattice Points	N	1-10	The time at which an answer is de-
		1-10	sired
		31-32	"ØN"
		41-50	N - the number of lattice points in the r direction where answers are de- sired. This value is right adjusted with no decimal point (N≤400).
		51-60	M - the number of lattice points in the $\phi$ direction where answers are desired. This value is right adjusted with no decimal point (M $\leq$ 400).
	N1	1-10	Additional time at which answers are desired. This card (N1) is repeated as required. (Note: Card N for lattice points may follow card N for individual points.)

Contrails

Contrails

# SECTION IV SAMPLE PROBLEMS

This section presents two typical samples and their solutions as obtained from the digitial computer program. These sample problems are primarily to familiarize the reader with input and output format of the program. A sample test problem is discussed in Appendix E.

A. SAMPLE PROBLEM 1

### 1. Geometry

 $r_1 = 0.7$  inch  $r_2 = 0.9$  inch  $\phi_1 = 0$  degrees  $\phi_2 = 270$  degrees

2. Thermophysical Properties

Based on glass reinforced polyester\*

K(v) = K<sub>o</sub> [1 + bv] Case 4  
K<sub>o</sub> = 0.925 x 10<sup>6</sup> Btu/sec inch °R  
b = 0.00125  
$$\alpha$$
 = 0.000122 inch<sup>2</sup>/sec

3. Initial Temperature Distribution

$$h(r,\phi) = 600^{\circ}R$$

4. Boundary Conditions

at r <sub>1</sub>	v	=	1000°R,
at r <sub>2</sub>	v	=	1000°R,
at $\phi_1$	v	=	1000°R,
at $\phi_2$	v	=	1000°R.

\* Data per Reference 5.

and

Contrails

In this case the steady state solution can be input directly since it is obviously 1000°R at all points. It can be input in either the real or the transform variable. In this case it will be input in the transform variable. Referring to Table I.

i**f** 

$$K(v) = K_0 [1 + bv]$$

then

$$\Gamma = v + \frac{bv^2}{2}$$

which for v = 1000°R yields

$$T = 1625^{\circ}R = f(r,\phi).$$

Since the boundary conditions define a step function,  $g(\theta)$  is equal to unity.

The input to obtain the temperature distribution at 40, 60, 80, and 120 seconds for five values in each of the radial and circumferential directions is shown in Table III. Printout is shown in Table IV. Figures 3 through 7 are illustrations of the temperature distribution.

# B. SAMPLE PROBLEM 2

1 Geometry

$$r_1 = 0.2 \text{ inch}$$
$$r_2 = 0.8 \text{ inch}$$
$$\phi_1 = 0 \text{ degree}$$

 $\phi_2 = 90 \text{ degrees}$ 

2 Thermophysical properties

Same as sample problem 1.

**3** Boundary Conditions

at 
$$r_1$$
  $v = (720 - 25.4\phi)g(\theta)$ ,  
at  $r_2$   $\frac{\partial v}{\partial r} = 0$ ,

Contrails

at 
$$\phi_1$$
 v = (700 + 100r) g( $\theta$ ),  
at  $\phi_2$  v = (700 - 100r) g( $\theta$ );

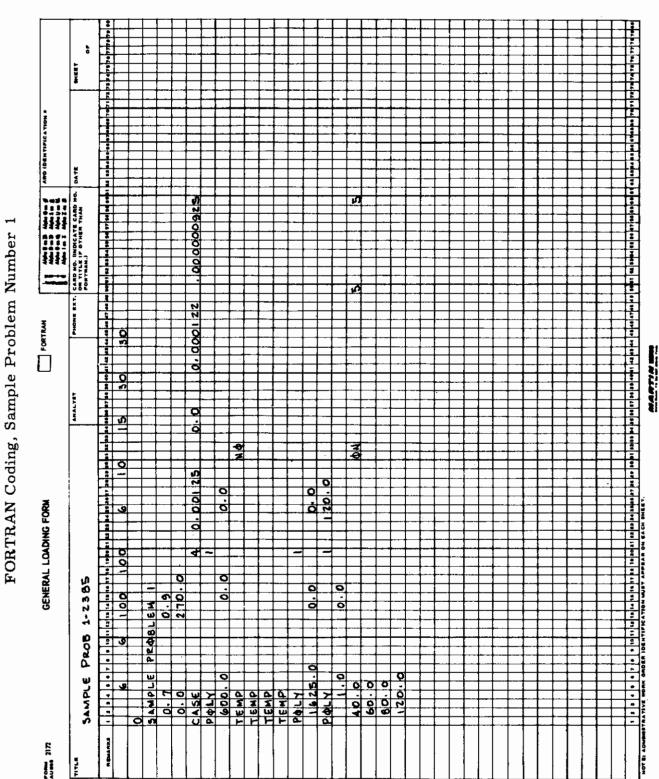
where

$$g(\theta) = 0.8 + 0.00333\theta$$

# 4. Initial Temperature Distribution

 $h(r,\phi) = 600^{\circ}R.$ 

The input to obtain the temperature distribution at 40, 60, 80, 120 seconds for five points in the radial direction and five points in the circumferential direction is shown in Table V. Printout is shown in Table VI. Figures 8 through 12 illustrate the temperature distribution.



Contrails

TABLE III



#### TABLE IV

#### Program Printout, Sample Problem Number 1

SAMPLE PROBLEM 1 TNPHT GEOMETRY R1= 0.70000000E 00 R2= 0.90000000F 00 P1= 0. P2= 0.47123883E 01 (RADIANS) THERMO PHYSICAL PROPERTIES TRANSFORM ACCORDING TO CASE 4,8= 0.12500000E-02 C= 0. ALPHA= 0.12200000F-03 KZERD= 0.92500000E-06 INITIAL TEMPERATURE DISTRIBUTION POLYNOMIAL DATA, 1 TERMS 1 9.60000000E 033[R\*\* 0. 3[P\*\* 0. 1 BOUNDRY CONDITIONS AT R1, TEMP L11= э. L12= 1.00 0. AT RZ, TEMP LZ1= L22∓ 1.00 AT PL, TEMP 0. K11= K12= 1.00 AT P2, TEMP KZl= 0. K22= 1.00 STEADY STATE SOLUTION IS BEING INPUT POLYNOMIAL DATA, 1 TERMS { 0.16250000E 04)(R\*\* 0. }{P\*\* 0. 1 TIME FUNCTION POLYNOMIAL DATA, I TERMS, X=DUMMY VARIABLE ( 0.10000000E 01)1K++ 0. 1 EVALUATE POLYNONIAL FROM 0. TO 0.12000000E 03 5 LATTICE POINT ANSWERS IN -R-0.70000000E 00 0.75000000E 00 0.80000000E 00 0.94999999E 00 0.9000000E 00 5 LATTICE POINT ANSWERS IN -PH1-0.11780971E 01 0.23561941E 01 0.35342912E 01 0.47123883E 01 Ο. TIME= 0.4000000E 02 R= 0.7000000F 00 PHI= 0. IRADIANS) TEMPERATURE= 0.99999999 03 TINE= 0.4000000E D2 R= 0.75000000E 00 PHE = 0. (RADIANS) TEMPERATURE= 0.99999999E 03 PHI = 0. TIME= 0.4000000E 02 R= 0.80000000E 00 (RADIANS) TEMPERATURE = 0.999999998 03 TIME= 0.40000000E 02 R= 0.84999999E 00 PHI = 0. **ERADIANSE** TEMPERATURE= 0.999999998 03 PHI = 0. (RADIANS) TINE= 0.4000000E 02 R= 0.9000000E 00 TEMPERATURE= 0.999999996 03 TIME= 0.4000000E 02 R= 0.7000000E 00 PHI= 0.11783971E 01 (RADIANS) TEMPERATURE= 0.999999998 03 PHI= 0.11783971E 01 (RADIANS) R= 0.75000000E 00 TINE\* 0.40000000E 02 TEMPERATURE= 0.89553053E 03

Contrails

TIME=		R= 0.80000000E 0.85510616E 03	00	PH[ =	0.11783971E 01	(RADIANS)
TEME=	0.40000000E 02 TEMPERATURE=		00	PH[ =	0.11783971E 01	(RADIANS)
TIME≠	0.40000000E D2 Temperature=	R= 0.9000000E 0.99999999E 03	00	PHI =	0.11783971E 01	(RADIANS)
TIME=	0.40000000E 02 TEMPERATURE=	R≠ 0.7000000E 0.99999999E 03	00	PHI =	0.23561941E 01	(RADIANS)
TIME=	0.40000000E 02 TEMPERATURE=		00	PHI =	0.23561941E 01	(RADIANS)
T[ME=		R= 0.80000000E 0.84493773E 03	00	PHI≠	0.23561941E 01	[RADIANS]
fime=		R= 0.849999998 0.89500820E 03	00	PH[ =	0.23561941E 01	IRADIANS }
TIME=		R= 0.90000000E 0.999999996 03	00	PH[ =	0.23561941E 01	(RADIANS)
TIME=	0.40000000E 02 TEMPERATURE=	R= 0.70000000E 0.99999999E 03	00	PH1 =	0.35342912E 01	(RADEANS)
T [ ME =	0.40000000E 02 TEMPERATURE=	R= 0.75000000E 0.89539008E 03	00	PHI =	0.35342912E 01	(RADEANS)
TIME=		R= 0.80000000E 0.85490806E 03	00	PH[ =	0.353429128 01	(RADIANS)
TIME=	0.40000000E 02 TEMPERATURE=		00	PH[ =	0.35342912E 01	(RADIANS)
TIME=		R= 0.90000000E 0.99999999E 03	00	PH[ =	0.35342912E 01	(RADIANS)
TIME=		R= 0.70000000E 0.99999999E 03	00	PHI =	0.47123883E 01	(RADIANS)
TIME=		R= 0.75000000E 0.99999995E 03	00	PHI ≈	0.47123883E 01	(RADIANS)
TIME=	0.4000000CE 02 TEMPERATURE=	R= 0.83000000E 0.99999992E 03	00	PHI =	0.47123883E 01	(RADIANS)
TIME≠		R= 0.84999999E 0.99999995E 03	00	PH[ =	0.47123883E 01	[RADIANS]
TINE=		R= 0.90000000E 0.999999999E 03	00	PH[ =	0.47123883E 01	(RADIANS)
TIME=	0.60000000E 02 Temperature=	R= 0.70000000E 0.99999999E 03	00	PHI =	с.	(RADIANS)
TIME=		R= 0.75000000E 0.99999999E 03	00	PHT =	0.	(RADIANS)
TIME=		R= 0.80000000E 0.99999999E 03	00	PHI =	0.	(RADIANS)
TIME=	0.60000000E D2 TEMPERATURE=	R= 0.84999999E 0.99999999E 03	00	PHI =	0.	(RADIANS)
FIME=		R= 0.9000000E 0.99999999E 03	00	PHI =	0.	(RADIANS)

Contrails

FIME=	0.6000000000000000000000000000000000000	B- 0 70000000		0 H F -	0 117000715 01	
1146-		R∓ 0.70000000E 0.99999999E 03	00	PHIX	0.11783971E 01	(KAUTANS)
TIME=	0.60000000E 02 TEMPERATURE=	R≠ 0.75000000E 0.94338583E D3	00	PHI =	0.11783971E 01	(RADIANS)
TIME=		R= 0.80000000E 0.92201011E 03	00	PHI ≠	0.11783971E 01	(RADIANS)
T[ME=	0.60000000E 02 Temperature=	R= 0.84999999E 0.94686591E 03	00	PHE =	0.11783971E 01	(RADIANS)
TIME=	0.60000000E 02 TEMPERATURE=		00	9HT =	0.11783971E 01	IRADIANS I
[[ME=	0.60000000E 02 [Emperature=		00	PHI =	0.23561941E 01	(RADEANS)
TIME=	0.6000000CE 02 Temperature=	R= 0.75000000E 0.93992796E 03	00	PHI =	0.23561941E 01	(RADIANS)
T[ME=	0.60000000E 02 TEMPERATURE=		00	PHI =	0.23561941E 01	(RADIANS)
TIME=	0.60000000E 02 Temperature=	R= 0.849999998 C.94357659E 03	00	PH[ =	0.23561941E 01	(RADIANS)
FIME=		R= 0.93003000E 0.999999999F 03	00	PHI =	0.23561941E 01	(RADIANS)
T[ME=	0.600CD000E 02 Temperature=	R= 0.70000000F 0.999999999F 03	00	PH[ =	0.35342912E 01	(RADIANS)
ſĭme≈	0.60000000E 02 TEMPERATURE=	R= 0.75000000E 0.94331553E 03	00	PH[ =	0.35342912E 01	(RADIANS)
TIME=		R= 0.80000000E 0.92191216E 03	C:0	PHI =	0.35342912E 01	(RADIANS)
TIME=	0.60000000E 02 TEMPERATURE=	R= 0.849999998 0.94679937E 03	00	PHI =	0.35342912E 01	(RADIANS)
TIME=		R= 0.90000000E 0.999999999E 03	0 <b>0</b>	PH[ =	0.35342912E 01	(RADIANS)
<b>TIME</b> ≠		R= 0.70000000E 0.999999996 03	00	PHI =	0.471238838 01	(RADIANS)
TIME=		R= 0.75000000E 0.99999997E 03	00	PH[ =	0.47123883E 01	(RADIANS)
TIME≠	0.60000000E 02 TEMPERATURE=	R= 0.80000000E 0.99999995E 03	00	PHI =	0.47123883E 01	(RADIANS)
TIME=		R= 0.849999998 0.99999997E 03	00	PH[ =	0.47123883E 01	(RADIANS)
TIME=		R≈ 0.90000000E 0.999999998 03	00	PHI =	0.47123883E 01	(RADIANS)
TIME=		R= 0.7000000E 0.99999999E 03	00	PH[ =	0.	{RADIANS}
TIME=		R= 0.75000000E 0.99999999E 03	00	PHI =	0.	(RADIANS)
TIME=		R≠ 0.80000000E 0.999999996 03	00	= 1H9	0.	(RADIANS)

Contrails

TIME=	0.8000000CE 02 TEMPERATURE=		00	<b>P</b> HE =	0.	[RADIANS]
TIME=	0.80000000E 02 TEMPERATURE=		00	PHI =	0.	(RADIANS)
TIME=	0.80000000E 02 Temperature=	R= 0.70000000E 0.999999996 03	00	PHI =	0.11783971E 01	(RADIANS)
TINE=	0.80000000E 02 TEMPERATURE=	R= 0.75000000E 0.96917486E 03	00	PHI =	0.11783971E 01	[RADIANS]
T I ME=	0.80000000E D2 TEMPERATURE=	R= 0.80000000E 0.95762274E 03	00	PHI =	0.11783971E 01	(RADIANS)
TIME=	0.80000000E D2 TEMPERATURE=	R= 0.84999999E 0.97106580E 03	00	PHI =	0.11783971E 01	(RADIANS)
TIME=		R= 0.9000000E 0.999999995 03	00	PHI =	0.11783971E 01	ERADEANS )
TIME=	0.80000000E 02 TEMPERATURE=	R= 0.7000000F 0.99999999E 03	00	PHI =	0.23561941E 01	(RADIANS)
TIME=	0.800000000000000000000000000000000000	R= 0.75000000E 0.96749291E 03	00	PHI =	0.23561941E 01	(RADIANS)
TIME=	0.80000000E 02 TEMPERATURF=		00	PHI =	0.23561941E OI	{RADIANS}
TIME=	0.8000000E 02 TEMPERATURE=	R= 0.84999999F 0.96946320E 03	00	PHI =	0.23561941E 01	(RADIANS)
TIME=	0.80000000E 02 TEMPERATURE=	R= 0.9000000F D.99999999E 03	00	PHI =	9.23561941E 01	(RADEANS I
[[ME=	0.80000000E D2 TEMPERATURE=		00	PHI =	0.35342912E 01	(RADIANS)
TIME=		R≠ 0.75000000E 0.96913924E 03	00	PH[ =	0.35342912E 01	(RADIANS)
TIME=	0.80000000E 02 TEMPERATURE*		00	PH[ =	0.35342912E 01	(RADEANS)
TIME*	0.80000000E 02 TEMPERATURE=	R= 0.84999999E 0.97103207E 03	00	PHI =	0,35342912E 01	(RADIANS)
TIME±		R≠ 0.93000000E 0.99999999€ 03	00	PHI =	0.35342912E D1	(RADIANS)
TIME=		R= 0.70000000E 0.99999999E 03	00	PHI =	0.47123883E 01	(RADIANS)
LIWE*	0.8000000E 02 TENPERATURE=	R= 0.75000000E 0.99999997E 03	00	PHI =	0.47123883E 01	(RADIANS)
TIME=		R= 0.80000000E 0.99999997F 03	00	PHI =	0.47123883E 01	(RADIANS)
FINE=		R= 0.84999999E 0.99999997E 03	00	PHI =	0.47123883E 01	(RADIANS)
TIME=		R= 0.90000000E 0.99999999E 03	00	PHI =	0.47123883E 01	(RADEANS)
TIME*	0.12000000E 03 TEMPERATURE=	R= 0.70000000E 0.99999999E 03	00	PH[ =	0.	(RADIANS)

Contrails

TIME=		R= 0.75000000E 0.99999999E 03	00	PHE =	0.	(RADIANS)
TTME=		R= 0.80000000E 0.99999999E D3	00	PHI =	0.	(RADIANS)
TIME=		R= 0.84999999E 0.99999999E 03	00	PHI =	0.	(RADIANS)
T[ME=		R= 0.90000000E 0.99999999E 03	00	PHI =	0.	(RADIANS)
TIME=	0.12000000E 03 TEMPERATURE=	R= 0.70000000E 0.99999999E 03	00	PHI =	0.11783971E 01	(RADIANS)
tiwe≖		R= 0.75000000E 0.99079582F 03	00	PHI =	0.11783971E 01	(RADIANS)
TIME=		R= 0.80000000E 0.98734950E 03	00	PHI =	0.11783971E 01	(RADIANS)
ŦIME=		R= 0.849999999F 0.99135558E 03	00	PH[ =	0.11783971E 01	(RADIANS)
TIME=		R= 0.90000000E 0.99999999E 03	00	PH[ =	0.11783971E 01	(RADIANS)
TIMF=		R= 0.70000000E 0.99999999E 03	00	PHI =	0.23561941E 01	(RADIANS)
TIME=		R= 0.75000000F 0.99039390E 03	00	₽H[ =	0.23561941E 01	(RADIANS)
¶IME=		R= 0.80000000E 0.98678927E 03	00	PHI =	0.23561941E 01	IRADIANS }
TIME=		R= 0.84999999E C.99097077E 03	00	PHI =	0.23561941E 01	(RADIANS)
TIME=		R= 0.90000000E 0.999999999E 03	00	PHI =	0.23561941E 01	(RADIANS)
fIME=		R= 0.7000000F 0.99999999E 03	00	₽H[ =	0.35342912E 01	(RADEANS)
TIME=		R= 0.75000000E 0.99078654E 03	00	PHI =	0.35342912E 01	(RADIANS)
TIME=	_	R= 0.80000000E 0.98733665E 03	00	PH[=	0.35342912E 01	(RADIANS)
TIME=		R= 0.849999998 0.99134679E 03	00	PHI ≠	0.35342912E 01	(RADIANS)
TIME=		R= 0.90000000E 0.999999999E 03	00	PH[ =	0.35342912E 01	(RADIANS)
TEME=		R= 0.70000000F 0.999999999E 03	00	PHI =	0.47123883E 01	(RADIANS)
TIME=	*******	R= 0,75000000E 0.999999999E 03	00	PHI =	0.47123883E 01	(RADIANS)
TIME=		R= 0.80000000E 0.99999999E 03	C0	PH[ =	0.47123883E 01	(RADTANS)
TIME=		R= 0.849999998 0.999999998 03	00	PHI =	0.47123883E 01	(RADIANS)

Contrails

TINE= 0.12000000E 03 R= 0.90000000E 00 PHI= 0.47123883E 01 (RADIANS) TEMPERATURE= 0.99999999E 03

END-OF-DATA ENCOUNTERED ON SYSTEM INPUT FILE.

.

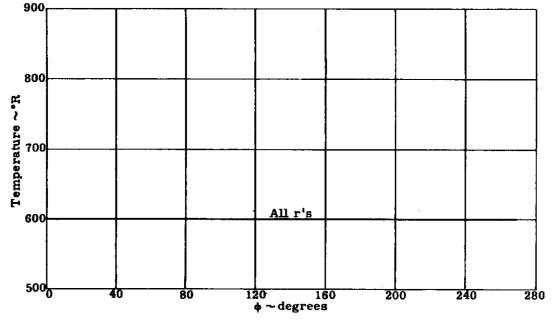
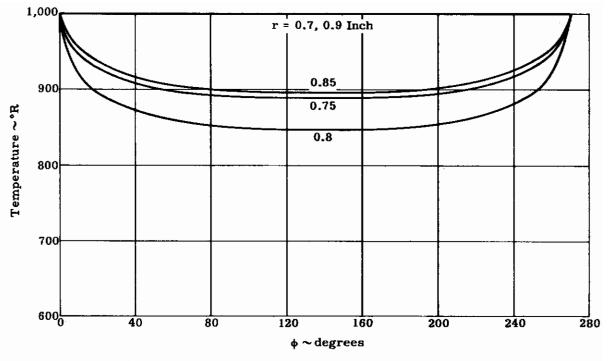
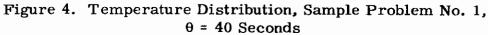


Figure 3. Temperature Distribution, Sample Problem No. 1,  $\theta = 0$  Second

Contrails





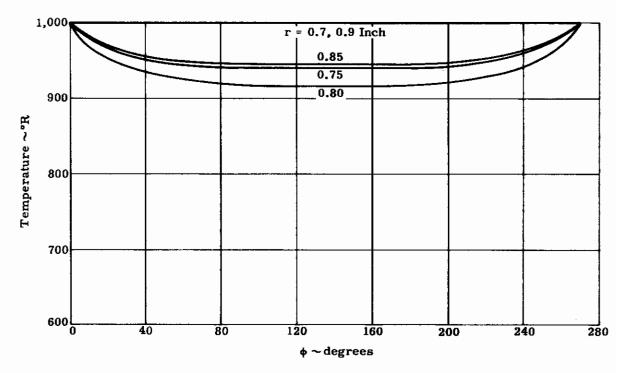
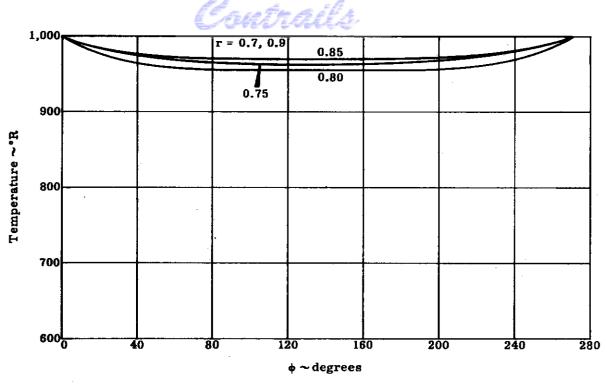
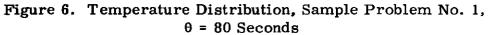
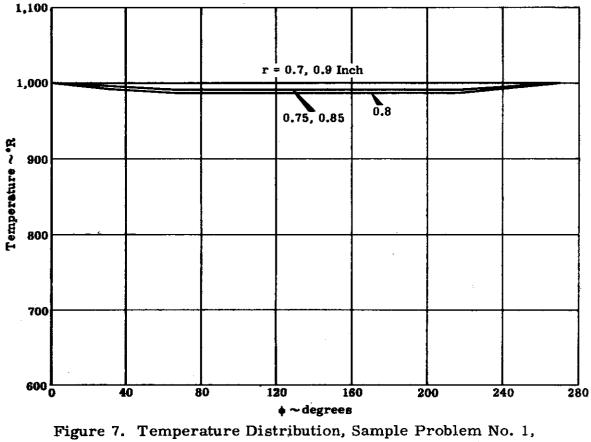


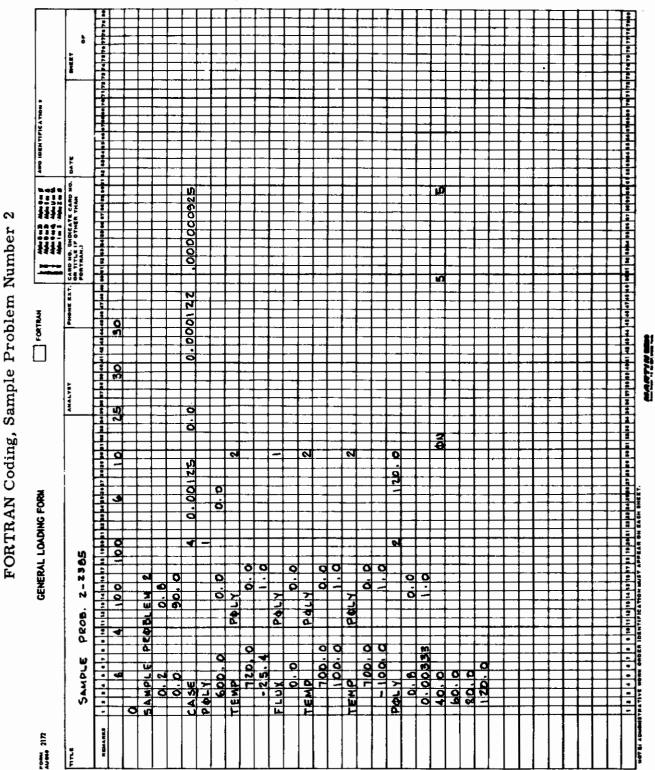
Figure 5. Temperature Distribution, Sample Problem No. 1,  $\theta = 60$  Seconds







 $\theta$  = 120 Seconds



Contrails

TABLE V

1001

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# TABLE VI

Contrails

# Program Printout, Sample Problem Number 2

SAMPLE PROBLEM 2		
INPUT GEOMETR/ R1= 0.20000000E-00 R2= 0.800000 P1= 0. P2= 0.157079	00E 00 61E 01 (RADIANS)	
THERNO PHISICAL PROPERTIES TRANSFORM ACCORDING TO CASE 4,B= 0.1 Alpha= 0.12200000E-03 KZERD= 0.		
INITIAL TEMPERATURE DISTRIBUTION POLYNOMIAL DATA, 1 TERMS ( 0.60000000E D3)(R**	0. ){P** 0. }	
BOUNDRY CONDITIONS AT R1, TEMP L11= 0. L12= POLYNOMIA: DATA, 2 TERMS, X=DUMMY VA		
I 0.72000000E 03)(X** I -0.25400000E 02)(X** AT R2, FLUX L21= 1.00 L22= POLYNOMIAL DATA, 1 TERMS, X=DUMMY VA	L.COCO) 0.	
I D. IIX++ AY P1, TEMP K11= O, K12= PGLYNOHIAL DATA; 2 TERMS; X=DUMHY YA	0. ) : 1.00 RIABLE	
I 0.7000000E D3)1X** ( 0.1000000E D3)1X** AT P2, TEMP K21= 0. K22= PCL/NOMIAL DATA, 2 TERNS, X=DUMMY VA I 0.700000DE D3)1X**	1.0000) 4.00 RIABLE 0. )	
1 -0.10009000E 03){X**	1.0000)	
TIME FUNCTION POLINDHIAL DATA, 2 TERMS, X=DUNMY VA { 0.80000000E 00}{X**		
POLYNOMIAL DATA: 2 TERMS: X=DUNNY VA	0. )	
POLYNOMIAL DATA, 2 TERMS, X=DUNMY VA { 0.80000000E 00}{X** { 0.33300000E-02}{X** EVALUATE POLYNOMIAL FROM 0.	0. ) 1.0000) FO 0.12000000E 03	0
POLYNOMIAL DATA, 2 TERMS, X=DUNMY VA { 0.80000000E 00}{X** { 0.33300000E-02}{X** EVALUATE POLYNOMIAL FROM 0. TI T2 T3 0. 0. 0.52713818E-	0. ) 1.0000) FO 0.12000009E 03 F4 STEADY(IR, [P) 1 -07 09.71517314E-05 1	
POLYNOMIAL DATA,       2 TERMS, X=DUNMY VA         {       0.80000000E       001 (X**         {       0.33300000E-021 (X**         EVALUATE       POLYNOMIAL       FROM       0.         T1       T2       T3         0.       0.527138188E         0.       0.23593566E	0. ) 1.0000) FO 0.1200000E 03 FO 0.1200000E 03 -07 00.71517314E-05 1 02 0. 0.10640674E 04 2	
POLYNOMIAL DATA, 2 TERMS, X=DUNMY VA { 0.80000000E 00}{X** { 0.33300000E-02}{X** EVALUATE POLYNOMIAL FROM 0. TI T2 T3 0. 0. 0.52713818E-	0. ) 1.0000) FO 0.1200000E 03 FO 0.1200000E 03 14 STEADYIIR, [P) 11 -07 00.71517314E-05 1 02 0. 0.10640674E 04 2 01 -0. 0.10756797E 04 3	
POLYNOMIAL       DATA,       2       TERMS,       X=DUNMY       VA         {       0.8000000E       001 (X**       {       0.33300000E-021 (X**         EVALUATE       POLYNOMIAL       FROM       0.         T1       T2       T3         0.       0.52713818E         0.       0.23593566E         0.       0.         0.       0.16640617E         0.       0.         0.       0.26464082E	0. ) 1.0000) FO 0.1200000E 03 FO 0.1200000E 03 14 STEADY(IR, [P) 11 07 00.71517314E-05 1 02 0. 0.10640674E 04 2 01 -0. 0.10756797E 04 3 02 0. 0.11162323E 04 4 02 -0. 0.11225780E 04 5	
POLYNOMIAL DATA, 2 TERMS, X=DUNMY VA         { 0.80000000E 00}{X**         { 0.33300000E-02}{X**         EVALUATE POLYNOMIAL FROM         0.         0.         0.         0.352713818E         0. <t< td=""><td>0. ) 1.0000) FO 0.1200000E 03 FO 0.1200000E 03 07 00.71517314E-05 1 02 0. 0.10640674E 04 2 01 -0. 0.10756797E 04 3 02 0. 0.11126323E 04 4 02 -0. 0.11225780E 04 5 02 0. 0.11710614E 04 6</td><td></td></t<>	0. ) 1.0000) FO 0.1200000E 03 FO 0.1200000E 03 07 00.71517314E-05 1 02 0. 0.10640674E 04 2 01 -0. 0.10756797E 04 3 02 0. 0.11126323E 04 4 02 -0. 0.11225780E 04 5 02 0. 0.11710614E 04 6	
POLYNOMIAL DATA, 2 TERMS, X=DUNMY VA         { 0.8000000E 00}{X**         { 0.33300000E-02}{X**         EVALUATE POLYNOMIAL FROM         0.         0.         0.         0.352713818E         0. <tr< td=""><td>0. ) 1.0000) FO 0.1200000E 03 FO 0.1200000E 03 01 -00.71517314E-05 1 02 00.10640674E 04 2 01 -0. 0.10756797E 04 3 02 0. 0.11162323E 04 4 02 -0. 0.11710614E 04 5</td><td></td></tr<>	0. ) 1.0000) FO 0.1200000E 03 FO 0.1200000E 03 01 -00.71517314E-05 1 02 00.10640674E 04 2 01 -0. 0.10756797E 04 3 02 0. 0.11162323E 04 4 02 -0. 0.11710614E 04 5	
POLYNOMIAL DATA,       2 TERMS, X=DUNMY VA         {       0.8000000E       001 {X**         {       0.33300000E-021 {X**         EVALUATE       POLYNOMIAL       FROM       0.         II       T2       T3         0.       0.52713818E         0.       0.23593566E         0.       0.23593566E         0.       0.35817416F         0.       0.16640617E         0.       0.26466082E         0.       0.28750360E         0.32769979E 02       0.         0.20392770E-08       0.         0.24793645E-15       0.	0. ) 1.0000) FO 0.1200000E 03 FO 0.1200000E 03 07 00.71517314E-05 1 02 0. 0.10640674E 04 2 01 -0. 0.10756797E 04 3 02 0. 0.11162328E 04 4 02 -0. 0.1125780E 04 5 92 0. 0.11710614E 04 6 -11 0. 0.1014208E 04 1 -02 0.45899782E-32 0.10750722E 04 2 -03 -0.11691849E-32 0.10728598E 04 3	
FOL FNOMIAL DATA,         2 TERMS, X=DUNMY VA           {         0.80000000E         001 (X**           {         0.33300000E-021 (X**           EVALUATE         POL YNOMIAL         FROM         0.           T1         T2         T3           0.         0.23593566E         0.         0.23593566E           0.         0.         -0.58817416F           0.         0.         -0.58817416F           0.         0.         -0.26464082E           0.         0.         0.28750360E           0.32769979E         0.         0.32619344E           0.20392770E-00         0.         0.44599714E           0.2479363E-15         0.         -0.36396254E           0.14373831E-20         0.         0.10297225E	0. ) 1.0000) FO 0.1200000E 03 FO 0.1200000E 03 	
FOL FNOMIAL DATA,         2 TERMS, X=DUNMY VA           {         0.80000000E         001 (X**           {         0.33300000E-021 (X**           EVALUATE         POL YNOMIAL         FROM         0.           T1         T2         T3           0.         0.23593566E         0.         0.23593566E           0.         0.         -0.58817416F           0.         0.         -0.58817416F           0.         0.         -0.26464082E           0.         0.         0.28750360E           0.32769979E         0.         0.32619344E           0.20392770E-00         0.         0.44599714E           0.2479363E-15         0.         -0.36396254E           0.14373831E-20         0.         0.10297225E	0. ) 1.0000) FO 0.1200009E 03 FO 0.1200009E 03 1.0000 FO 00.71517314E-05 1 02 0. 0.10640674E 04 2 01 -0. 0.10756797E 04 3 02 0. 0.11162323E 04 4 02 -0. 0.11225780E 04 5 02 0. 0.11710614E 04 6 -11 0. 0.11014208E 04 1 -02 0.45899782E-32 0.10550722E 04 2 -03 -0.11691849E-32 0.10728598E 04 3 -02 0.52605853E-32 0.10889541E 04 4 -02 -0.52605853E-32 0.11015144E 04 5	
POLYNOMIAL DATA, 2 TERMS, X=DUNMY VA         I       0.80000000E         O.33300000E-021X**         I       0.33300000E-021X**         EVALUATE POLYNOMIAL FROM       0.         II       T2         T3       0.         0.       0.52713818E         0.       0.23593566E         0.       0.23593566E         0.       0.358817416F         0.       0.36466082E         0.       0.16640617E         0.       0.24750360E         0.32769979E       0.       0.32619344E         0.24793645E-15       0.       0.63396254E         0.14373831E-20       0.       0.10297225E         0.87403295E-25       0.       0.16779971E         0.51701507E-28       0.       0.1779071E         0.5270508E       0.       0.20184871E	0. ) 1.0000) FO 0.1200000E 03 FO 0.1200000E 03 	
POLYNOMIAL DATA, 2 TERMS, X=DUNMY VA         { 0.80000000E 00}{X**         { 0.33300000E-02}{X**         EVALUATE POLYNOMIAL FROM 0.         T1       T2         T3         0.0.0.000E-02}{X**         EVALUATE POLYNOMIAL FROM 0.         T1       T2         0.0.0.0.23593566E         0.0.0.0.23593566E         0.0.0.0.0.23593566E         0.0.0.0.0.0.8817416F         0.0.0.0.0.26464082E         0.0.0.0.0.26464082E         0.0.0.0.28750360E         0.327699779E 02       0.0.0.14599714E         0.20392770E-08       0.0.14599714E         0.24793645E-15       0.0.0.14599714E         0.16373831E-20       0.10297225E         0.87403295E-25       0.0.10297225E         0.87403295E-25       0.0.1790741E         0.51701507E-28       0.0.02184871E         0.0.20348471E       0.0.0218481E         0.0.2034845E-0.0.0.0218481E       0.0.0218481E	0. ) 1.0000) FO 0.1200000E 03 FO 0.1200000E 03 	
POLYNOMIAL DATA, 2 TERMS, X=DUNMY VA         { 0.80000000E 00}{X**         { 0.33300000E-02}{X**         EVALUATE POLYNOMIAL FROM 0.         T1       T2         T3         0.0.0.000E-02}{X**         EVALUATE POLYNOMIAL FROM 0.         T1       T2         0.0.0.0.23593566E         0.0.0.0.23593566E         0.0.0.0.0.23593566E         0.0.0.0.0.0.8817416F         0.0.0.0.0.26464082E         0.0.0.0.0.26464082E         0.0.0.0.28750360E         0.327699779E 02       0.0.0.14599714E         0.20392770E-08       0.0.14599714E         0.24793645E-15       0.0.0.14599714E         0.16373831E-20       0.10297225E         0.87403295E-25       0.0.10297225E         0.87403295E-25       0.0.1790741E         0.51701507E-28       0.0.02184871E         0.0.20348471E       0.0.0218481E         0.0.2034845E-0.0.0.0218481E       0.0.0218481E	0. ) 1.0000) FO 0.1200000E 03 FO 0.1200000E 03 00 0.1200000E 03 01 0. 0.1200000E 03 02 0. 0.10640674E 04 02 0. 0.10756797E 04 02 0. 0.11710614E 04 02 0. 0.11162328E 04 4 4 02 0. 0.11162328E 04 11 0. 0.11014208E 04 11 0. 0.11014208E 04 12 0. 0.11014208E 04 13 0.02 0.3078565E-32 0.10728598E 04 3 0.2 0.3078565E-32 0.10689541E 04 5 0.2 0.57150564E-32 0.1105804E 04 5 0.2 0.57150564E-32 0.1105804E 04 5 0.16933679E-38 0.1054208E 04 5 0.16933679E-38 0.1054208E 04 5 0.16933679E-38 0.1055064E 04 5 0.105791487E-28 0.1054206E 04 3 10 07 0.18894386E-28 0.1054206E 04 3 10 07 0.18894386E-28 0.10544066E 04 3 10 10 10	
POLYNOMIAL DATA, 2 TERMS, X=DUNMY VA         { 0.80000000E         0.33300000E         0.32100E         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.000         0.0000         0.0000         0.0000         0.0000         0.0000         0.0000         0.0000         0.0000         0.0000         0.00000         0.00000         0.000000         0.0000000         0.0000000000         0.00000000000000000000000000000000000	0. ) 1.0000) FO 0.1200000E 03 FO 0.1200000E 03 FO 0.1200000E 03 02 0. 0.10640674E 04 02 0. 0.10756797E 04 02 0. 0.11162323E 04 4 02 0. 0.11162323E 04 4 02 0. 0.11710614E 04 52 0. 0.11710614E 04 6 11 0. 0.11014208E 04 11 0. 0.11014208E 04 11 0. 0.11014208E 04 11 0. 0.11014208E 04 11 0. 0.11014208E 04 12 0.307855E-32 0.10550722E 04 03 -0.11691849E-32 0.10550722E 04 03 -0.31691849E-32 0.10550722E 04 03 -0.31693865E-32 0.10689541E 04 4 -02 0.57150564E-32 0.11065804E 04 50 0.5936579E-36 0.99902129E 03 1 07 0.75791487E-28 0.10645059E 04 3 -07 0.5345597E-28 0.10544606E 04 3 -07 0.5345597E-28 0.10544606E 04 3 -07 0.8345597E-28 0.10544606E 04 3 -07 0.8345597E-28 0.10544504E 04 5 -06 -0.85012673E-28 0.1071369E 04 5 -06 -0.85012673E-28 0.1071369E 04 5 -07 0.5345597E-28 0.1071369E 04 -07 0.5345597E-28 0.1071369E 04 -07 0.5345597E-28 0.1071369E 04 -07 0.5345597E-28 0.1071369E 04 -07 0.5345597E-28 0.10741369E 04 -07 0.5345597E-28 0.10741369E 04 -07 0.5345597E-28 0.10741369E 04 -07 0.5345597E-28 0.10741369E 04 -07 0.5345597E-28 0.107407E-28 0.1074	
POLYNOMIAL DATA, 2 TERMS, X=DUNMY VA         I       0.8000000E         O.33300000E-02] (X**         EVALUATE POLYNOMIAL FROM       0.         T1       T2         T3       0.000000E         O.33300000E-02] (X**         EVALUATE POLYNOMIAL FROM       0.         T1       T2         T3       0.00000000000000000000000000000000000	0. ) 1.0000) FO 0.1200002E 03 FO 0.1200002E 03 FO 0.1200002E 03 02 0. 0.10640674E 04 02 0. 0.10756797E 04 02 0. 0.11162323E 04 02 0. 0.11162323E 04 02 0. 0.11225783E 04 02 0. 0.112056797E 04 03 0. 11014208E 04 11 0. 0.11014208E 04 11 0. 0.11014208E 04 11 0. 0.11014208E 04 11 0. 0.11015144E 04 02 0. 0.11691849E-32 0.10728598E 04 03 0.20785565E-32 0.10550722E 04 20 0.52605853E-32 0.10550722E 04 20 0.52605853E-32 0.1015144E 04 502 0.52605853E-32 0.1005804E 04 602 0.57150564E-32 0.1005804E 04 502 0.57150564E-32 0.1005804E 04 500 0.575791487E-28 0.10645759E 04 4 505 0.6933679E-28 0.1054606E 04 3 1054606E 04 3 07 0.53455977E-28 0.10645759E 04 4 505 0.92357065E-28 0.10732670E 04 505 0.923570E 04 505 0.92	
POLYNOMIAL DATA, 2 TERMS, X=DUNMY VA         { 0.80000000E         0.33300000E         0.32100E         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.00         0.000         0.0000         0.0000         0.0000         0.0000         0.0000         0.0000         0.0000         0.0000         0.0000         0.00000         0.00000         0.000000         0.0000000         0.0000000000         0.00000000000000000000000000000000000	0. ) 1.0000) FO 0.1200000E 03 FO 0.1200000E 03 FO 0.1200000E 03 02 0. 0.10640674E 04 2 01 -0. 0.10756797E 04 3 02 0. 0.11162323E 04 4 02 0. 0.11126780E 04 5 02 0. 0.111710614E 04 6 -11 0. 0.11014208E 04 1 -02 0.48899782E-32 0.10550722E 04 2 0.0.11691849E-32 0.1072598E 04 3 -02 0.3078565E-32 0.10015144E 04 5 -02 0.31505656-32 0.11015144E 04 5 -02 0.371505565E-32 0.11015144E 04 5 -02 0.371505565E-32 0.11015144E 04 5 -02 0.371505565E-32 0.11015144E 04 5 -02 0.3571505565E-32 0.11015144E 04 5 -03 -0.116933679E-36 0.99902129E 03 1 -07 0.75791487E-28 0.10540061E 04 2 -07 0.0189433865-28 0.10544606E 04 3 -07 0.35455977E-28 0.10645759E 04 4 -06 0.9235705E-28 0.1071369E 04 5 -06 0.9235705E-28 0.1071369E 04 5 -06 0.9235705E-28 0.10713267E 04 6 -19 0.27365293E-32 0.10317192E 04 1	
POLYNOMIAL DATA, 2 TERMS, X=DUNMY VA         I       0.8000000E       001 (X**         I       0.33300000E-021 (X**         EVALUATE POLYNOMIAL FROM       0.         TI       T2       T3         0.       0.32593566E         0.       0.23593566E         0.       0.23593566E         0.       0.016640617E         0.       0.6640617E         0.       0.16640617E         0.       0.23759379E         0.327699778E 02       0.         0.23793645E-15       0.         0.237699778E 02       0.         0.32619344E       0.32619344E         0.4373831E-20       0.         0.44793645E-15       0.         0.4579714E-       0.32619344E         0.51701507E-28       0.         0.51701507E-28       0. <td>0. ) 1.0000) FO 0.1200002E 03 FO 0.1200002E 03 FO 0.1200002E 03 02 0. 0.10640674E 04 02 0. 0.10756797E 04 02 0. 0.11162323E 04 4 02 0. 0.11710614E 04 6 02 0. 0.11710614E 04 6 11 0. 0.11014208E 04 11 0. 0.11014208E 04 11 0. 0.11014208E 04 11 0. 0.11014208E 04 12 0.3078555E-32 0.10550722E 04 02 0.33078555E-32 0.10550722E 04 02 0.57150564E-32 0.11065804E 04 502 0.57150564E-32 0.11065804E 04 502 0.57150564E-32 0.11065804E 04 503 -0.11894385E-28 0.10544606E 04 304 0.99902129E 03 107 0.75791487E-28 0.10645759E 04 05 0.85012673E-28 0.10544606E 04 305 0.10545597E-28 0.10544606E 04 306 0.92357065E-28 0.10732670E 04 10 0.27365293E-32 0.1037192E 04 11 0.102248114E-23 0.1028241E 04 211 0.33533850E-24 0.10356669E 04 30</td> <td></td>	0. ) 1.0000) FO 0.1200002E 03 FO 0.1200002E 03 FO 0.1200002E 03 02 0. 0.10640674E 04 02 0. 0.10756797E 04 02 0. 0.11162323E 04 4 02 0. 0.11710614E 04 6 02 0. 0.11710614E 04 6 11 0. 0.11014208E 04 11 0. 0.11014208E 04 11 0. 0.11014208E 04 11 0. 0.11014208E 04 12 0.3078555E-32 0.10550722E 04 02 0.33078555E-32 0.10550722E 04 02 0.57150564E-32 0.11065804E 04 502 0.57150564E-32 0.11065804E 04 502 0.57150564E-32 0.11065804E 04 503 -0.11894385E-28 0.10544606E 04 304 0.99902129E 03 107 0.75791487E-28 0.10645759E 04 05 0.85012673E-28 0.10544606E 04 305 0.10545597E-28 0.10544606E 04 306 0.92357065E-28 0.10732670E 04 10 0.27365293E-32 0.1037192E 04 11 0.102248114E-23 0.1028241E 04 211 0.33533850E-24 0.10356669E 04 30	
POLYNOMIAL DATA, 2 TERMS, X=DUNMY VA	0. ) 1.0000) FO 0.1200002E 03 FO 0.1200002E 03 FO 0.1200002E 03 02 0. 0.10640674E 04 22 01 -0. 0.10756797E 04 33 02 0. 0.11162323E 04 44 02 -0. 0.112257802E 04 55 02 0. 0.11710614E 04 56 -11 0. 0.11014208E 04 11 -02 0.45899782E-32 0.10550722E 04 25 -03 -0.11691849E-32 0.10728598E 04 35 -02 0.33078555E-32 0.10889541E 04 45 -02 0.52605853E-32 0.11065804E 04 55 -02 0.52605853E-32 0.11065804E 04 55 -02 0.52605853E-32 0.11065804E 04 55 -02 0.57155564E-32 0.11065804E 04 55 -02 0.57155564E-32 0.11065804E 04 55 -03 -0.11894386E-28 0.10544606E 04 33 -07 0.53455977E-28 0.10645759E 04 45 -05 0.65012673E-28 0.10544606E 04 33 -07 0.53455977E-28 0.10645759E 04 45 -05 0.65012673E-28 0.10732670E 04 45 -05 0.45012673E-28 0.10732670E 04 45 -11 0.12248114E-23 0.10282341E 04 25 -11 0.12248114E-23 0.10282341E 04 25 -11 0.12248114E-23 0.10282341E 04 25 -11 0.12353850E-24 0.103356669E 04 35 -11 0.12248114E-23 0.10282341E 04 25 -11 0.12353850E-24 0.10356669E 04 35 -11 0.12248114E-23 0.10282341E 04 25 -11 0.12353850E-24 0.10356669E 04 35 -11 0.12248114E-23 0.10282341E 04 25 -11 0.12248114E-23 0.10356669E 04 35 -11 0.12248114E-23 0.1035669E 04 35 -	

Contrails

-0.17436476E 02	-0.	0.77290743E-24	9.44223133E-28	0.10074655E	04	1	5
-0.10850725E-08	-0.	0.34593667E-15	0.19793319E-19	0.10141319E	04	2	5
-0.13192373E-15	~0.	-0.86240039E-16	-0.49343616E-23	0.10168617E	04	3	5
-0.76481266E-21	-0.	0-24399023E-15	0.13960291E-19	0.10188134E	04	4	5
-0.46506145E-25	-0.	-0.3880251LE-15	-0.22201477E-19	0.10199094E	04	5	5
-0.27509693E-28	-0.	0.42154727E-15	0.24119501E-19	0.10202305E	04	6	5
-0.17436610E 02	-0.	0.478275676-28	0. 71 465873E-24	0.99694684E	03	1	6
-0.10550809E-08	-0.	0.214065856-19	0.31986580E-15	0.99993795E	03	2	6
-0.13192475E-15	-0.	~0.53365398E-20	-0.797407226-15	0.99810152E	03	3	6
-0.76481858E-21	-0.	0,15098133E-19	0.22560237E-15	0.99673614E	03	4	6
-0.46506504E-25	-0.	-0.240110226-19	-0.35878234E-15	0.99595206E	03	5	6
-0.27509905E-28	-0.	0.26085375E-19	0.389778176-15	0.99572010E	03	6	6
0.44150918E 02	0.	0.29595746E-32	0.11549085E-19	0.10081296E	04	1	7
0.27475132E-08	0.	0.132464176-23	0.51691213E-11	0.9858350TE	03	2	7
0.33404420E-15	0.	-0.33022562E-24	-0.12886324E-11	0.97933614E	03	3	7
0.19365829E-20	0.	0.93427398E-24	0.36457975E-11	0.97442137E	03	4	7
0.11775826E-24	0.	-0.14858044E-23	-0.57980231E-11	0.97151839E	03	5	7
Q.69657322E-28	0.	0.161416576-23	0.62989244E-11	0.97064191E	03	6	7
-0.50206479E 02	-0.	0.18313869E-36	0.18663668E-15	0.958033428	03	1	
-0.31243510E-CB	-0.	0.81968920E-28	0.83534543E-07	0.97204189E	03	2	8
-0.37986036E-15	-0.	-0.204343858-28	-0.23824686E-07	0.96059722E	03	3	6
-0.22021968E-20	-0.	0.57812939E-28	0.589171796-07	0.95132963E	03	4	6
-0.13390950E-24	-0.	-0.91941684E-28	-0.93697789E-07	0.94533459E	03	5	8
-0.79211238E-28	-0.	0.99884685E-28	0.13179250E-06	0.94339016E	03	6	8
0.32769869E 02	0.	0.	0.30161042E-11	0.10383348E	04	1	9
0.20392702E-08	0.	0,50722378E-32	0.13499431E-02	0.95889435E	03	2	9
0.24793562E-L5	c.	-0.12644800E-32	-0.33653312E-03	0.94220467E	03	3	9
0.143737836-20	0.	0.35774654E-32	0.95211915E-03	0.92726015E	03	4	9
0.87403001F-25	0.	-0.56893526E-32	-0.15141842E-02	0.91570383E	03	5	9
0.51701334E-28	0.	0.618085566-32	0.16449972E-02	0.91105254E	03	6	9
0.11926919E-03	0.	-0.	0.48741141E-07	0.105712006-	-02	1	10
0.74221262E-14	0.	-0.	0.21815482E 02	0.94421585E	03	2	10
0.90238628E-21	0.	0.	-0.54384753E 01	0.91165409E	03	3	10
0.523148096-26	0.	-0.	0.15386529E 02	0.90590479E	03	4	10
0.318111905-30	0.	0.	-0.24469666E 32	0.86845119E	03	5	10
0.188172145-33	0.	-0.	0.26581643E 02	0.87382974E	03	6	10

ti#E=	0.40000000E 02	R= 0.2000000E-00	PH[ =	0.	(RADIANS)
	TEMPERATURE=	0.68284091E 03			
€£ME≠		R= 0.3500000E-00	PHI =	0.	[RADIANS]
	TEMPERATURE=	0.69436102E 03			
				-	
L E ME =		R= 0.5000000E-00	PHI =	0.	(RADIANS)
	TEMPERATURE=	0.70877225E 03			
TIME-	0.40000005 02	R= 0.64999999E 00	PHI =	٥.	(RADIANS)
1146-		0.72110973E 03	111	••	(KHOIHAS /
	TEHE CARIONL-				
TINE=	0.4000000E 02	R= 0.80000000E 00	PHI =	0-	(RADIANS)
		0.74548862E 03		•••	• • • • • • •
TEME=	0.4000000E 32	R= 0.2000000E-00	PHI =	0.39269903E-00	(RADIANS)
	TEMPERATURE=	0.6641940ZE 03			
T[ME=		R= 0.3500000E-00	PHI =	0.39269903E-00	[RADIANS]
	TEMPERATURE=	0.60492823E 03			
LIWE=		R= 0.5000000E-00	PHI =	0.39269903E-00	(RADIANS)
	TEMPERATURE=	0.60424066E 03			
TIME-	0 40000005 02	R= 0.64999999E 00	PHI =	0.39269903E-00	( PADIANS )
ITHE-		0.59773344E 03	F 114 -	01342077032-00	
	TEAT ENATORES	0.,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,			
TIME =	0.40000000F 32	R= 0.83000000€ 00	PHI ≠	0.39269903E-00	(RADIANS)
		0.60081771E 03			
TIME=	0.4000000E 02	R= 0.2000000E-00	₽H[=	0.78539805E 00	(RADIANS)
-	TEMPERATURE=	0.66164771E 03			
TIME=		R= 0.3500000E-00	= 1H9	0.78539805E 00	(RADIANS)
	<b>TEMPERATURE</b> =	0.59783714E 03			

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TIME=	0.40000000E 02 TEMPERATURE=	R= 0.5000000E-00 0.59914182E 03	PH[ =	0.78539805E 00 (RADIANS)
TIME=	0.40000000E 02 * TEMPERATURE=	R= 0.64999999E_00 0.59515677E_03	PHI =	0.78539805E 00 (RADIANS)
TIME=	0.40000000E 02 TEMPERATURE=	R= 0.80000000E 00 0.59714668E 03	P41=	0.78539805E 00 (RADIANS)
TIME=		R= C.2000000E-00 C.64539223E D3	PHI =	0.11783971E 01 (RADIANS)
îIME≠	0.40000000E 02 TEMPERATURE=		PHI =	0.11783971E 01 (RADIANS)
TIME≖	0.40000000E 02 TEMPERATURE=		PHI =	0.11783971E 01 {RADIANS}
TLHE=	0.40000000E 02 TEMPERATURE=		PHI =	0.11783971E 01 (RADIANS)
TIME=		R= 0.8000000E 00 0.59883289E 03	PH[ =	0.11783971E 01 (RADIANS)
T (ME=	0.40000000E 02 TEMPERATURE=	R= 0.2000000E-00 0.64463718E 03	PHI =	0.15707961E D1 (RADIANS)
TIME=	0.4000000E 02 TEMPERATURE=	R= 0.35000000E-00 0.62747079E 03	PH] =	0.15707961E 31 (RADIANS)
T EME=	0.40000000E 02 TEMPERATURE=	R= 0.5000000E-00 0.61312303E 03	PHI =	0.15707961E 31 (RADIANS)
TINE=	0.40000000E 32 Temperature=	R= 0.64999999E 00 0.59666834E 03	PH1 =	0.15707961E 01 (RADIANS)
TINE=	0.40000000E 02 TEMPERATURE=	R= 0.80000000E 00 0.59453669E 03	PHI =	0.15707961E 01 (RADIANS)
TIME=	0.60000000E 02 TEMPERATURE=	R= 0.2000000E-00 0.71989307E 03	PHI =	0. (RADIANS)
TIRE=	0.60000000E 02 TEMPERATURE=		PHI =	0. (RADIANS)
<b>ГLME</b> ≖	0.60000000E 02 TEMPERATURE=		PHI =	0. (RADIANS)
TEME=	0-60000000E 02 TEMPERATURE=	R= 0.649999995 00 0.75988066E 03	PH[ =	0. (RADIANS)
TIME=		R= 0.80000000E 00 0.78534646E 03	P <u>HI</u> =	0. (RADIANS)
T L ME +	0.60000000E 02 TEMPERATURE=	R= 0.2000000E-00 0.70039690E 03	PHI =	0.39269903E-00 (RADIANS)
TIME=	0.60000000E 02 TEMPERATURE=	R= 0.35000000E-00 0.61812373E 03	PHI =	0.39267903E-00 (RADIANS)
<b>TINE</b> ≭		R= 0.50000000E-00 0.60948319E 03	PHI =	0.39269903E-00 (RADIANS)
TIME=		R= 0.649999999E 00 0.59947894E 03	PH[ =	0.39269903E-00 (RADIANS)
TIME=		R= 0.80000000E 00 0.60137347E 03	PHI =	0.39269903E-00 (RADIANS)
TIME=	0.6000000E 02	R= 0.2000000E-00	PHI =	0.78539805E 00 (RADIANS)

	Contra	rils	
	TEMPERATURE= 0.69773465E 03		
TIME=	D.60000000E 02 R= 0.35000000E-00 TEMPERATURE= 0.60268202E 03	PHI =	0.78539805E 00 [RADIANS]
TIME≖	0.60000000E 02 R= 0.50000000E-00 TEMPERATURE= 0.59929526E 03	PHI =	0.78539805E 00 (RADIANS)
TIME=	0.60000000E J2 R= 0.64999999E 00 FEMPERATURF= 0.59451863E 03	PHI =	0.78539805E 00 (RADIANS)
TIME=	0.60000000E 02 R= 0.80000000E 00 femperature= 0.59646590E 03	PHI ≭	0.78539805E 00 (RADIANS)
TIME=	0.60000000E 02 R= 0.20000000E-00 TEMPERATURE= 0.68073674E 03	PHI =	0.11783971E 01 (RADIANS)
TIME=	0.60000000E 02 R= 0.35000000E-00 TEMPERATURE* 0.60161132E 03	₽HI =	0.117839716 01 [RADIANS]
TIME	0.60000000E 02 R= 0.50000000E-00 TEMPERAFURE= 0.59952266E 03	PH[ =	0.11783971Ë 01 (RADIANS)
TIME=	0.60300000E DZ R= 0.64999999E 00 TEMPERATURE= 0.59479115E 03	PHI =	0.11783971E 01 (RADIANS)
ŦĽĦE=	0.60000000E 02 R= 0.80000000E 00 TEMPERATURE= 0.59791932E 03	PHI =	0.11783971E 01 (RADIANS)
TIME=	0.60000000E D2 R= 0.2000000E-00 Temperature= 0.6799471DE 03	PH[ ≠	0.15707961E 01 (RADIANS)
TIME=	0.60000000E D 2 R* 0.35000000E-00 TEMPERATURE= 0.66199214F 03	PHI =	0.15707961E 01 (RADIANS)
TINE=	0.60000000E D2 R= 0.50000000E-00 Temperature= 0.64698175E 03	PHI =	0.15707961E 01 (RADIANS)
₹ <b>T</b> ME=	0.60000000E 02 R= 0.649999999E 00 TEMPERATURE= 0.62976302E 03	PHI =	0.15707961E 01 (RADIANS)
TIME=	0.60000000E 02 R= 0.80000000E 00 TEMPERATURE= 0.62753208E 03	PHI =	0.15707961E D1 (RADIANS)
TIME=	0.80000000E 02 R= 0.20000000E-00 FEMPERATURE≅ 0.75605733E 03	PHI =	D. (RADIANS)
TIME=	0.80000000E 02 R# 0.35000000E-00 TEMPERATURE# 0.76860051E 03	PHI =	0. (RADIANS)
t[ME=	0.80000000E 02 R= 0.50000000E+00 TENPERATURE= 0.78428653E 03	PHI =	0. (RADIANS)
T[ME=	0.8000000CE 02 R= 0.649999999E 00 TEMPERATURE= 0.79771102E 03	PHI =	0. (RADIANS)
TIME=	0.80000000E 02 R= 0.80000000E 00 TEMPERATURE= 0.82422649E 03	PHI =	0. (RADIANS)
ſſME≠	0.80000006E 02 R= 0.20000000E-00 Temperature= 0.73574660E 03	PH[ =	0.39269903E-00 (RADIANS)
1 ( ME =	0.80000000E_02 R= 0.35000000E-00 TEMPERATURE= 0.63483462E_03	PHI =	0.39269903E-00 (RADEANS)
ſ[#E≖	0.80000000E 02 R= 0.5000000E-00	PHI =	0.39269903E-00 (RADIANS)

Contrails

	TEMPERATURE=	0.61723180E 03		
T[ME=	0.8000000CE 02 TEMPERATURE=	R≠ 0.64999999E 00 0.60327910E 03	PHI =	0.39269903E-00 (RADIANS)
T I ME =	0.80000000E 02 TEMPERATURE=	R= 0.80000000E 00 0.60368118E 03	PHI =	0.39269903E-00 (RADIANS)
TIME=	0.8000000CE 02 Temperature=	R± 0.20000000E-00 0.73297232E 03	PHI =	0.78539805E 00 IRADIANS)
r:me=	0.80000000E 02 TEMPERATURE=	R= 0.35000000E-00 0.61101406E 03	PH[ =	0.78539805E 00 (RADIANS)
TIME=	0.80000000E 02 Temperature=	R= 0.50000000E-00 0.59999804E 03	₽HI =	0.78539805E 00 (RADIANS)
<b>[[ME</b> ≠	0.8000000CE 02 Temperature=	R= 0.64999999E 00 0.59432294E 03	PHI =	0.78539805E 00 (RADIANS)
TIME=	0.80000000E 02 TEMPERATURE=	R# 0.80000000E 00 0.59615901E 03	PHI =	0.78539805E 00 (RADIANS)
TIME=	0.80000000E 02 Temperature=	R= 0.20000000E-00 0.71525703E 03	PHI =	0.11783971E 31 (RADIANS)
Γ∐HE×	0.80000000E 02 Temperature*	<b>R* 0.35000000E-00</b> 0.61377184E 03	PHI =	0.11783971E 01 (RADIANS)
TIME=	0.8000000QE 02 Tenperature=	R= 0.50000000E-00 0.60192450E 03	PH <b>I</b> =	0.11783971E 01 (RADIANS)
TIME=	0+80000000E D2 femperature=	R= 0.64999999E 00 0.59438409E 03	PHI =	0.11783971E 01 (RADIANS)
TIME=	0.80000000E 02 Temperature=	R= 0.80000000E 00 0.59701450E 03	PHI =	0.11783971E 01 (RADIANS)
T [RE=	G.80000000E 02 Temperature=	R= 0.2000000E-00 0.71443398E 03	PHI =	0.15707961E 01 (RADIANS)
TIME=	0.8000000CE 02 TEMPERATURE=	R= 0.35000000E-00 0.69571693E 03	PHI =	0.15707961E 01 (RADIANS)
rime=	0.80000000E 02 TEMPERATURE=	R= 0,50000000E-00 0.68006610E 03	₽HI =	0.15707961E 01 (RADIANS)
TIME=	0.80000000E 02 TEMPERATURE*	R= 0.649999999E 00 0.66213883E 03	PHI =	0.15707961E 01 (RADIANS)
TIME=		R= 0.83000000E 00 0.65978186E 03	= IH9	0.15707961E 01 (RADIANS)
tene=		R= 0.20000000E-00 0.82598023£ 03	PHI =	D. IRADIANS)
TIME=		R= 0.35000000E-00 C.83948170E 03	PHI =	0. (RADIANS)
ftme=	0.12000COCE 03 TEMPERATURE=	R= 0.53000090E-00 0.85636165E 03	PHI =	0. (RADIANS)
FINE=		R= 0.649999998 00 0.87080405E 03	PH[ =	0. (RADIANS)
TINE=	0.12000000E 03	R= 0.8000000E 00	PH[ =	0. ERADIANSI

Contrails

	TEMPERATURE=	0.89931993E 03		
	I CHPEKALUKE=	0.899319936 03		
TIME=	0.12000000E 03 TEMPERATURE=	R= 0.2000000E+00 0.80411071E 03	PHI =	0.39269903E-00 (RADIANS)
ſ[ME≖	0.12000000E 03 TEMPERATURE=	R= 0.35000000E-00 0.67477295E 03	PH[ =	0.39269903E-00 (RADIANS)
TIME=	0.12000000E 03 FEMPERATURE=	R= 0.5000000E-00 0.63892967E 03	PHI =	0.39269903E-00 (RADIANS)
TIME=	0.12000000E 03 TEMPERATURE=	R= 0.64999999E 00 0.61598204E 03	PHI =	0-39269903E-00 (RADIANS)
FIME=	0.12000000E 03 TEMPERATURE=	R≢ 0.80000000E 00 0.61299543E 03	PHI =	0.39269903E-00 (RADIANS)
TIME≈	0.1200000CE 03 TEMPERATURE=	R= 0.2000000E-00 0.80112283£ 03	PH[ =	0.78539805E 00 (RADIANS)
TINE=	0.12000000E 03 TEMPERATURE=	R≠ 0.35000000€-00 0.63573340E 03	PH[ =	0.78539805E 00 (RADIANS)
TEME=	0.12000000E 03 TEMPERATURE=	R= 0.5000000E-00 0.60465853E 03	PH[ =	0.78539805E DO IRADIANS)
T I ME =	0.12000000E 03 TEMPERATURE=	R= 0.64999999E 00 0.59474177E 03	PHI =	0.78539805E 30 (RADIANS)
TIME=	0.12000000E 03 TEMPERATURE=	R= 0.80000000E 00 0.59607594E 03	PH[ =	0.78539805E 00 (RADIANS)
TIME=	0.12000000E 03 TEMPERATURE=	R= 0.2000000E-00 0.78203952E 03	PHI =	0.11783971E 01 [RADIANS]
<b>F</b> ↓ME≠	0.12000000E 03 TEMPERATURE=	R= 0.3500000E-00 D.64688766E 03	₽H[ =	0-11783971E 01 (RADIANS)
ŤĮME=	0.12000000E 03 TEMPERATURE=	R= 0.5000000E-00 0.61398914E 03	PHI =	0.11783971E 01 (RADIANS)
TEME=	0.12000000E 03 TEMPERATURE=	R= 0.64999999E 00 0.59765728E 03	PHI =	0.11783971E 01 IRADIANS
TINE=	0.12000000E 03 TEMPERATURE=	R= 0.8000000E 00 0.59766819E 03	PHI =	0.11783971E D1 (RADIANS)
TIME=	0.120000COE 03 TEMPERATURE=	R= 0.20000000E-00 0.78115273E 03	PHI =	0.15707961E 01 (RADIANS)
rine≠		R≖ 0.35000000E~00 0.76098222E 03	PHI =	0.15707961E 01 (RADIANS)
TIME=		R= 0.50000000E-00 0.74410966E 03	PHE =	0.15707961E 31 (RADIANS)
TIME=		R= 0.64999999E 00 0.72474324F 03	PHE =	0.15707961E 01 (RADIANS)
TIME=		R* 0.80000000E 00 0.72223310E 03	PH[ =	0.15707961E 01 (RADIANS)
END-OF-DATA ENCOUNTERED ON SYSTEM INPUT FILE.				
PP	,F0081 ,008180,	181-26203		

END OF JOB + FD081 + START TIME=171347 STOP FIME=172148

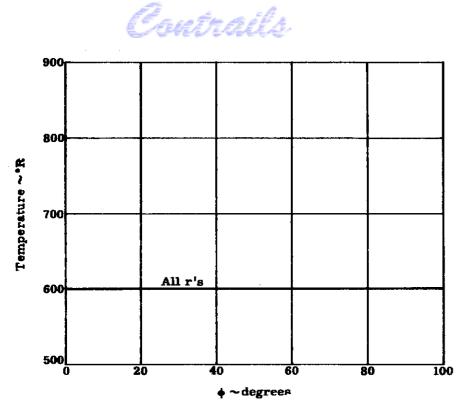


Figure 8. Temperature Distribution, Sample Problem No. 2,  $\theta = 0$  Second

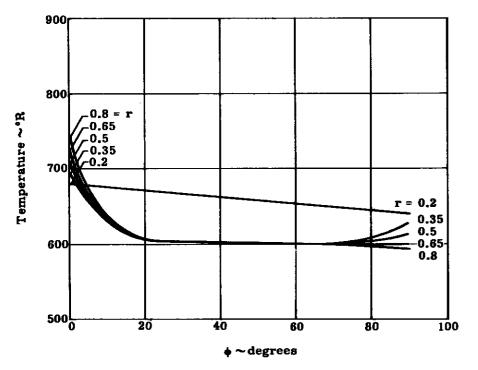


Figure 9. Temperature Distribution, Sample Problem No. 2,  $\theta = 40$  Seconds

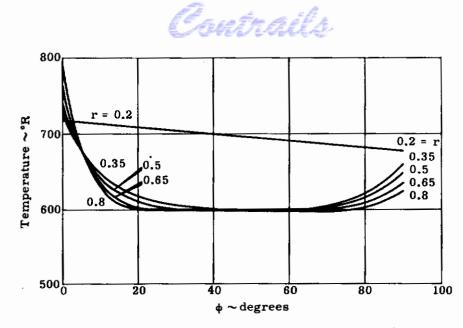


Figure 10. Temperature Distribution, Sample Problem No. 2,  $\theta = 60$  Seconds

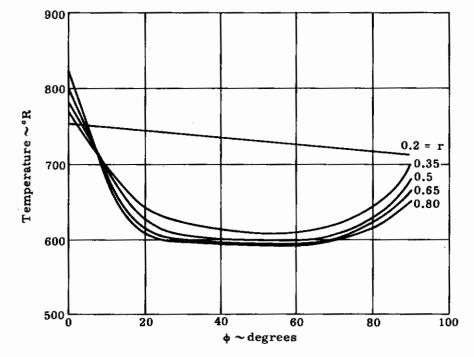


Figure 11. Temperature Distribution, Sample Problem No. 2,  $\theta = 80$  Seconds

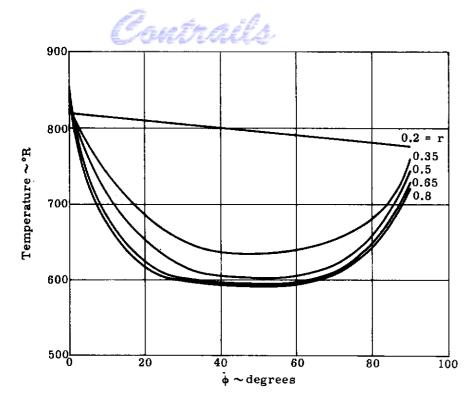


Figure 12. Temperature Distribution, Sample Problem No. 2,  $\theta$  = 120 Seconds

Contrails

# APPENDIX A

# STEADY STATE SOLUTION

Contrails

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## APPENDIX A

Contrails

# STEADY STATE SOLUTION

The steady state solution resulting from the coordinate varying boundary condition functions in Equations (75) through (78) is required to obtain  $f(r,\phi)$  as discussed in Section II. This steady state solution can be written

$$f(r,\phi) = T_{r1}(r,\phi) + T_{r2}(r,\phi) + T_{\phi1}(r,\phi) + T_{\phi2}(r,\phi)$$
(99)

where the individual functions are the result of the prescribed boundary condition at the particular surface noted by the subscript. A solution similar to that used in Reference 4 is presented in this Appendix. The solution primarily differs from that used in Reference 4 in that basic exponentials are used rather than hyperbolic functions.

The use of hyperbolic functions in the solution of problems in heat transfer is so universal that this departure should be explained. The use of basic exponentials offers several advantages over hyperbolic functions in preparing mathematical solutions applicable to digital computers. A prime advantage is that the solution in basic exponentials can be manipulated to avoid machine overflow by keeping arguments raised to positive or negative powers less than or greater than unity, respectively. Hyperbolic functions, as calculated by machine, necessarily contain both a positive and negative exponent of the argument and cannot be so manipulated. Secondly, the basic exponential form is easier to evaluate in certain indeterminate forms and special cases. The solution used in the digital program is as follows\*:

1. 
$$T_{r1}(r,\phi)$$
  
 $T_{r1}(r,\phi) = \sum_{\gamma} P_{\gamma} \left[ B_{\gamma} \sin \gamma \phi + F_{\gamma} \cos \gamma \phi \right] \xi_{r1}$  (100)

where in general  $(\gamma \neq 0)$ 

$$\xi_{r1} = \frac{(-1)^{\ell_{22}} \left(\frac{r}{r_{1}}\right)^{-\gamma} + \left(\frac{r_{1}}{r_{2}}\right)^{\gamma} \left(\frac{r}{r_{2}}\right)^{\gamma}}{\left(\frac{r}{r_{1}}\right)^{-\ell_{11}} \left[\left(-1\right)^{\ell_{22}} \left(-1\right)^{-\ell_{11}} + \left(\frac{r_{1}}{r_{2}}\right)^{-2\gamma}\right]} \quad \text{and} \quad (101)$$

\*Valid for  $\phi_1 = 0$ .

$$P_{\gamma} = \frac{\int_{\phi_1}^{\phi_2} F_{r1}(\phi) \left[ B_{\gamma} \sin \gamma \phi + F_{\gamma} \cos \gamma \phi \right] d\phi}{\int_{\phi_1}^{\phi_2} \left[ B_{\gamma} \sin \gamma \phi + F_{\gamma} \cos \gamma \phi \right]^2 d\phi}$$
(102)

If  $B_\gamma$  is infinite, that particular term in the series of Equation (100) is indeterminate and must be replaced by

$$\mathbf{P'} \sin \gamma \phi \, \xi_{\mathbf{r}1} \tag{103}$$

where

$$P' = \frac{\int_{\varphi_1}^{\varphi_2} F_{r1}(\phi) \sin \gamma \phi}{\left[\frac{\phi}{2} - \frac{1}{4\gamma} \sin 2\gamma \phi\right]_{\phi_1}^{\phi_2}} . \qquad (104)$$

The arbitrary function in Equation (104) is defined in relation to the boundary condition at the surface as follows:

<u>1</u> If  $l_{12}$  equals unity

$$F_{r1}(\phi) = T \left[ f_{r1}(\phi) \right]$$
 (transform). (105)

 $\underline{2}$  If  $\ell_{12}$  equals zero

$$F_{r1}(\phi) = \frac{1}{k_o} f_{r1}(\phi)$$
 (106)

If  $\gamma$  equals zero, i.e., both  $k_{11}$  and  $k_{21}$  equal zero, an additional term must be added to Equation (110) as follows:

1 If  $(\ell_{12}, \ell_{22})$  equals (1, 0), the term is

$$\frac{1}{\phi_2 - \phi_1} \int_{\phi_1}^{\phi_2} \mathbf{F}_{r1}(\phi) \, d\phi.$$
 (107)

Contrails

 $\underline{2}$  If ( $\ell_{12}$ ,  $\ell_{22}$ ) equals (1, 1) the term is

$$\frac{\ln \frac{r}{r_2}}{(\phi_2 - \phi_1)\ln \frac{r}{r_2}} \int_{\phi_1}^{\phi_2} F_{r1}(\phi) d\phi.$$
(108)

 $\underline{3}$  If  $(\ell_{12}, \ell_{22})$  equals (0, 1) the term is

$$\frac{\mathbf{r}_{1} \quad \mathbf{r}_{2}}{\mathbf{\phi}_{2} - \mathbf{\phi}_{1}} \quad \int_{\mathbf{\phi}_{1}}^{\mathbf{\phi}} \mathbf{F}_{r1}(\mathbf{\phi}) \, d\mathbf{\phi} \quad . \tag{109}$$

- $\underline{4}$  If ( $\ell_{12}$ ,  $\ell_{22}$ ) equals (0, 0) the term is infinite.
- 2. T<sub>r2</sub> (r, φ)

$$T_{r2}(r,\phi) = \sum_{\gamma} L_{\gamma} \left[ B_{\gamma} \sin \gamma \phi + F_{\gamma} \cos \gamma \phi \right] \xi_{r2}$$
(110)

where, in general ( $\gamma \neq 0$ )

$$\xi_{r2} = \frac{(-1)^{\ell_{12}} \left(\frac{r_{1}}{r_{2}}\right)^{\gamma} \left(\frac{r}{r_{1}}\right)^{-\gamma} + \left(\frac{r}{r_{2}}\right)^{\gamma}}{\frac{r}{r_{2}}^{2\gamma}} \qquad (111)$$

$$\frac{\int_{-\frac{\gamma}{r_{2}}}^{\frac{\varphi}{r_{2}}} F_{r2}(\phi) \left[B_{\gamma} \sin \gamma \phi + F_{\gamma} \cos \gamma \phi\right] d\phi}{\int_{-\frac{\varphi}{r_{1}}}^{\frac{\varphi}{r_{2}}} \left[B_{\gamma} \sin \gamma \phi + F_{\gamma} \cos \gamma \phi\right]^{2} d\phi} \qquad (112)$$

If  $B_{\gamma}$  is infinite, that particular term in the series (Equation (109) is replaced by

$$L'_{\gamma} \sin \gamma \phi \xi_{r2}$$
(113)

where

$$L'_{\gamma} = \frac{ \int_{r_2}^{\phi_2} F_{r_2}(\phi) \sin \gamma \phi \, d\phi}{ \left[ \frac{\phi}{2} - \frac{1}{4\gamma} \sin 2\gamma \phi \right]_{\phi_1}^{\phi_2}}.$$
 (114)

The arbitrary function in Equation (114) is defined in relation to the boundary condition at the surface as follows:

Contrails

<u>1</u> If  $l_{22}$  equals unity

$$F_{r2}(\phi) = \Upsilon \left[ f_{r2}(\phi) \right]$$
 (transform). (115)

 $\frac{2}{2}$  If  $\ell_{22}$  equals zero

$$F_{r2}(\phi) = \frac{1}{K_o} f_{r2}(\phi). \qquad (116)$$

If  $\gamma$  is equal to zero, an additional term must be added to Equation (109), as follows:

 $\underline{1}$  If  $(\ell_{12}, \ell_{22})$  equals (0, 1) the term is

$$\frac{1}{\Phi_2 - \Phi_1} \int_{\Phi_1}^{\Phi_2} \mathbf{F}_{r2}(\phi) \, d\phi \quad . \tag{117}$$

 $\underline{2}$  If  $(\ell_{12}, \ell_{22})$  equals (1, 1) the term is

$$\frac{\ell_{n} \frac{\mathbf{r}}{\mathbf{r}_{2}}}{(\boldsymbol{\varphi}_{2} - \boldsymbol{\varphi}_{1}) \ell_{n} \frac{\mathbf{r}_{2}}{\mathbf{r}_{1}}} \int_{\boldsymbol{\varphi}_{1}}^{\boldsymbol{\varphi}_{2}} \mathbf{F}_{r2}(\boldsymbol{\varphi}) d\boldsymbol{\varphi}.$$
(118)

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 $\underline{3}$  If ( $\ell_{12}$ ,  $\ell_{22}$ ) equals (1, 0) the term is

$$\frac{r_2 \ln \frac{r}{r_2}}{(\phi_2 - \phi_1)} \int_{\phi_1}^{\phi_2} F_{r2}(\phi) d\phi. \qquad (119)$$

 $\underline{4}$  If  $(\ell_{12}, \ell_{22})$  equals (0, 0) the term is infinite.

3. 
$$T_{\phi 1}(\mathbf{r}, \phi)$$
  
 $T_{\phi 1}(\mathbf{r}, \phi) = \sum_{\epsilon} Q_{\epsilon} \left[ M_{\epsilon} \sin(\epsilon \ln \mathbf{r}) + F_{\ell} \cos(\epsilon \ln r_{1}) \right] \xi_{\phi 1}$  (120)

where  $\varepsilon$  are the real positive roots of

$$\frac{\ell_{11}\epsilon}{r_{1}}\cos\left(\epsilon \ell nr_{1}\right) + \ell_{12}\sin\left(\epsilon \ell nr_{1}\right) \qquad \ell_{12}\cos\left(\epsilon \ell nr_{1}\right) - \frac{\ell_{11}\epsilon}{r_{1}}\sin\left(\epsilon \ell nr_{1}\right) = 0$$

$$\frac{\ell_{21}\epsilon}{r_{2}}\cos\left(\epsilon \ell nr_{2}\right) + \ell_{22}\sin\left(\epsilon \ell nr_{2}\right) \qquad \ell_{22}\cos\left(\epsilon \ell nr_{2}\right) - \frac{\ell_{21}\epsilon}{r_{1}}\sin\left(\epsilon \ell nr_{2}\right) = 0$$
(121)

Equation (121) can be solved explicitly similar to Equation (45). In general ( $\epsilon \neq 0$ ) the terms in Equation (120) are defined as:

$$\xi_{\phi 1} = \frac{\left(-1\right)^{k} 2^{2} e^{-\epsilon \phi} + e^{-\epsilon (2\phi_{2}-\phi)}}{\left[\left(-1\right)^{k} 1^{1} \left(-1\right)^{k} 2^{2} + e^{-2\epsilon \phi_{2}}\right] e^{-k} 1^{1}} \qquad (122)$$

$$Q_{\epsilon} = \frac{\int_{r_{1}}^{r_{2}} F_{\phi 1}(r) \left[M_{\epsilon} \sin\left(\epsilon \ln r\right) + F_{\epsilon} \cos\left(\epsilon \ln r\right)\right] \frac{dr}{r}}{\int_{r_{1}}^{r_{2}} \left[M_{\epsilon} \sin\left(\epsilon \ln r\right) + F_{\epsilon} \cos\left(\epsilon \ln r\right)\right]^{2} \frac{dr}{r}} \qquad (123)$$

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$$M_{\epsilon} = \frac{\frac{\ell_{11}^{\epsilon}}{r_{1}} \sin (\epsilon \ell n r_{1}) - \ell_{12} \cos (\epsilon \ell n r_{1})}{\frac{\ell_{11}^{\epsilon}}{r_{1}} \cos (\epsilon \ell n r_{1}) + \ell_{12} \sin (\epsilon \ell n r_{1})} \qquad (124)$$

If  $M_{\epsilon}$  is infinite, that particular term in the series from Equation (120) is replaced by

$$Q' \sin(\epsilon \ln r) \xi_{\pm 1}$$
(125)

where

$$Q' = \frac{\int_{r_1}^{r_2} F_{\phi 1}(r) \sin(\epsilon \ln r) \frac{dr}{r}}{\left[\frac{\ln r}{2} - \frac{1}{4\epsilon} \sin(2\epsilon \ln r)\right]_{r_1}^{r_2}}.$$
 (126)

The arbitrary function in Equation (126) is defined in relation to the boundary condition at the surface as follows:

 $\underline{1}$  If  $k_{12}$  is equal to unity

$$\mathbf{F}_{\phi 1}(\mathbf{r}) = \Upsilon \left[ \mathbf{f}_{\phi 1}(\mathbf{r}) \right] . \tag{127}$$

 $\frac{2}{2}$  If  $k_{12}$  is equal to zero

$$F_{\phi 1}(\mathbf{r}) = \frac{\mathbf{r}}{K_o} f_{\phi 1}(\mathbf{r}). \qquad (128)$$

If  $\epsilon$  is equal to zero, i.e., both  $\ell_{12}$  and  $\ell_{22}$  equal zero, an additional term must be added to Equation (120) as follows

 $\underline{1}$  If (k<sub>12</sub>, k<sub>22</sub>) equals (1,0) the term is

$$\frac{1}{\ln \frac{r_2}{r_1}} \int_{r_1}^{r_2} F_{\phi 1}(r) \frac{dr}{r} . \qquad (129)$$

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 $\underline{2}$  If  $(k_{12}, k_{22})$  equals (1,1) the term is

$$\frac{\phi_2 - \phi}{\phi_2 \ln \frac{r_2}{r_1}} \int_{r_1}^{r_2} F_{\phi 1}(r) \frac{dr}{r} . \qquad (130)$$

 $\underline{3}$  If (k<sub>12</sub>, k<sub>22</sub>) equals (0,1) the term is

$$\frac{\phi - \phi_2}{\ln \frac{r_2}{r_1}} \int_{r_1}^{r_2} F_{\phi 1}(r) \frac{dr}{r} . \qquad (131)$$

 $\underline{4}$  If  $(k_{12}, k_{22})$  equals (0,0) the term is infinite.

4. Τ<sub>φ2</sub>(r,φ)

$$T_{\phi 2}(\mathbf{r}, \phi) = \sum_{\epsilon} \left[ M_{\epsilon} \sin(\epsilon \ln \mathbf{r}) + F_{\epsilon} \cos(\epsilon \ln \mathbf{r}) \right] \xi_{\phi 2}$$
(132)

where in general

$$\xi_{\phi 2} = \frac{\binom{k_{12}}{e} - \frac{\epsilon(\phi_{2} + \phi)}{e} + e}{\left[\binom{k_{21}}{e} - \frac{k_{12}}{e} + \frac{\epsilon(\phi_{2} - \phi_{2})}{e} + 1\right] \binom{k_{21}}{\epsilon}}.$$
 (133)  
$$r_{2}$$

$$W_{\epsilon} = \frac{\int_{r_{1}}^{r} F_{\phi 2}(r) \left[M_{\epsilon} \sin(\epsilon \ln r) + F_{\epsilon} \cos(\epsilon \ln r)\right] \frac{dr}{r}}{\int_{r_{1}}^{r_{2}} \left[M_{\epsilon} \sin(\epsilon \ln r) + F_{\epsilon} \cos(\epsilon \ln r)\right] \frac{dr}{r}} . (134)$$

If  $M_{\epsilon}$  is infinite, that particular term in the series from Equation (132) is replaced by

W' sin (
$$\epsilon lnr$$
)  $\xi_{\phi 2}$  (135)

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where

$$W' = \frac{\int_{\phi_2}^{r_2} F_{\phi_2}(r) \sin(\epsilon \ln r) \frac{dr}{r}}{\left[\frac{\ell n r}{2} - \frac{1}{4\epsilon} \sin(2\epsilon \ell n r)\right]_{r_1}^{r_2}}.$$
 (136)

The arbitrary function in Equation (136) is defined in relation to the boundary condition at the surface as follows:

 $\underline{1}$  If  $k_{22}$  is equal to unity

$$F_{\phi 2}(r) = T \left[ f_{\phi 2}(r) \right] \quad (transform) . \tag{137}$$

 $\underline{2}$  If  $k_{22}$  is equal to zero

$$F_{\phi 2}(r) = \frac{r}{K_0} f_{\phi 2}(r)$$
 (138)

If  $\epsilon$  is equal to zero an additional term must be added to Equation (132), as follows

1 If  $(k_{12}, k_{22})$  equals (0, 1) the term is

$$\frac{1}{\ln \frac{r_2}{r_1}} \int_{r_1}^{r_2} F_{\phi 2}(r) \frac{dr}{r} .$$
 (139)

 $\underline{2}$  If (k<sub>12</sub>, k<sub>22</sub>) equals (1,1) the term is

$$\frac{\phi}{\phi_2 \ln \frac{r_2}{r_1}} \int_{r_1}^{r_2} F_{\phi 2}(r) \frac{dr}{r} . \qquad (140)$$

 $\frac{3}{2}$  If  $(k_{12}, k_{22})$  equals (1, 0) the term is

$$\frac{\phi}{\ln \frac{\mathbf{r}_2}{\mathbf{r}_1}} \int_{\mathbf{r}_1}^{\mathbf{r}_2} \mathbf{F}_{\phi 2}(\mathbf{r}) \frac{\mathrm{d}\mathbf{r}}{\mathbf{r}}$$
(141)

 $\frac{4}{10}$  If  $(k_{12}, k_{22})$  equals (0, 0) the term is infinite.

The preceding solution characteristically converges to zero at a corner if both adjacent faces have prescribed temperature as the boundary condition. Consequently, a dummy term equal to the sum of one-half of the adjacent transform temperatures prescribed at that corner must be added before  $f(r,\phi)$  is used in Equation (80). The average of the prescribed temperatures, rather than either of the temperatures, is used to null out possible mismatch in defining arbitrary functions at a corner.

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## APPENDIX B

## FORTRAN LANGUAGE OF THE PROGRAM

Contrails

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G. C.C. C.C.C.C.	
\$IBFTC MAIN Common/ckout/nans(10)	000010 000020
COMMDN/GCAB/ARE(2), AREARE(200)/HCAB/PHI(2), PHIPHI(200)	000030
COMMON/SPACE1/RR(400), PP(400)	000040
COMMON/TORIAN/STOOD, ONLY, SNOW	000050
COMMON/ZOL/JPRINT(35) 1 FORMAT(3F10.0,A2,8X,2[10,A6]	000060 000070
2 FORMAT(1HO, 5HT[ME=E16.8,5X,2HR=E16.8,5X,4HPH[=E16.8,1X,	000080
1 9H(RADIANS))	000090
3 FORMAT(F10.0,50X,A6)	000100
5 FORMAT(7011) 10 FORMAT(1H015,1X,29HLATTICE POINT ANSWERS IN -R- /(8E16.8))	000110 000120
11 FORMAT(1HO15,1X,31HLATTICE POINT ANSWERS IN -PHI- /(BE16.8))	000130
20 FORMAT(1615)	000140
30 FORMATE 44HOERROR IN INPUT, PROBLEM UNABLE TO CONTINUE /	000150
1 52HOALTERATION OF FIXED INPUT SHOULD BE DONE WITH CARE )	000160 000170
CALL ATHRUZ (DNN, 6HON )	000180
CALL ATHRUZIALASS, 6HLAST T)	000190
100 CONTINUE	000200
OVER=0.0 READ(5,20) NANS	000210 000220
C NANS(1)= THE NUMBER OF GAMMAS USED IN MAIN	000230
C NANS(2) = THE NUMBER OF BETAS USED IN MAIN	000240
C NANS(3)= THE NUMBER OF INTERVALS FOR PHI INTEGRATION IN STATE	000250
C NANS{4}= THE NUMBER OF INTERVALS FOR R INTEGRATION IN STATE C NANS(5)= THE NUMBER OF LATTICE POINTS IN THE R DIRECTION IN STATE	000260 000270
C NANS(6) = THE NUMBER OF LATTICE POINTS IN THE PHI DIRECTION IN STATE	000280
C NANSITI = THE NUMBER OF GAMMAS / EPSILONS USED IN STATE	000290
C NANS(8)= THE NUMBER OF INTERVALS FOR PHI INTEGRATION IN MAIN	000300
C NANS(9)= THE NUMBER OF INTERVALS FOR R INTEGRATION IN MAIN C	000310 000320
IF(NANS(1).GT.30.dR.NANS(2).GT.30.DR.NANS(3).GT.200.DR.	000330
1 NANS (4). GT. 200. OR. NANS (5). GT. 7. OR. NANS (6). GT. 25. OR.	000340
2 NANS(7).GT.30.OR.NANS(8).GT.200.DR.NANS(9).GT.200.DR.	000350
3 NANS(10).GT.3} GO TO 9000 READ(5,5} JPRINT	000360 000370
C JPRINT IS THE INTERMEDIATE PRINT INDICATOR FOR INDVIDUAL SUBROUTINES	000380
IF(JPRINT(1).EQ.1) WRITE(6,20) NANS	000390
CALL INPUT IF(STOOD.NE.SNOW) CALL STATE	000400 000410
IF(STOOD.EQ.ONLY) GO TO 100	000420
CALL ARBCOE	000430
200 CONTINUE	000440
C READ(5,1) TIME,R,P,OPTION,N,M READ(5,1) TIME,R,P,OPTION,N,M,OVER	000450 000460
IF(OPTION_EQ.ONN) GO TO 300	000470
P=P+.01745329	000480
WRITE(6,2) TIME,R,P	000490
CALL SERIES(TIME+R+P+NG+NB) IF(OVER.EQ.ALASS) GO TO 100	000500 000510
GO TO 200	000520
300 CALL SIZE(RR,N,ARE(1),ARE(2))	000530
CALL SIZE(PP,M,PHI(1),PHI(2))	000540
IF(JPRINT(1)_NE.1) GO TO 400 WRITE(6.10) N.(RR(1),I=1.N)	000550 000560
WRITE(6,11) M, (PP(1), I=1, M)	000570
400 D0 500 IP=1,M	000580
DD 500 [R=1,N	000590
WRITE(6+2) TIME+RR(IR)+PP(IP) 500 CALL SERIES(TIME+RR(IR)+PP(IP))	000600 000610
IF(DVER.EQ.ALASS) GO TO 100	000620
READ(5,3) TIME, OVER	000630
GO TO 400 9000 WRITE(6,30)	000640 000650
STOP	000660
END	000670

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<b>SIBFTC</b>	BES	000680
	SUBROUTINE BES(A,X,Y,B,BP)	000690
2	FORMAT(1H ,4E20.8)	000700
-	DOUBLE PRECISION P , BJO , BJI , ARG , BR	000710
	P=0.	000720
	BJO=0.	000730
	BJ1≈0.	000740
		000750
	ARG=0.	000760
	PI=3.1415927	000770
	INEG=0	000780
	P=Y	000790
	ARG =.5+A+X	000800
	IF(ARG5)90,91,91	- + +
	IF(P)91,11,11	000810
91	CONTINUE	000820
	[F1P)5,11,4	000830
5	INEG=-1	000840
	[=P	000850
	PINT=I	000860
	NIT=1-I	000870
	PF=1.+P-PINT	000880
	P=PF	000890
	GO TO 11	000900
4	IF(ABS (P-1.)+1.)11,11,6	000910
	INEG=1	000920
0	I=P	000930
	PINT=I	000940
	NIT=1-1	000950
		000960
	PF=P→PINT	000970
	P=PF	000980
11	CONTINUE	000990
	P=P	
	ARG=.5+A+X	001000
	IF(ARG+P)15,10,15	001010
10	B=1.	001020
	BP=0.	001030
	GO TO 50	001040
15	1F(ARG)17,16,17	001050
16	ER=0.	001060
	GO TO 25	001070
17	IF{ARG-4.) 20,30,30	001080
20	ER=EXP (P+ALOG(ARG))	001090
25	AD=P+2.	001100
	AP=P+1.	001110
	A1=ARG++2	001120
	AK=1.	001130
	CALL GAMMA(AP,G)	001140
	T1=ER/G	001150
	B#T1	001160
	BP=T1=P	001170
	DO 28 1=1,100	001180
	TN=-T1/AK+A1/AP	001190
	B=B+TN	001200
	TNP=TN+AD	001210
	BP=BP+TNP	001220
		001230
	IF(ABS (TN)1E-07)26,26,27	001240
	IF(ABS (TNP)1E-07)29,29,27	001250
27		001250
	AK=AK+1.	001270
	AD=AD+2.	001280
	AP = AP + 1	001290
29	BP=BP/X	001300
	IF(INEG)60,50,60	
60	BJO=B	001310
	BJO=BJO	001320
	BJ1=(B+P-X+BP)/(A+X)	001330
	BJ1≠BJ1	001340
	GO TO 50	001350

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30	F1=SQRT (PI+ARG)	001360
	IDER=0	001370
	A1=-(A+X)++2	001380
	R=4.*P=*2	001390
	F2=2.*ARG-{2.*P+1.}*PI/4.	001400
31	CF2=COS (F2)	001410
	SF2=SIN (F2)	001,420
	T1= (R-1.)+(R-9.)/(128.*A1)	001430
	T1M=T1	001440
	T2=(1R)/(8.*A*X)	001450
	T2M=T2	001460
	\$1=1.+T1	001470
	S2=T2	001480
	2=2.	001490
	J=1	001500
	DO 36 [=1,100	001510
	ICNT=1 CO_TO(40_45_40)	001520 001530
40	GC TD(40,45,40),J TMl=(R-{4.#Z-3.}##2}#{R-{4.#Z-1.}##2}/{{2.#Z~1.}#Z#128.#A1}	001540
40	IF(ABS (TMI)-ABS (T1M))43.51.51	001550
51	IF(ABS (TMI)-1.)43,41,41	001560
-	GO TO(42, 42, 37), J	001570
	J=2	001580
•	GO TO 44	001590
43	TI=TI+THI	001600
	TIN=TMI	001610
	SI=SI+T1	001620
	IF(ABS (T1)1E-07)41,41,44	001630
	GO TO(45,45,36),J	001640
45	TH2=(R-{4.+Z-3.}++2)+(R-{4.+Z-5.}++2)/((2.+Z-1.)+(Z-1.)+128.+A1)	D01650
	IF(ABS (TM2)-ABS (T2M))48,49,49	001660
	IF(ABS (TM2)-1.)48,46,46	001670
	GO_TO(47,37,47),J	001680
47	J=3	001690
	GO TO 36	001700
48	T2=T2+TM2	001710
	T2N=TN2	001720
	S2=S2+T2	001730
34	IF(ABS (T2)1E-07)46,46,36	001740
	Z=Z+1. IF(IDER)39,38,39	001750 001760
	B=(CF2+S1+SF2+S2)/F1	001770
20	F2=F2-PI/2.	001780
	R=4.*(P+1.)**2	001790
	IDER=1	001800
	GO TO 31	001810
39	BD=(CF2+S1+SF2+S2)/F1	001820
	BP=P+B/X-A+BD	001830
	BJO∓B	001840
	B10≈B10	001850
	BJ1=BD	001860
	BJ1=BJ1	001870
	IF(INEG)65,70,80	001880
65	DG 61 I=1,NIT	001890
	BR=P+BJO/ARG-BJ1	001900
	BJ1=BJ0	001910 001920
	BJD=BR	001930
91	P=P-1.	001940
	B=BJO PO=D=B(Y=A=B)	001950
	BP=P+B/X-A+BJ1 Go To 70	001960
90	P=P+1.	001970
00	DO 81 I=1.NIT	001980
	BR=(P+BJ1)/ARG-BJ0	001990
	BJO=BJ1	002000
	BJ1=BR	002010
81	P=P+1.	002020
	B=BJ1	002030

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BP=A+BJO-P+B/X	002040
70 RETURN	002050
END	002060
SIBFTC POLYH	002070
SUBROUTINE POLYH(Z,X,Y,NX,NY,NTERMS)	002080
c	002090
C ACCEPTS NO MORE THAN 10 TERMS	002100
C C	002110
COMMON/Z01/JPRINT(35)	002120
DIMENSION $A(2), V(2), E(20), COE(10)$	002130
DIMENSION $X(1), Y(1), Z(7, 1)$	002140
1 FORMAT(3F10.0)	002150
2 FORNAT(35HOPOLYNOMIAL EXCEEDS PROGRAM DESIGNS)	002160
3 FORMAT( 3H X=E16.8,5X,2HY=E16.8,5X, 2HZ(I1,1H,I2,2H)=E16.8)	002170
4 FORMAT(15X,1H(E16.8,5H)(R++F10.4,5H)(P++F10.4,1H))	002180
2000 FORMAT(1X,17HPOLYNOMIAL DATA, ,12,1X,5HTERMS)	002190
WRITE(6,2000) NTERMS	002200
IF(NTERMS.LE.10) GD TO B	002210
WRITE(6,2)	002220
STOP	002230
8 CONTINUE	002240
READ(5,1)(COE(I),E(2+I-1),E(2+I),I=1,NTERMS)	002250
WRITE(6,4) (COE(I),E(2+I-1),E(2+I),I=1,NTERMS)	002260
DO 200 IY=1,NY	002270
V(2)=Y(IY)	002280
DD 200 IX=1,NX	002290
V(1)=X(1X)	002300
Z(IX, IY)=0.	002310 002320
DD 60 NT=1,NTERMS 1F(CDE(NT).EQ.O.) GO TO 60	002320
DD 40 L=1.2	002340
K=NT+L−1	002350
1F(E(K),EQ.0.) GO TO 35	002360
IF(V(L).EQ.0.) GO TO 60	002370
C INDETERMINANT FORM OFFO IS SET TO UNITY	002380
A(L)=V(L)++E(K)	002390
GO TO 40	002400
35 A(L) = 1.0	002410
50 CONTINUE	002420
Z(IX, IY) = Z(IX, IY) + COE(NT) + A(1) + A(2)	002430
60 CONTINUE	002440
[F(JPRINT(3).EQ.1) WRITE(6,3) V, 1X, 1Y, Z(1X, 1Y)	002450
200 CONTINUE	002460
RETURN	002470
END	002480

SIBFT	C VLINE	002490
	SUBROUTINE VLINE(NX,NY,XIN,YIN,XARRAY,YARRAY,ZARRAY,L,M,ZOUT)	002500
	DIMENSION XARRAY(1),YARRAY(1),ZARRAY(L,M),A(2)	002510
С		002520
	DO 100 I=2.NX	002530
	K=I	002540
100	IF(XIN.LE.XARRAY(I)) GO TO 110	002550
110	DO 200 [=2,NY	002560
	]=[	002570
200	IF(YIN.LE.YARRAY(I)) GD TO 210	002580
210	REG=(YIN-YARRAY(J-1))/(YARRAY(J)-YARRAY(J-1))	002590
	DO 220 $i=1,2$	002600
	A(1)=ZARRAY(K-1, J-1)+(ZARRAY(K-1, J)-ZARRAY(K-1, J+1))+REG	002610
220	K=K+1	002620
	ZDUT = A(1) + (A(2) - A(1)) = (XIN - XARRAY(K-3)) / (XARRAY(K-2) - XARRAY(K-3))	002630
	RETURN	002640
	END	002650

Contrails	
\$IBFTC LEFT	002660
SUBROUTINE LEFT(A,B,C,X,Y,Z)	002670
A=X	002680
B=Y	002690
C=Z	002700
RETURN	002710
END	002720
<pre>\$[BFTC SIZE</pre>	002730
SUBROUTINE SIZE(A,MAX,AMIN,AMAX)	002740
DIMENSION A(1)	002750
A(1)=AMIN	002760
A(MAX)=AMAX	002770
L=MAX-1	002780
AL=L	002800
DX={AMAX-AMIN}/AL	002810
DO 10 I=2,L	002810
AI=I-1	002820
10 A(I)=AI+DX+A(1)	002830
RETURN	002840
END	002850
<pre>\$IBFTC WODFER SUBROUTINE WODFER COMMON/SPACE/YDUM(200),Y(200) COMMON/ZCAB/XTRAN(50),YTRAN(50),MAXMAX COMMON/ZCCAB/AZERO COMMON/ZCAB/AZERO COMMON/ZO1/JPRINT(35) 1 FORMAT(40HOTRANSFORMED THERMO PHYSICAL PROPERTIES } 2 FORMAT(10X, 9HXTRAN(1)=E16.8,5X, 9HYTRAN(1)=E16.8,5X,3HI= ,15) IF(JPRINT(7).EQ.1) WRITE(6,1) YTRAN(1)=0. DO 40 I=2,MAXMAX Y(1)=YDUM(I-1) Y(50)=YDUM(I-1) Y(50)=YDUM(I-1) Y0IFF=XTRAN(I)-XTRAN(I-1) Y0IFF=XTRAN(I)-YTRAN(I)-1) Y0IFF=YDUM(I-1)+(YDIFF=(X-XTRAN(I-1)))/XDIFF 30 CONTINUE CALL SIMP(50,DX,Y,YTRAN(I)) YTRAN(I)=YTRAN(I)/AZERO +YTRAN(I),YTRAN(I),I,I=1,MAXMAX) RETURN END</pre>	002860 002870 002880 002900 002910 002910 002920 002930 002940 002950 002950 002960 002970 002980 002990 003000 003010 003020 003040 003050 003050 003060 003050 003060 003070 003080 003110 003110

STBFTC POLYGN	003130
SUBROUTINE POLYGN(X,Y,NY,NTERMS)	003140
C	003150
C ACCEPTS NO MORE THAN 10 TERMS	003160
COMMON/ZO1/JPRINT(35)	003170
DIMENSION X(1),Y(1),COE(10),ORDER(10)	003180
1 FORMAT(3F10.0)	003190
2 FORMAT(35HOPOLYNOMIAL EXCEEDS PROGRAM DESIGNS)	003200
3 FORMAT(15X,1H(E16.8,5H)(X++F10.4,1H))	003210
4 FORMAT(18H POLYNOMIAL DATA, ,12,1X,23HTERMS, X=DUMMY VARIABLE)	003220
5 FORMAT(3H X=E16.8,5X,2HY(13,2H)=E16.8)	003230
2 FORMAT(35HOPOLYNOMIAL EXCEEDS PROGRAM DESIGNS) 3 FORMAT(15X,1H{E16,8,5H}(X**F10.4,1H}) 4 FORMAT(18H POLYNOMIAL DATA, ,12,1X,23HTERMS, X=DUMMY VARIABLE)	003200 003210 003220

C 003240 WRITE(6,4) NTERMS 003250 IF(NTERMS.LE.10) GO TO 7 003260 WRITE(6,2) 003270 STOP 003280 7 DO 8 I=1,NTERMS 003290 READ(5,1) COE(1),ORDER(I) 003300 WRITE(6,3) COE(1),ORDER(I) 003310 B CONTINUE 003300 V(I)=0. 003340 DO 50 I=1,NY 00330 Y(I)=0. 003340 DO 30 J=1,NTERMS 003350 IF(ORDER(J).EQ.0.) GO TO 10 C INDETERMINANT FORM 0**0 IS SET TO UNITY 003370 IF(X(I).EQ.0.) GO TO 30 A*X(I)**ORDER(J) GO TO 20 00340 10 A=1.0 00340 20 Y(I)=Y(I)+CDE(J)*A 00340 SO IF(JPRINT(8).EQ.1) WRITE(6,5) X(1),I,Y(I) RETURN 003450		
WRITE(6,4) NTERMS       003250         IF(NTERMS.LE.10) GO TO 7       003260         WRITE(6,2)       003270         STOP       003280         7 DO 8 I=1,NTERMS       003290         READ15,11 COE(1),ORDER(I)       003300         WRITE(6,3) COE(1),ORDER(I)       003310         B CONTINUE       003320         DO 50 I=1,NY       003320         DO 50 I=1,NY       003330         Y(1)=0.       003340         DO 30 J=1,NTERMS       003340         IF(ORDER(J).EQ.0.) GO TO 10       003360         C INDETERMINANT FORM 0**0 IS SET TO UNITY       003370         IF(X(I).EQ.0.) GO TO 30       003380         A=X(I)*ORDER(J)       003390         GO TO 20       003400         10 A=1.0       00340         20 Y(I)=Y(I)+COE(J)*A       003420         30 CONTINUE       003430         50 IF(JPRINT(8).EQ.1) WRITE(6,5) X(1),I,Y(I)       003440	c	003240
IF(NTERMS.LE.10) GO TO 7       003260         WRITE(6,2)       003270         STOP       003280         7 DO 8 I=1,NTERMS       003290         READ(5,1) COE(I),ORDER(I)       003300         WRITE(6,3) COE(I),ORDER(I)       003310         B CONTINUE       003320         DO 50 I=1,NY       003320         Y(I)=0.       003320         DO 30 J=1,NTERMS       003340         DO 30 J=1,NTERMS       003350         IF(ORDER(J).EQ.0.) GO TO 10       003360         C       INDETERMINANT FORM 0++0 IS SET TO UNITY       003370         GO TO 20       003400       003390         GO TO 20       003400       003400         10 A=1.0       003410       003420         20 Y(I)=Y(I)+CDE(J)=A       003420         30 CONTINUE       003420         50 IF(JPRINT(8).EQ.1) WRITE(6,5) X(1),I,Y(I)       003440	-	003250
WRITE(6,2)       003270         STOP       003280         7 DD 8 I=1,NTERMS       003290         READ15,1) CDE(I),ORDER(I)       003300         WRITE(6,3) CDE(I),ORDER(I)       003310         B CONTINUE       003220         DO 50 I=1,NY       003320         Y(I)=0.       003340         DO 30 J=1,NTERMS       003340         IF(ORDER(J).EQ.0.) GO TO 10       003360         C INDETERMINANT FORM 0++0 IS SET TO UNITY       003370         IF(X(I).EQ.0.) GO TO 30       003390         A=X(I)+ORDER(J)       003400         GO TO 20       003400         10 A=1.0       003410         20 Y(I)=Y(I)+CDE(J)+A       003420         30 CONTINUE       003420         50 IF(JPRINT(8).EQ.1) WRITE(6,5) X(I),I,Y(I)       003440		003260
STOP       003280         7 DD 8 I=1,NTERMS       003290         READ15,1) COE(I),ORDER(I)       003300         WRITE(6,3) CDE(I),ORDER(I)       003310         B CONTINUE       00320         D0 50 I=1,NY       003320         D0 50 I=1,NY       003340         Y(I)=0.       003340         D0 30 J=1,NTERMS       003350         IF(ORDER(J).EQ.0.) GO TO 10       003360         C       INDETERMINANT FORM 0++0 IS SET TO UNITY       003370         IF(X(I).EQ.0.) GO TO 30       003390         A=X(I)+HORDER(J)       003400         GO TO 20       003400         10 A=1.0       003420         20 Y(I)=Y(I)+CDE(J)=A       003420         30 CONTINUE       003420         50 IF(JPRINT(8).EQ.1) WRITE(6,5) X(I),I,Y(I)       003440	•••••••••••••••••••••••••••••••••••••••	003270
7       DO       8       I=1,NTERMS       003290         READ15,1)       COE(I),ORDER(I)       003300         WRITE(6,3)       COE(I),ORDER(I)       003310         B       CONTINUE       003320         DO       50       I=1,NY       003320         DO       50       I=1,NY       003320         Y(I)=0.       0030       J=1,NTERMS       003340         DO       30       J=1,NTERMS       003350         IF(ORDER(J).EQ.0.)       GO       TO       003360         C       INDETERMINANT FORM       0++0       IS       SET         IF(X(I).EQ.0.)       GO       TO       003390         A=x(I)++ORDER(J)       003400       003400         GO       TO       003410         A=x(I)+CDE(J)=A       003420       003420         30       CONTINUE       003430         50       IF(JPRINT(8).EQ.1)       WRITE(6,5)       X(I),I,Y(I)		003280
READ15,1) COE(1),ORDER(I)       003300         WRITE(6,3) COE(1),ORDER(I)       003310         B CONTINUE       003320         DO 50 I=1,NY       003330         Y(1)=0.       003340         DO 30 J=1,NTERNS       003350         IF(ORDER(J).EQ.0.) GO TO 10       003360         C INDETERMINANT FORM 0++0 IS SET TO UNITY       003370         IF(X(I).EQ.0.) GO TO 30       003380         A=X(I)++ORDER(J)       003400         GO TO 20       003400         10 A=1.0       003420         20 Y(I)=Y(I)+COE(J)=A       003420         30 CONTINUE       003430         50 IF(JPRINT(8).EQ.1) WRITE(6,5) X(I),I,Y(I)       003440		003290
WRITE(6,3) COE(1), ORDER(1)       003310         B CONTINUE       003320         D0 50 1=1,NY       003330         Y(1)=0.       003340         D0 30 J=1,NTERNS       003350         IF(ORDER(J).EQ.0.) GO TO 10       003360         C INDETERMINANT FORM 0++0 IS SET TO UNITY       003370         IF(X(1).EQ.0.) GO TO 30       003380         A=X(1)++ORDER(J)       003390         GO TO 20       003400         10 A=1.0       003410         20 Y(1)=Y(1)+COE(J)=A       003420         30 CONTINUE       003430         50 IF(JPRINT(8).EQ.1) WRITE(6,5) X(1),I,Y(1)       003440		003300
B CONTINUE       003320         D0 50 I=1,NY       003330         Y(I)=0.       003340         D0 30 J=1,NTERNS       003350         IF(ORDER(J).EQ.0.) GD TO 10       003360         C INDETERMINANT FORM 0**0 IS SET TO UNITY       003370         IF(X(I).EQ.0.) GO TO 30       003380         A=x(I)*+ORDER(J)       003390         GO TO 20       003400         10 A=1.0       003400         20 Y(I)=Y(I)+COE(J)*A       003420         30 CONTINUE       003430         50 IF(JPRINT(8).EQ.1) WRITE(6,5) X(I),I,Y(I)       003440		003310
Y(I)=0.       003340         D0 30 J=1,NTERNS       003350         IF(ORDER(J).EQ.0.) GD TO 10       003360         C INDETERMINANT FORM 0++0 IS SET TO UNITY       003370         IF(X(I).EQ.0.) GD TO 30       003380         A=X(I)++ORDER(J)       003390         GD TO 20       003400         10 A=1.0       003420         20 Y(I)=Y(I)+CDE(J)+A       003420         30 CONTINUE       003430         50 IF(JPRINT(8).EQ.1) WRITE(6,5) X(I),I,Y(I)       003440	B CONTINUE	003320
D0 30 J=1,NTERNS       003350         IF(ORDER(J).EQ.0.) GO TO 10       003360         C INDETERMINANT FORM 0++0 IS SET TO UNITY       003370         IF(X(I).EQ.0.) GO TO 30       003390         A=X(I)++ORDER(J)       003390         GD TO 20       003400         10 A=1.0       003410         20 Y(I)=Y(I)+CDE(J)+A       003420         30 CONTINUE       003430         50 IF(JPRINT(8).EQ.1) WRITE(6,5) X(I),I,Y(I)       003440	DO 50 I=1,NY	003330
IF(ORDER(J).EQ.O.) GO TO 10       003360         C       INDETERMINANT FORM 0+0 IS SET TO UNITY       003370         IF(X(I).EQ.O.) GO TO 30       003380         A=x(I)++ORDER(J)       003390         GO TO 20       003400         10 A=1.0       003410         20 Y(I)=Y(I)+COE(J)+A       003420         30 CONTINUE       003430         50 IF(JPRINT(8).EQ.1) WRITE(6,5) X(I),I,Y(I)       003440	Y(I)=0.	003340
C       INDETERMINANT FORM       0++0       IS SET TO UNITY       003370         IF(X(I).EQ.0.) GO TO 30       003380       003390         A=X(I)++ORDER(J)       003390         GO TO 20       003400         10 A=1.0       003410         20 Y(I)=Y(I)+COE(J)+A       003420         30 CONTINUE       003430         50 IF(JPRINT(8).EQ.1) WRITE(6,5) X(I),I,Y(I)       003440	DO 30 J=1,NTERNS	003350
IF(X(I).EQ.0.) GO TO 30       003380         A=X(I)++ORDER(J)       003390         GO TO 20       003400         10 A=1.0       003410         20 Y(I)=Y(I)+COE(J)+A       003420         30 CONTINUE       003430         50 IF(JPRINT(8).EQ.1) WRITE(6,5) X(I),I,Y(I)       003440	IF(ORDER(J).EQ.O.) GO TO 10	003360
A=X(I)++ORDER(J)       003390         GD TO 20       003400         10 A=1.0       003410         20 Y(I)=Y(I)+COE(J)+A       003420         30 CONTINUE       003430         50 IF(JPRINT(8).EQ.1) WRITE(6,5) X(I),I,Y(I)       003440	C INDETERMINANT FORM O++O IS SET TO UNITY	003370
GD T0 20       003400         10 A=1.0       003410         20 Y(I)=Y(I)+CDE(J)=A       003420         30 CONTINUE       003430         50 IF(JPRINT(8).EQ.1) WRITE(6,5) X(I),I,Y(I)       003440	IF(X(I).EQ.0.) GO TO 30	003380
10 A=1.0       003410         20 Y(I)=Y(I)+CDE(J)=A       003420         30 CONTINUE       003430         50 IF(JPRINT(8).EQ.1) WRITE(6,5) X(I),I,Y(I)       003440	A=X(1)++ORDER(J)	003390
20 Y(I)=Y(I)+CDE(J)=A 003420 30 CONTINUE 003430 50 IF(JPRINT(8).EQ.1) WRITE(6,5) X(I),I,Y(I) 003440	GO TO 20	003400
30 CONTINUE 003430 50 IF(JPRINT(8).EQ.1) WRITE(6,5) X(1),I,Y(I) 003440	10 A=1.0	003410
50 IF(JPRINT(8).EQ.1) WRITE(6,5) X(1),I,Y(1) 003440	20 Y(I)=Y(I)+COE(J)+A	003420
	30 CONTINUE	003430
RETURN 003450	50 [F(JPRINT(8).EQ.1) WRITE(6,5) X(1),I,Y(I)	003440
	RETURN	003450
END 003460	END	003460

Contrails

SIBFTC ENOM	003470
SUBROUTINE ENDM(IG,IB,EHOM)	003480
	003490
COMMON/CCAB/CSUB(30,30)	003500
COMMON/CEQUITINANS(10)	003510
COMMON/ECAB/GAMMOS(30),BAYTOS(30,30)	003520
COMMON/SCAB/ARE(2).AREARE(200)	003530
COMMON/RCAB/AL(2,2),AK(2,2)	003540
COMMON/SPACE/DUM(200) + ST02(200)	003550
COMMON/201/JPRINT(35)	003560
1 FORMAT(6H EHOM=E16.8,5X,12HCSUB(1G,1B)=E16.8)	003570
C REF. P135 (11), THEORY OF BESSEL FUNCTIONS *G.N.WATSON* CAMBRIDGE 1958	003580
	003590
NR=NANS(9)	003600
REG1=1.0/ BAYTOS(IG,IB)++2	003610
DO 500 IR=1,NR	003620
CALL ABES(BAYTOS(IG,IB),AREARE(IR),GAMMOS(IG),U,UP,W,WP)	003630
IF(IR.GT.1) GO TO 40	003640
REG2=AREARE(IR)==2	003650
CSUB(IG,IB)=(-AL(1,1)+WP-AL(1,2)+W)/(AL(1,1)+UP+AL(1,2)+U)	003660
A(1)=.5=REG2+{{1REG1+GAMMOS(IG)++2/REG2)+(CSUB(IG,IB)+U+W)++2	003670
1 +REG1+(CSUB(IG,IB)+UP+WP)++2)	003680
40 STO2(IR)=(CSUB(IG,IB)=U+W)=AREARE(IR)	003690
IF(IR.NE.NR) GO TO 500	003700
REG2=AREARE(IR)++2	003710
A(2)=.5+REG2+((1REG1+GAMMOS(IG)++2/REG2)+(CSUB(IG+IB)+U+W)++2	003720
1 +REG1*(CSUB(IG,IB)+UP+WP)**2)	003730
500 CONTINUE	003740
EHOM=A{2}-A(1)	003750
IF(JPRINT(9).EQ.1) WRITE(6,1) EHOM,CSUB(IG,1B)	003760
RETURN	003770
END	003780

SIBFTC GAMEPS	003790
SUBROUTINE GAMEPS(ISEEK, MANY, VALUES)	003800
C SELECT ISEEK=1 OR 2 FOR GAMMAS-SIGMAS,OR EPSILONS	003810
C MANY= THE NUMBER OF EIGEN VALUES DESIRED	003820
DIMENSION VALUES(1)	003830
COMMON/GCAB/ARE(2),AREARE(200)/HCAB/PHI(2),PHIPHI(200)	003840
COMMON/RCAB/AL(2,2),AK(2,2)	003850

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Contrails

COMMON/ZO1/JPRINT(35)	003860
1 FORMAT(1X,32H*GAMEPS* ILLEGAL SELECTION ERROR,5X,7HISEEK= [5]	003870
500 FORMAT(1X,32H+GAMEPS+ ERROR IN TAKING THE LOG)	003880
950 FORMAT(1X,17H+GAMEPS+ ISEEK= 13,3X, 5HI12= 15,3X, 5HI22= 15,3X,	003890
1 6HMANY= [5,5X,5HREG]=E16.8,5X,7HARE(1)=E16.8/1X,7HARE(2)=E16.8,	003900
2 5X, 7HPH1(1)=E16.8,5X, 7HPH1(2)=E16.8,5X, 8HAL(1,2)=E16.8/ 1X,	003910
3 8HAL(2,2}=E16.8,5X, 8HAK(1,2)=E16.8,5X, 8HAK(2,2}=E16.8/ 1X,	003920
4 7HVALUES=/ (1X,6E20.8))	003930
P1=3.1415926	003940
IF(ISEEK.EQ.1.OR.ISEEK.EQ.2) GO TO 100	003950
WRITE(6,1) ISEEK STOP	003960 003970
100 IF(ISEEK.NE.1) GO TO 2	003980
C GAMMAS OR SIGMAS	003990
REG1=PHI(2)-PHI(1)	004000
REG2=AK(1,2)	004010
REG3=AK(2,2)	004020
GD TO 3	004030
C EPSILONS	004040
2 REGI=ARE(2)/ARE(1)	004050
IF(REG1.LE.O.) GO TO 9997	004060
REG1=ALOG(REG1)	004070
REG2=AL(1,2) REG3=AL(2,2)	004080
3 I12=SIGN(ABS(REG2)+.005,REG2)	004090 004100
I22=SIGN(ABS(REG3)+.005,REG3)	004110
IF(112-NE-122) GQ TQ 20	004120
C SPECIAL CASE OF BOUNDARY CONDITIONS	004130
C REG2=REG3=0.	004140
IF(I12.NE.O) GD TO 8	004150
VALUES(1)=0.	004160
DO 5 M=2, MANY	004170
	004180
5 VALUES(M)=AM+PI/REG1 G0 TO 900	004190
C REG2=REG3	004200 004210
8 DO 10 M=1, MANY	004220
	004230
10 VALUES(M)=AM+P1/REG1	004240
GO TO 900	004250
20 PI02=1.5707963	004260
C SPECIAL CASE OF BOUNDARY CONDITIONS	004270
DO 15 M=1, MANY	004280
	004290
15 VALUES(M)=PIO2+AM/REGL GD TO 900	004300
9997 WRITE(6,500)	004310 004320
STOP	004330
900 1F(JPRINT(10).EQ.1) WRITE(6.950) ISEEK.I12.(22.	004340
1 MANY, REG1, ARE(1), ARE(2), PHI(1), PHI(2), AL(1,2), AL(2,2), AK(1,2),	004350
2 AK(2,2), (VALUES(I), I=1, MANY)	004360
RETURN	004370
END	004380
SIRFIC GTIME	004390
SUBROUTINE GTIME(TIME, BETA, GSIMP)	004400
CUMMON/COMTIM/XLAMDA(50),GLAMDA(50),NLAMDA	004410
COMMON/JOHN/GTHE TA, SAMETM	004420

	CUMMON/COMTIM/XLAMDA(50),GLAMDA(50),NLAMDA	004410
	COMMON/JOHN/GTHE TA, SAMETM	004420
	COMMON/SPACE/X(100),Y(100),SX(20),SY(20),DUM(160)	004430
	COMMON/VCAB/ALPHO	004440
	1 FORMAT(1H0,40H+GTIME+ ERROR, TIME OUT OF BOUNDS, MIN=E16,8,	004450
	15X, 4HMAX = E16.8, 5X, 5HTIME = E16.8	004460
С		004470
	IF(TIME.LT.XLAMDA(1).OR.TIME.GT.XLAMDA(NLAMDA))G0 T0 55	004480
	ABQ=-ALPHO*BETA**2	004490
	IFITIME_EQ.SAMETH) GD TO 25	004500

Contrails

		SAMETM=TIME	004510
		DX=TIME/19.0	004520
		DO 18 I=1,20	004530
		A[=[-]	004540
		SX([)=DX+AI	004550
	18	CALL CLINEINLAMDA, SX([), XLAMDA, GLAMDA, SY(L))	004560
	••	GTHETA=SY(20)	004570
с			004580
•	25	DO 30 1=2,20	004590
		A=SY(I)+EXP(ABQ+(TIME-SX(I)))	004600
	30	[F(ABS(A).GE0001) G0 T0 35	004610
		1=20	004620
	35	BEGIN=SX(1-1)	004630
		$DX = \{T   M \in B \in G \mid N \} / 99 = 0$	004640
		DD 45 I=1.100	004650
		A[=1-1	004660
		XII)=AI+DX+BEGIN	004670
		CALL CLINE(NLAMDA, X(I), XLAMDA, GLAMDA, Y(I))	004680
	45	Y(1)=Y(1)+EXP(ABQ+(TIME-X(1)))	004690
С			004700
-		CALL SIMP(100,DX,Y,REG)	004710
		GSINP=-ABQ+REG	004720
		GO TO 60	004730
С			004740
-	55	WRITE(6.1) XLAMDA(1).XLAMDA(NLAMDA).TIME	004750
		STOP	004760
c			004770
	60	RETURN	004780
	-+	END	004790

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$IBFTC WURZEL
                                                                             004800
      SUBROUTINE WURZEL
                                                                             004810
                                                                             004820
      COMMON/CKOUT/NANS(10)
      COMMON/ECAB/GAMMOS(30), BAYTOS(30,30)
                                                                             004830
      COMMON/GCAB/ARE(2), AREARE(200)/HCAB/PHI(2), PHIPHI(200)
                                                                             004840
                                                                            004850
      COMMON/ZO1/JPRINT(35)
    3 FORMAT( 14HOFIRST GUESS= E16.8,5X, 10HINTERVAL=
                                                                  E16.8)
                                                                             004860
                                                                             004870
    5 FORMAT(1H1)
      NB=NANS(2)
                                                                             004880
                                                                             004890
      NG=NANS(1)
С
                                                                             004900
      DO 4000 IG=1,NG
                                                                             004910
C INITIAL GUESS MUST NOT EXCEED FIRST MAX OR MIN
                                                                             004920
      G=GAMMOS[IG]
                                                                             004930
                                                                             004940
      IF(G.EQ.0.0) GO TO 350
      IF(1G.LT.3) GO TO 100
                                                                             004950
      X= 2.* BAYTOS(IG-1,1) - BAYTOS(IG-2,1)
                                                                             004960
      GO TO 370
                                                                             004970
  100 X= (.25+G) / ARE(1)
                                                                             004980
      GO TO 370
                                                                             004990
  350 X=1.0/(ARE(2)-ARE(1))
                                                                             005000
  370 DX=0.1/(ARE(2)-ARE(1))
                                                                            005010
С
                                                                            005020
С
                                                                            005030
      IF(JPRINT(12).GE.1) WRITE(6.3) X,DX
                                                                            005040
  400 CALL FFP(IG,X,Y,YP)
                                                                            005050
  500 [F(Y.EQ.0.0) GO TO 2100
                                                                            005060
      IF(S(GN(1.0, YP).NE.SIGN(1.0, Y)) GO TO 650
                                                                            005070
                                                                            005080
С
  THE FIRST ROOT IS BEHIND YOUR GUESS
                                                                             005090
С
  610 CALL LEFT (XH, YH, SH, X, Y, YP)
                                                                            005100
                                                                            005110
      X=XH-.1+DX
      IF(X.LE.0.0) GO TO 640
                                                                            005120
                                                                            005130
      CALL FFP(IG,X,Y,YP)
      IF(SIGN(1.0, YH).NE.SIGN(1.0, Y)) GO TO 630
                                                                            005140
      IF(ABS(Y).GE.ABS(YH)) GO TO 640
                                                                            005150
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Contrails

	C Creek Connect	
	GO TO 610	005160
630	CALL LEFT(XL,YL,SL,X,Y,YP) GO TO 1000	005170 005180
640	CALL LEFT (XL, YL, SL, XH, YH, SH)	005190
	DX=2.0+DX	005200
	GO TO 660	005210
C		005220
	E FIRST ROOT IS FOWARD OF YOUR GUESS, (OR YOU ARE PAST THE FIRST	005230
-	( OR MEN)	005240
	CALL LEFT{XL,YL,SL,X,Y,YP} X=XL+DX	005250 005260
000	CALL FFP(IG,X,Y,YP)	005270
	IF(Y.E0.0.) GD TO 2100	005280
	IF(SIGN(1.0, YL).NE.SIGN(1.0, Y)) GO TO 800	005290
	IF(ABS(Y).GE.ABS(YL)) DX=2.0+DX	005300
	GD TO 650	005310
	CALL LEFT(XH,YH,SH,X,Y,YP)	005320
C 1000	I Po 1	005330 005340
1000	IB=1 CALL BRIDGE(IB,XH,YH,SH,XL,YL,SL,IG)	005350
	1F(NB.LE.1) GO TO 4000	005360
	DX=2.5+DX	005370
	GD TO 2120	005380
C		005390
C Y=0		005400
2100	BAYTOS(IG,1)=X IF(NB.LE.1) GD TO 4000	005410 005420
	XH=X+DX	005430
	CALL FFP(IG, XH, YH, SH)	005440
C		005450
	OND AND REMAINING ROOTS	005460
2120	DD 3980 IB=2,NB	005470
	CALL LEFT (XL, YL, SL, XH, YH, SH)	005480 005490
	IF(1B.LT.3) GO TO 2200 DX=BAYTOS(IG,1B-1)-BAYTOS(IG,1B-2)	005500
	1F(DX.LE.0.) DX≠.25	005510
2200	X=XL+DX	005520
	CALL FFPIIG, X, Y, YP)	005530
	IF(Y.EQ.0.) GO TO 3970	005540
	IF(SIGN(1.0, YL).NE.SIGN(1.0, Y)) GO TO 2500	005550
	CALL LEFT(XL,YL,SL,X,Y,YP)	005560 005570
2500	GO TO 2200 Continue	005580
2900	CALL LEFT (XH, YH, SH, X, Y, YP)	005590
	CALL BRIDGEIIB, XH, YH, SH, XL, YL, SL, IG)	005600
	GO TO 3980	005610
с		005620
C Y=0		005630 005640
3970	BAYTOS(IG+IB)≠X IF(IB.GE_NB) GO TO 3980	005650
	XH=X+DX	005660
	CALL FFP(IG,XH,YH,SH)	005670
3980	CONTINUE	005680
	IF(JPRINT(12).GE.1) WRITE(6,5)	005690
4000	CONTINUE	005700
	RETURN	005710 005720
	END	007120
		0.06730
\$ [ BFT	C BRIDGE SUBROUTINE BRIDGE(IB,XH,YH,SH,XL,YL,SL,IG)	005730 005740
	COMMON/ECAB/GAMMOS(30)+BAYTUS(30+30)	005750
	COMMON/Z01/JPRINT(35)	005760
	DOUBLE PRECISION DI. D2+D3	005770
	FORMAT(34HOATTEMPT AT ROOT WAS NOT JUSTIFIED /20H XH, YH, SH, XL, YL, S	005780
	1L, 6E16.8)	005790 005800
	FORMAT( 6HOBETA(,12,1H,,12,5H) = E16.8/} Format(23HOFINE SEARCH PHASE IG= 12,3X,4HIB= 12}	005800
4	FURDALLED DEALED FORSE 10- 1213ATTILD- 121	

Contrails	
Proventies and the second	
C	005820
C	005830
C (XH,YH) AND (XL,YL) BOARDER A ROOT	005840
	005850
100 CONTINUE	005870
IF(SIGN(1.0,YH).EQ.SIGN(1.0,YL)) GD TO 9000	005880
C	005890
C COURSE SEARCH PHASE	005900
200 SLINE=(YH-YL)/(XH-XL)	005910
A=XH-YH/SLINE CALL FFP(IG,A,B,BP)	005920
C	005940
C NEIGHBORHOOD CRITERION	005950
IF(SIGN(1.0,SL).EQ.SIGN(1.0,SH).AND.SIGN(1.0,SL).EQ.SIGN(1.0,BP))	005960
1 J=J+1	005970
IF(J.GE.3) GO TO 7500	005980
C	005990
C iterative contraction	006000
DEL=(XH-XL)/3.0 DU 220 [=],3	006010
X=XL+DEL CALL FFP(IG,X,Y,YP)	006030
IF(Y.EQ.0.) GO TO 8050	006050
IF(SIGN(1.0,YL).NE.SIGN(1.0,Y)) GD TO 225	006060
CALL LEFT(XL,YL,SL,X,Y,YP)	006070
220 CONTINUE	006080
GO TO 100	006090
225 Continue	006100
Call Left(XH,YH,SH,X,Y,YP)	006110
GO TO 100	006120
C	006130
G FINE SEARCH PHASE 7500 CONTINUE	006140
DO B000 I=1,10	006160
IF(JPRINT(13).GE.2) WRITE(6,4) [G,IB	006170
IF(ABS(B).LE.1.E-6) GD TO 8040 D1=A D2=D	006180 006190
D2=B	006200
D3=BP	006210
D1=D1-D2/D3	006220
A=D1 CALL FFP(IG+A+B+BP)	006230
8000 CONTINUE	006250
WRITE(6,4) IG,IB	006260
C 8040 BAYTOS([G,1B}=A G0 T0 8080	006270
C 8050 BAYTOS(1G.[B)=X	006290 006300 006310
C 8080 [F(JPRINT(13).GE.L) WRITE(6,3) [G,[B,BAYTOS(IG,[B]	006320
RETURN	006340
9000 WRITE(6,1) XH, YH, SH, XL, YL, SL	006350
S TOP	006360
END	006370

SIBFTC ABES	006380
SUBROUTINE ABES(B6,R6,G6,A6,AP6,Y6,YP6)	006390
C WRITE(6,10001) B6,R6,G6	006400
C	006410
C INPUT BETA, R, GAMMA, DUTPUT J-GAMMA, J-PRIME-GAMMA, Y-GAMMA, Y-PRIME GAMM	006420
c	006430
DIMENSION Y(2)	006440
DOUBLE PRECISION Y	006450
DOUBLE PRECISION D1,D2,D3,D4,D5	006460

Contrails

DOUBLE PRECISION X025,P1,ONEOPI	006470
DOUBLE PRECISION PIO2	006480
DOUBLE PRECISION PIO4	006490
DOUBLE PRECISION WOOD	006500
DOUBLE PRECISION BROZ	006510
DOUBLE PRECISION XSORD	006520
DOUBLE PRECISION BLOCKA	006530 006540
DOUBLE PRECISION BLOCKB Double precision blockc	006550
DOUBLE PRECISION BLOCKD	006560
DOUBLE PRECISION BLOCKE	006570
DOUBLE PRECISION SUM1	006580
DOUBLE PRECISION SUM2	006590
DOUBLE PRECISION SUM3	006600
DOUBLE PRECISION BFACT	006610
DOUBLE PRECISION BFACT2	006620 006630
DOUBLE PRECISION ADENOM	006640
DDUBLE PRECISION BDENOM DDUBLE PRECISION HANKI	006650
DOUBLE PRECISION HANK2	006660
DOUBLE PRECISION HANK3	006670
DOUBLE PRECISION HANK4	006680
DOUBLE PRECISION TERM	006690
11 FORMAT(1X, 6HGAMMA=1PE16.8,5X,28HNEGATIVE ORDERS ARE ILLEGAL	
1 THIN ABES)	006710 57 006730
12 FORNAT(1X,48HNEGATIVE AND ZERO ARGUMENTS ARE ILLEGAL IN ABES,	, 5X, 006720 006730
1 4HARG= 3E16.8) 10000 FORMAT(4H N= [5.5%.5HY(N)=E16.8.5%.E16.8)	006740
10001 FORMAT(17H B,R,G,J,JP,Y,YP, 7E16.8)	006750
C	006760
C REF.A = APPLIED MATH FOR ENGR AND PHY +L.A.PIPES+ MCGRAW-HILL 195	8 006770
C (NOTE DISREPANCY IN PIPES TEXT, LOG SHOULD BE LN)	006780
C REF.B = THEORY OF BESSEL FUNCTIONS +G.N.WATSON+ CAMBRIDGE UNIV. 1	
C	006800
BR=B6+R6 1f(BR.LE.O.) GO TO 9001	006810 006820
1F(G6.LT.O.) GO TO 9002	006830
	006840
PI=3.14159265D0	006850
ONEOP [=.31830989D0	006860
PI02=1.5707963300	006870
P104=.7853981600	006880
BR02=BR/2+0 X025=-(BR02+BR02)	006890 006900
TWOBR = 2. + BR	006910
XSQRD=-(TWOBR+TWOBR)	006920
AAA=8.	006930
TOL=1.E-09	006940
c	006950
CALL BESIB6,R6,G6,A6,AP6)	006960
	006970
NG≖G6+.00001	
GMIX≠NG	006980 006990
GMIX≂NG FRACT=G6→GMIX	006990
GMIX≂NG FRACT±G6→GMIX 1F(FRACT•LE••0001) GD TO 50	006990
GMIX≂NG FRACT=G6→GMIX	006990 007000
GMIX≂NG FRACT±G6→GMIX IF(FRACT+LE++0001) GD TO 50 C	006990 007000 007010 007020 007020
GMIX=NG FRACT=G6→GMIX IF(FRACT.LE0001) GD TO 50 C C GAMMA IS NOT AN INTEGER CALL BES(B6,R6,-G6,A5,AP5) D1=G6	006990 007000 007010 007020 007030 007040
GMIX=NG FRACT=G6-GMIX IF(FRACT.LE0001) GD T0 50 C C GAMMA IS NOT AN INTEGER CALL BES(B6,R6,-G6,A5,AP5) D1=G6 D2=A6	006990 007000 007010 007020 007030 007040 007050
GMIX=NG FRACT=G6-GMIX IF(FRACT.LE0001) GD TO 50 C C GAMMA IS NOT AN INTEGER CALL BES(B6,R6,-G6,A5,AP5) D1=G6 D2=A6 D3=A5	006990 007000 007010 007020 007030 007040 007050 007060
GMIX=NG FRACT=G6-GMIX IF(FRACT.LE0001) GD TO 50 C C GAMMA IS NOT AN INTEGER CALL BES(B6,R6,-G6,A5,AP5) D1=G6 D2=A6 D3=A5 D4=DCOS(PI+D1)	006990 007000 007010 007020 007030 007040 007050 007060 007060
GMIX=NG FRACT=G6-GMIX IF(FRACT.LE0001) GD TO 50 C C GAMMA IS NOT AN INTEGER CALL BES(B6,R6,-G6,A5,AP5) D1=G6 D2=A6 D3=A5 D4=DCOS(PI+D1) D5=DSIN(PI+D1)	006990 007000 007010 007020 007030 007040 007050 007060
GMIX=NG FRACT=G6-GMIX IF(FRACT.LE0001) GD TO 50 C C GAMMA IS NOT AN INTEGER CALL BES(B6,R6,-G6,A5,AP5) D1=G6 D2=A6 03=A5 D4=DCOS(PI+D1) D5=DSIN(PI+D1) C 14.2) P.350 REF.A	006990 007000 007010 007020 007030 007040 007050 007060 007060 007080
GMIX=NG FRACT=G6-GMIX IF(FRACT.LE0001) GD TO 50 C C GAMMA IS NOT AN INTEGER CALL BES(B6,R6,-G6,A5,AP5) D1=G6 D2=A6 D3=A5 D4=DCOS(PI+D1) D5=DSIN(PI+D1)	006990 007000 007010 007020 007040 007050 007060 007060 007080 007080 007100 007100 007110
GMIX=NG FRACT=G6-GMIX IF(FRACT.LE0001) GD TO 50 C C C GAMMA IS NOT AN INTEGER CALL BES(B6,R6,-G6,A5,AP5) D1=G6 D2=A6 D3=A5 D4=DCOS(PI+D1) D5=DSIN(PI+D1) D5=DSIN(PI+D1) C 14-2) P.350 REF.A Y6=(D4=D2-D3)/D5 D2=AP6 D3=AP5	006990 007000 007010 007020 007030 007040 007050 007060 007060 007080 007080 007100 007100 007110 007120
GMIX=NG FRACT=G6-GMIX IF(FRACT.LE0001) GD TO 50 C C C GAMMA IS NOT AN INTEGER CALL BES(B6,R6,-G6,A5,AP5) D1=G6 D2=A6 D3=A5 D4=DCOS(PI+D1) D5=DSIN(PI+D1) C 14-2) P.350 REF.A Y6=(D4+D2-D3)/D5 D3=AP5 YP6=(D4+D2-D3)/D5	006990 007000 007010 007020 007030 007040 007050 007060 007060 007080 007080 007100 007110 007120 007130
GMIX=NG FRACT=G6-GMIX IF(FRACT.LE0001) GD TO 50 C C C GAMMA IS NOT AN INTEGER CALL BES(B6,R6,-G6,A5,AP5) D1=G6 D2=A6 D3=A5 D4=DCOS(PI+D1) D5=DSIN(PI+D1) D5=DSIN(PI+D1) C 14-2) P.350 REF.A Y6=(D4=D2-D3)/D5 D2=AP6 D3=AP5	006990 007000 007010 007020 007030 007040 007050 007060 007060 007080 007080 007100 007100 007110 007120

Contrails 50 IF(BR.GE.AAA)GO TO 100 007160 007170 C GAMMA IS AN INTEGER, ARGUMENT IS LESS THAN THE CROSS OVER POINT 007180 IF(NG.NE.1) GO TO 55 007190 AONE=A6 007200 APONE=AP6 007210 GO TO 56 007220 55 CONTINUE 007230 CALL BES(B6,R6,1.,ADNE,APONE) 007240 56 CONTINUE 007250 W000=2.000+(0L0G(BR02)+.577215700) 007260 D1=AONE 007270 DO 85 N=1,2 007280 AN=N 007290 BLOCKA=D1+W000 007300 BLOCK 8=0.000 007310 SUM1=BR02 007320 IF(N\_EQ.2) SUM1=BR02+BR02/2.000 007330 SUM2=1.000 007340 IF(N.EQ.2) SUM2=1.5D0 007350 DO 75 K=1,15 007360 NR=K-1 007370 R=NR 007380 IFINR.LT.1)GO TO 60 007390 D2=R+(AN+R) 007400 SUM1=SUM1+(XD2S/D2) 007410 D3=1.0/(AN+R)+1.0/R 007420 SUN2=SUN2+D3 007430 60 SUN3=SUN1+SUN2 007440 BLOCKB=BLOCKB+SUM3 007450 XYZ=SUH3 007460 IF(ABS(XYZ).LE.TOL) GO TO 78 007470 **75 CONTINUE** 007480 78 BLOCKD=1.000/BR02 007490 IF(N.EQ.2) BLOCKD=1.0D0/(BRO2+BRO2)+1.000 007500 C (4.7) P.351 REF.A 007510 Y{N}=ONEDPI+(BLOCKA-BLOCKB-BLOCKD) 007520 D2=BR 007530 D3=APONE 007540 D4=B6 007550 D1=D1/02-03/D4 007560 **85 CONTINUE** 007570 GO TO 200 007580 007590 C GAMMA IS AN INTEGER, ARGUMENT IS GREATER THAN THE CROSS OVER POINT 007600 100 CONTINUE 007610 D5=BR 007620 BLOCKA=DSQRT((2.0D0+PI)/D5)/PI 007630 DO 115 N=1,2 007640 AN=N 007650 D2=AN 007660 D1=D5-P102+D2-P104 007670 BLOCK B=DS IN(D1) 007680 BLOCKC=DCOS(D1) 007690 BLOCK D=0.000 007700 BLOCKE=0.0D0 007710 BFACT=1.000 007720 ADENOM=1.0D0 007730 J=1 007740 С J=CONVERGENCE INDICATOR 007750 BFACT2=1.0D0 007760 BDENO#=TWOBR 007770 IF(N.EQ.2)GO TO 101 007780 HANK1=.886226925D0 007790 HANK3=1.3293403900 007800 HANK 4=1.77245385D0 007810 GD TO 102 007820 101 HANK1=1.32934039D0 007830 HANK4=. 88622692500 007840 HANK3=2.5+HANK1 007850

Contrails

	102	HANK2=HANK1	007860
		DO 110 K=1,7	007870
		M≈K−1	007880
		AM=#	007890
		01=2=M	007900
		GO TO (104,105,104),J	007910
	104		
	104	IF(N.EQ.0)GO TO 103	007920
		HANK1=HANK1+(D2+D15D0)+(D2+D1-1.5D0)	007930
		BFACT=BFACT+D1+(D1-1.000)	007940
		HANK2=HANK2/((D2-D1+.5D0)+(D2-D1+1.5D0))	007950
		ADENON+ADENOM+XSQRD	007960
	103	TERN=(HANK1/(BFACT=HANK2))/ADENOH	007970
		BLOCKD=BLOCKD+TERM	007980
		XYZ=TERM	007990
		IF(ABS(XYZ).LE.TOL) J=J+1	008000
	105	GO TO (109,109,110,110),J	
			008010
	103	1F(N.EQ.0)GD TO 108	008020
		HANK3=HANK3+{D2+D1+.5D0}+{D2+D15D0}	008030
		BFACT2=BFACT2=(D1+1.000)+D1	008040
		HANK4=HANK4/((02-D1500)+(02-01+.500))	008050
		BDENOM* BDENOM* XSQRD	008060
	108	TERMA={HANK3/(BFACT2+HANK4))/BDENOM	008070
		BLOCKE=BLOCKE+TERMA	008080
		XYZ=TERMA	008090
		IF(ABS(XYZ).LE.TOL) J=J+2	008100
	110	IF(J.GT.3) GD TO 114	008110
~			
C		P.199 REF.B	008120
	114	Y(N)=BLOCKA+(BLOCKB+BLOCKD+BLOCKC+BLOCKE)	008130
С		WRITE(6,10000) N,Y(N)	008140
	115	CONTINUE	008150
С			008160
_			
L	RECU	JRRENCE FORMULAS	008170
	200	IF(NG.NE.0)GO TO 210	008180
С			008190
	GAMP	NA ZERO	008200
•	•	D1=B6	008210
		YP6=-Y(1)+D1	008220
		D1=BR	008230
		Y6=(2.0D0=Y(1))/D1-Y(2)	008240
		RETURN	008250
С			008260
5	310	15/10 NG 1100 TO 200	
_	210	IF(NG.NE.1)GO TO 220	008270
С			008280
С	GAMP	NA ONE	008290
		Y6=Y(1)	008300
		D1=GMIX	008310
		D2=R6	008320
		D3=86	008330
		YP6=(D1+Y(1))/D2-D3+Y(2)	008340
		RETURN	008350
С			008360
Υ.	224	16/NG NE 2100 TO 220	
~	224	IF(NG.NE.2)GD TO 230	008370
С			008380
С	GAMP	1A TWO	008390
		D3=Y(1)	008400
		D4=Y(2)	008410
		Y6=Y(2)	008420
		GO TO 270	008430
С			008440
	230	D4=Y{2}	008450
	2.50	D2=Y(1)	008460
		00 240 N=3,NG	008470
		AN=N-1	008480
		D5= BR	008490
		D1=AN	008500
		D1=(2.0D0+D1)/D5	008510
		D3=D4	008520
		D4=D1+D3-02	008530
C		WRITE(6,10000) N,D4,D3	008540
_			

Contrails

	D2*D3	008550
240	CONTINUE	008560
	Y6=D4	008570
C		008580
270	CONTINUE	008590
	D1=B6	008600
	D2=GM IX	008610
	D5=R6	008620
	YP6=D1+D3-{D2+D4}/D5	008630
C	WRITE(6,10001) B6,R6,G6,A6,AP6,Y6,YP6	008640
	RETURN	008650
C		008660
9001	CONTINUE	008670
	WRITE(6,12) BR, B6, R6	008660
	STOP	008690
9002	CONTINUE	008700
	WRITE(6,11) G6	008710
	STOP	008720
	END	008730

SIBFIC GAMMA SUBROUTINE GAMMA(X,Y) DIMENSION A(10) A(1) = .83333333E-01A(2) =-.27777778E-02 A(3) = .79365079E-03 A(4) =-.59523810E-03 A(5) = .84175084E-03 A(6) =-.19175269E-02 A(7) = .64102564E-02 A(8) =-.29550654E-01 A(9) = .17964437E 00 A(10)=-.13924322E 01 IF(X)10,13,30 10 K000FX=X XINT=K000FX XF=XINT-X AX≖X XM=1.0 J=3-K000FX DO 15 I=1,J XM=XM+AX 15 AX=AX+1.0 IF(ABS(XM)-1.0E-30)11,11,29 11 IE=K000FX/2 IF(K000FX-2+IE)13,12,13 12 Y=-1.0E 30 GO TO 50 13 Y=1.0E 30 GO TO 50 29 AX=3.0-XF GO TO 38 30 IF(X-1.0) 34, 37, 36 34 IF(X-1.0E-30)13,13,37 37 AX=X+2.0 XM=X+(X+1.0) GO TO 38 36 IF(X-2.0)39,39,14 39 AX=X+1.0 XM=X GO TO 38 14 AX=X XM=1.0 IF(X-30.0)38,13,13 38 C=1.0/AX++2 T1=A(1}/AX

009170

009180

009190

008740

Contrails

	F=T1	009200
	DO 35 I=2,10	009210
	TN=T1+A([]/A([-1)+C	009220
	IF(ABS(TN)-ABS(T1))32,32,33	009230
22	F=F+TN	009240
36		
	T1=TN	009250
	1F{ABS(TN}2E-08)33,33,35	009260
35	CONTINUE	009270
33	EX={AX-•5}+ALOG{AX}-AX+F+•91893853	009280
	Y=EXP(EX)	009290
	Y=Y/XM	009300
	RETURN	
50		009310
	END	009320
SIBET	C AMSAFC	009330
•••	FUNCTION AMSAFC(IG,V)	009340
	COMMON/ECAB/DUM(30), EPILON(30), DUMY(870)	009350
	COMMON/WCAB/AM(30),AF(30)	009360
	COMMON/201/JPRINT(35)	009370
	FORMATI1X,7HANSAFC=E16.8]	009380
C		009390
	A=ALOG(V)	009400
с		009410
-	A=A+EPILON(IG)	009420
	IF(AM(IG).EQ.0.) GO TO 110	009430
	B=AM(IG)=SIN(A)	009440
	GO TO 120	009450
110	B=0.0	009460
120	IF(AF(IG).EQ.0.) GO TO 130	009470
	C=COS(A)	009480
	GO TO 140	009490
	C=0.0	009500
140	ANSAFC=B+C	009510
		~~///
	IF(JPRINT(16).EQ.1) WRITE(6,1) AMSAFC	009520
8800		009520
8800	RETURN	009520 009530
8800		009520
8800	RETURN	009520 009530
8800	RETURN	009520 009530
	RETURN END	009520 009530 009540
	RETURN END C SERIES	009520 009530 009540
\$IBFT	RETURN END	009520 009530 009540 009550 009550
	RETURN END C SERIES	009520 009530 009540
\$IBFT	RETURN END C SERIES	009520 009530 009540 009560 009560 009570 009580
\$IBFT	RETURN END C SERIES SUBROUTINE SERIESITIME,R,P)	009520 009530 009540 009550 009560 009560
\$IBFT	RETURN END C SERIES SUBROUTINE SERIES/TIME,R,P) DUUBLE PRECISION SERIA, SERIB, TERMA, TERMB	009520 009530 009540 009560 009560 009570 009580
\$IBFT	RETURN END C SERIES SUBROUTINE SERIES/TIME,R,P) DUUBLE PRECISION SERIA, SERIB, TERMA, TERMB COMMON/ACAB/ARBA(30,30), ARBG(30,30) CONMON/CCAB/CSUB(30,30)	009520 009530 009540 009560 009560 009570 009580 009590 009600
\$IBFT	RETURN END C SERIES SUBROUTINE SERIES/TIME,R,P) DUUBLE PRECISION SERIA,SERIB,TERMA,TERMB COMMON/ACAB/ARBA(30,30),ARBG(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CKOUT/NANS(10)	009520 009530 009540 009560 009560 009570 009580 009590 009600 009610
\$IBFT	RETURN END C SERIES SUBROUTINE SERIES/TIME,R,P) DUUBLE PRECISION SERIA,SERIB,TERMA,TERMB COMMON/ACAB/ARBA(30,30),ARBG(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CKOUT/NANS(10) COMMON/ECAB/GAMMOS(30),BAYTOS(30,30)	009520 009530 009540 009560 009560 009570 009580 009590 009600 009610 009620
\$IBFT	RETURN END C SERIES SUBROUTINE SERIES/TIME,R,P) DUUBLE PRECISION SERIA,SERIB,TERMA,TERMB COMMON/ACAB/ARBA(30,30),ARBG(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/GAMMOS(30),BAYTOS(30,30) COMMON/ECAB/GAMMOS(30),BAYTOS(30,30) COMMON/JDHN/GTHETA,SAMETM	009520 009530 009540 009560 009560 009580 009580 009590 009600 009610 009620 009630
\$IBFT	RETURN END C SERIES SUBROUTINE SERIES/TIME,R,P) DUUBLE PRECISION SERIA, SERIB, TERMA, TERMB COMMON/ACAB/ARBA(30,30), ARBG(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/SICAD(30), BAYTOS(30,30) COMMON/JOHN/GTHETA, SAMETM COMMON/JOCAB/STEADY(7,25), XR(7), YP(25), KR,KP	009520 009530 009540 009560 009560 009580 009580 009590 009600 009610 009620 009630 009640
\$IBFT	RETURN END C SERIES SUBROUTINE SERIES/TIME,R,P) DUUBLE PRECISION SERIA,SERIB,TERMA,TERMB COMMON/ACAB/ARBA(30,30),ARBG(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/GAMMOS(30),BAYTOS(30,30) COMMON/ECAB/GAMMOS(30),BAYTOS(30,30) COMMON/JDHN/GTHETA,SAMETM	009520 009530 009540 009560 009560 009570 009580 009590 009600 009610 009620 009630 009630
\$IBFT	RETURN END C SERIES SUBROUTINE SERIES/TIME,R,P) DUUBLE PRECISION SERIA, SERIB, TERMA, TERMB COMMON/ACAB/ARBA(30,30), ARBG(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/SICAD(30), BAYTOS(30,30) COMMON/JOHN/GTHETA, SAMETM COMMON/JOCAB/STEADY(7,25), XR(7), YP(25), KR,KP	009520 009530 009540 009560 009560 009580 009590 009600 009610 009620 009630 009640 009650
\$IBFT C	RETURN END C SERIES SUBROUTINE SERIES/TIME,R,P) DUUBLE PRECISION SERIA, SERIB, TERMA, TERMB COMMON/ACAB/ARBA(30,30), ARBG(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/CSUB(30), BAYTOS(30,30) COMMON/CCAB/STEADY(7,25), XR(7), YP(25), KR, KP COMMON/VCAB/ALPHO COMMON/Z01/JPRINT(35)	009520 009530 009540 009560 009560 009570 009580 009590 009600 009610 009620 009630 009640 009650 009660
\$IBFT C	RETURN END C SERIES SUBROUTINE SERIES(TIME,R,P) DUUBLE PRECISION SERIA, SERIB, TERMA, TERMB COMMON/ACAB/ARBA(30,30), ARBG(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/GSUB(30), BAYTOS(30,30) COMMON/CCAB/GAMMOS(30), BAYTOS(30,30) COMMON/CAB/STEADY(7,25), XR(7), YP(25), KR, KP COMMON/VCAB/ALPHO COMMON/VCAB/ALPHO COMMON/Z01/JPRINT(35) FORMAT(3X,6HTERM A,10X,6HTERM B,10X,8HSERIES A,8X,8HSERIES B,	009520 009530 009540 009560 009560 009580 009580 009590 009600 009610 009620 009630 009640 009650 009660 009660
\$IBFT C	RETURN END C SERIES SUBROUTINE SERIES(TIME,R,P) DUUBLE PRECISION SERIA, SERIB, TERMA, TERMB COMMON/ACAB/ARBA(30,30), ARBG(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/GSUB(30), BAYTOS(30,30) COMMON/CAB/AB/ANDIS(30), BAYTOS(30,30) COMMON/JOHN/GTHETA, SAMETM COMMON/JOHN/GTHETA, SAMETM COMMON/CCAB/STEADY(7,25), XR(7), YP(25), KR,KP COMMON/VCAB/ALPHO COMMON/Z01/JPRINT(35) FORMAT(3X,6HTERM A,10X,6HTERM B,10X,8HSERIES A,8X,8HSERIES B, 8X,5HGAMMA,11X,4HBETA,12X,6HGTHETA,10X,5HGSIMP)	009520 009530 009540 009540 009560 009570 009580 009570 009600 009610 009620 009630 009630 009640 009650 009660 009660
\$IBFT C 3	RETURN END C SERIES SUBROUTINE SERIES/TIME,R,P) DUUBLE PRECISION SERIA,SERIB,TERMA,TERMB COMMON/ACAB/ARBA(30,30),ARBG(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/GAMMOS(30),BAYTOS(30,30) COMMON/CCAB/GAMMOS(30),BAYTOS(30,30) COMMON/JOHN/GTHETA,SAMETM COMMON/JOHN/GTHETA,SAMETM COMMON/VCAB/ALPHO COMMON/VCAB/ALPHO COMMON/VCAB/ALPHO COMMON/VCAB/ALPHO COMMON/VCAB/ALPHO SA,SHGAMMA,11X,4HBETA,12X,6HGTHETA,10X,5HGSIMP) FORMAT(1X,8E16.8)	009520 009530 009540 009540 009560 009570 009580 009590 009600 009610 009620 009630 009640 009640 009660 009660 009660 009660 009660
\$IBFT C 3 4 5	RETURN END C SERIES SUBROUTINE SERIES(TIME,R,P) DUUBLE PRECISION SERIA, SERIB, TERMA, TERMB COMMON/ACAB/ARBA(30,30), ARBG(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/GSUB(30), BAYTOS(30,30) COMMON/CAB/AB/ANDIS(30), BAYTOS(30,30) COMMON/JOHN/GTHETA, SAMETM COMMON/JOHN/GTHETA, SAMETM COMMON/CCAB/STEADY(7,25), XR(7), YP(25), KR,KP COMMON/VCAB/ALPHO COMMON/Z01/JPRINT(35) FORMAT(3X,6HTERM A,10X,6HTERM B,10X,8HSERIES A,8X,8HSERIES B, 8X,5HGAMMA,11X,4HBETA,12X,6HGTHETA,10X,5HGSIMP)	009520 009530 009540 009540 009560 009570 009580 009600 009610 009620 009630 009640 009640 009650 009660 009660 009670 009660 009670 009690 009700
\$IBFT C 3	RETURN END C SERIES SUBROUTINE SERIES/TIME,R,P) DUUBLE PRECISION SERIA, SERIB, TERMA, TERMB COMMON/ACAB/ARBA(30,30), ARBG(30,30) COMMON/ACAB/ARBA(30,30), ARBG(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/GAMMOS(30), BAYTOS(30,30) COMMON/CAB/GAMMOS(30), BAYTOS(30,30) COMMON/JDHN/GTHETA,SAMETM COMMON/JDHN/GTHETA,SAMETM COMMON/VCAB/ALPHO COMMON/VCAB/ALPHO COMMON/VCAB/ALPHO COMMON/ZOI/JPRINT(35) FORMAT(3X,6HTERM A,10X,6HTERM B,10X,8HSERIES A,8X,8HSERIES B, 1 8X,5HGAMMA,11X,4HBETA,12X,6HGTHETA,10X,5HGSIMP) FORMAT(1X,8E16.8) FORMAT(9X,12HTEMPERATURE=E16.8,10X,E16.8)	009520 009530 009540 009540 009560 009570 009580 009590 009600 009610 009620 009630 009640 009650 009640 009650 009680 009680 009690 009710
\$IBFT C 3 4 5	RETURN END C SERIES SUBROUTINE SERIES/TIME,R,P) DUUBLE PRECISION SERIA, SERIB, TERMA, TERMB COMMON/ACAB/ARBA(30,30), ARBG(30,30) COMMON/ACAB/ARBA(30,30), ARBG(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CKOUT/NANS(10) COMMON/CCAB/GAMMOS(30), BAYTOS(30,30) COMMON/CCAB/GAMMOS(30), BAYTOS(30,30) COMMON/CAB/STEADY(7,25), XR(7), YP(25), KR,KP COMMON/VCAB/ALPHO COMMON/VCAB/ALPHO COMMON/ZOL/JPRINT(35) FORMAT(3X,6HTERM A,10X,6HTERM B,10X,8HSERIES A,8X,8HSERIES B, 1 8X,5HGAMMA,11X,4HBETA,12X,6HGTHETA,10X,5HGSIMP) FORMAT(1X,8E16.8) FORMAT(9X,12HTEMPERATURE=E16.8,10X,E16.8) NG=NANS(1)	009520 009530 009540 009540 009560 009570 009580 009600 009610 009620 009630 009640 009640 009650 009660 009660 009670 009660 009670 009690 009700
\$IBFT C 3 4 5	RETURN END C SERIES SUBROUTINE SERIES/TIME,R,P) DUUBLE PRECISION SERIA, SERIB, TERMA, TERMB COMMON/ACAB/ARBA(30,30), ARBG(30,30) COMMON/ACAB/ARBA(30,30), ARBG(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/GAMMOS(30), BAYTOS(30,30) COMMON/CAB/GAMMOS(30), BAYTOS(30,30) COMMON/JDHN/GTHETA,SAMETM COMMON/JDHN/GTHETA,SAMETM COMMON/VCAB/ALPHO COMMON/VCAB/ALPHO COMMON/VCAB/ALPHO COMMON/ZOI/JPRINT(35) FORMAT(3X,6HTERM A,10X,6HTERM B,10X,8HSERIES A,8X,8HSERIES B, 1 8X,5HGAMMA,11X,4HBETA,12X,6HGTHETA,10X,5HGSIMP) FORMAT(1X,8E16.8) FORMAT(9X,12HTEMPERATURE=E16.8,10X,E16.8)	009520 009530 009540 009540 009560 009570 009580 009590 009600 009610 009620 009630 009640 009650 009640 009650 009680 009680 009690 009710
\$IBFT C 3 4 5 C	RETURN END C SERIES SUBROUTINE SERIES/TIME,R,P) DUUBLE PRECISION SERIA, SERIB, TERMA, TERMB COMMON/ACAB/ARBA(30,30), ARBG(30,30) COMMON/ACAB/ARBA(30,30), ARBG(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CKOUT/NANS(10) COMMON/CCAB/GAMMOS(30), BAYTOS(30,30) COMMON/CCAB/GAMMOS(30), BAYTOS(30,30) COMMON/CAB/STEADY(7,25), XR(7), YP(25), KR,KP COMMON/VCAB/ALPHO COMMON/VCAB/ALPHO COMMON/ZOL/JPRINT(35) FORMAT(3X,6HTERM A,10X,6HTERM B,10X,8HSERIES A,8X,8HSERIES B, 1 8X,5HGAMMA,11X,4HBETA,12X,6HGTHETA,10X,5HGSIMP) FORMAT(1X,8E16.8) FORMAT(9X,12HTEMPERATURE=E16.8,10X,E16.8) NG=NANS(1)	009520 009530 009540 009540 009560 009570 009580 009580 009590 009600 009610 009620 009630 009640 009650 009660 009660 009670 009680 009690 009710 009710 009730
\$IBFT C 3 4 5	RETURN END C SERIES SUBROUTINE SERIES/TIME,R,P) DUUBLE PRECISION SERIA, SERIB, TERMA, TERMB COMMON/ACAB/ARBA(30,30), ARBG(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/GAMMOS(30), BAYTOS(30,30) COMMON/ECAB/GAMMOS(30), BAYTOS(30,30) COMMON/JDHN/GTHETA, SAMETM COMMON/JDHN/GTHETA, SAMETM COMMON/VCAB/ALPHO COMMON/VCAB/ALPHO COMMON/Z01/JPRINT(35) FORMAT(3X,6HTERM A,10X,6HTERM B,10X,8HSERIES A,8X,8HSERIES B, 1 8X,5HGANNA,11X,4HBETA,12X,6HGTHETA,10X,5HGSIMP) FORMAT(1X,8E16.8) FORMAT(9X,12HTEMPERATURE=E16.8,10X,E16.8) NG=NANS(1) NB=NANS(2)	009520 009530 009540 009540 009560 009570 009580 009590 009600 009610 009620 009620 009630 009640 009650 009660 009660 009660 009660 009670 009680 009690 009710 009710
\$IBFT C 3 4 5 C C	RETURN END C SERIES SUBROUTINE SERIES/TIME,R,P) DUUBLE PRECISION SERIA, SERIB, TERMA, TERMB COMMON/ACAB/ARBA(30,30), ARBG(30,30) COMMON/ACAB/ARBA(30,30), ARBG(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CKOUT/NANS(10) COMMON/CCAB/GAMMOS(30), BAYTOS(30,30) COMMON/CCAB/GAMMOS(30), BAYTOS(30,30) COMMON/CAB/STEADY(7,25), XR(7), YP(25), KR,KP COMMON/VCAB/ALPHO COMMON/VCAB/ALPHO COMMON/ZOL/JPRINT(35) FORMAT(3X,6HTERM A,10X,6HTERM B,10X,8HSERIES A,8X,8HSERIES B, 1 8X,5HGAMMA,11X,4HBETA,12X,6HGTHETA,10X,5HGSIMP) FORMAT(1X,8E16.8) FORMAT(9X,12HTEMPERATURE=E16.8,10X,E16.8) NG=NANS(1)	009520 009530 009540 009540 009560 009570 009580 009600 009610 009620 009630 009630 009640 009650 009660 009650 009660 009650 009680 009690 009700 009710 009720 009730
\$IBFT C 3 4 5 C	RETURN END C SERIES SUBROUTINE SERIES/TIME,R,P) DOUBLE PRECISION SERIA, SERIB, TERMA, TERMB COMMON/ACAB/ARBA(30,30), ARBG(30,30) COMMON/CAB/ARBA(30,30), ARBG(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/SUB/GAMMOS(30), BAYTOS(30,30) COMMON/CCAB/STEADY(7,25), XR(7), YP(25), KR,KP COMMON/UCAB/ALPHO COMMON/VCAB/ALPHO COMMON/VCAB/ALPHO COMMON/VCAB/ALPHO COMMON/VCAB/ALPHO COMMON/Z01/JPRINT(35) FORMAT(3X,6HTERM A,10X,6HTERM B,10X,8HSERIES A,8X,8HSERIES B, 1 8X,5HGAMMA,11X,4HBETA,12X,6HGTHETA,10X,5HGSIMP) FORMAT(1X,8E16.6) FORMAT(9X,12HTEMPERATURE=E16.8,10X,E16.8) NG=NANS(1) NB=NANS(2) IF(JPRINT(17).GE.2) WRITE(6,3)	009520 009530 009540 009540 009560 009560 009570 009580 009600 009610 009620 009630 009640 009640 009650 009660 009660 009660 009670 009700 009710 009720 009730 009750 009760
\$IBFT C 3 4 5 C C	RETURN END C SERIES SUBROUTINE SERIES(TIME,R,P) DOUBLE PRECISION SERIA,SERIB,TERMA,TERMB COMMON/ACAB/ARBA(30,30),ARBG(30,30) COMMON/CCAB/SUB(30,30) COMMON/CCAB/SUB(30,30) COMMON/CCAB/STEADY(7,25),AR(7),YP(25),KR,KP COMMON/OCAB/STEADY(7,25),XR(7),YP(25),KR,KP COMMON/VCAB/ALPHO COMMON/Z01/JPRINT(35) FORMAT(3X,6HTERM A,10X,6HTERM B,10X,8HSERIES A,8X,8HSERIES B, 1 8X,5HGAMMA,11X,4HBETA,12X,6HGTHETA,10X,5HGSIMP) FORMAT(1X,8E16.8) FORMAT(1X,8E16.8) FORMAT(9X,12HTEMPERATURE=E16.8,10X,E16.8) NG=NANS(1) NB=NANS(2) IF(JPRINT(17).GE.2) WRITE(6,3) SERIA=0.0D0	009520 009530 009540 009540 009560 009560 009580 009590 009600 009610 009620 009630 009640 009640 009650 009660 009660 009670 009660 009710 009710 009720 009730 009740 009750 009760
\$IBFT C 3 4 5 C C	RETURN END C SERIES SUBROUTINE SERIES(TIME,R,P) DUUBLE PRECISION SERIA,SERIB,TERMA,TERMB COMMON/ACAB/ARBA(30,30),ARBG(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/CSUB(30,BAYTOS(30,30) COMMON/JOHN/GTHETA,SAMETM COMMON/JOHN/GTHETA,SAMETM COMMON/JOHN/GTHETA,SAMETM COMMON/JOHN/GTHETA,SAMETM COMMON/JOHN/GTHETA,SAMETM SCOMMON/ZOAB/STEADY(7,25),XR(7),YP(25),KR,KP STEADY(7,25),XR(7),YP(25),KR,KP STEADY(7,25),XR(7),YP(25),KR,KP STEADY(7,25),XR(7),YP(25),KR,KP STEADY(7,25),XR(7),YP(25),KR,KP STEADY(7,25),XR(7),YP(25),KR,KP STEADY(7,25),XR(7),YP(25),KR,KP STEADY(7,25),XR(7),YP(25),XR(7),YP(25),KR,KP STEADY(7,25),XR(7),YP(2	009520 009530 009540 009540 009560 009560 009580 009590 009600 009610 009620 009630 009640 009650 009640 009650 009660 009660 009680 009680 009700 009710 009720 009730 009750 009760
\$IBFT C 3 4 5 C C	RETURN END C SERIES SUBROUTINE SERIES(TIME,R,P) DOUBLE PRECISION SERIA,SERIB,TERMA,TERMB COMMON/ACAB/ARBA(30,30),ARBG(30,30) COMMON/CCAB/SUB(30,30) COMMON/CCAB/SUB(30,30) COMMON/CCAB/STEADY(7,25),AR(7),YP(25),KR,KP COMMON/OCAB/STEADY(7,25),XR(7),YP(25),KR,KP COMMON/VCAB/ALPHO COMMON/Z01/JPRINT(35) FORMAT(3X,6HTERM A,10X,6HTERM B,10X,8HSERIES A,8X,8HSERIES B, 1 8X,5HGAMMA,11X,4HBETA,12X,6HGTHETA,10X,5HGSIMP) FORMAT(1X,8E16.8) FORMAT(1X,8E16.8) FORMAT(9X,12HTEMPERATURE=E16.8,10X,E16.8) NG=NANS(1) NB=NANS(2) IF(JPRINT(17).GE.2) WRITE(6,3) SERIA=0.0D0	009520 009530 009540 009540 009560 009570 009580 009590 009600 009610 009620 009630 009640 009640 009650 009660 009660 009660 009670 009710 009710 009720 009730 009740 009750 009760
\$IBFT C 3 4 5 C C	RETURN END C SERIES SUBROUTINE SERIES(TIME,R,P) DUUBLE PRECISION SERIA,SERIB,TERMA,TERMB COMMON/ACAB/ARBA(30,30),ARBG(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/CSUB(30,BAYTOS(30,30) COMMON/JOHN/GTHETA,SAMETM COMMON/JOHN/GTHETA,SAMETM COMMON/JOHN/GTHETA,SAMETM COMMON/JOHN/GTHETA,SAMETM COMMON/JOHN/GTHETA,SAMETM SCOMMON/ZOAB/STEADY(7,25),XR(7),YP(25),KR,KP STEADY(7,25),XR(7),YP(25),KR,KP STEADY(7,25),XR(7),YP(25),KR,KP STEADY(7,25),XR(7),YP(25),KR,KP STEADY(7,25),XR(7),YP(25),KR,KP STEADY(7,25),XR(7),YP(25),KR,KP STEADY(7,25),XR(7),YP(25),KR,KP STEADY(7,25),XR(7),YP(25),XR(7),YP(25),KR,KP STEADY(7,25),XR(7),YP(2	009520 009530 009540 009540 009560 009560 009580 009590 009600 009610 009620 009630 009640 009650 009640 009650 009660 009660 009680 009680 009700 009710 009720 009730 009750 009760
\$IBFT C 3 4 5 C C	RETURN END C SERIES SUBROUTINE SERIES(TIME,R,P) DUUBLE PRECISION SERIA,SERIB,TERMA,TERMB COMMON/ACAB/ARBA(30,30),ARBG(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/CSUB(30,30) COMMON/ECAB/GAMMOS(30),BAYTOS(30,30) COMMON/JOHN/GTHETA,SAMETM COMMON/JOHN/GTHETA,SAMETM COMMON/JOHN/GTHETA,SAMETM COMMON/VCAB/ALPHO COMMON/VCAB/ALPHO COMMON/ZOI/JPRINT(35) FORMAT(3X,6HTERM A,10X,6HTERM B,10X,8HSERIES A,8X,8HSERIES B, 1 8X,5HGANMA,11X,4HBETA,12X,6HGTHETA,10X,5HGSIMP) FORMAT(1X,8E16.8] FORMAT(1X,8E16.8] NG=NANS(1) NB=NANS(2) IF(JPRINT(17).GE.2) WRITE(6,3) SERIA=0.0D0 SERIB=0.0D0 DO 400 IG=1,NG	009520 009530 009540 009540 009560 009570 009580 009590 009600 009610 009620 009630 009640 009630 009640 009650 009660 009660 009670 009760 009710 009750 009760 009760 009780 009790
\$IBFT C 3 4 5 C C	RETURN END C SERIES SUBROUTINE SERIES/TIME,R,P) DUUBLE PRECISION SERIA,SERIB,TERMA,TERMB COMMON/ACAB/ARBA(30,30),ARBG(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/CSUB(30,30) COMMON/CCAB/GAMHOS(30),BAYTOS(30,30) COMMON/CCAB/GAMHOS(30),BAYTOS(30,30) COMMON/CCAB/AEPHO COMMON/CCAB/AEPHO COMMON/VCAB/AEPHO COMMON/ZOI/JPRINT(35) FORMAT(3X,6HTERM A,10X,6HTERM B,10X,8HSERIES A,8X,8HSERIES B, 1 8X,5HGAMNA,11X,4HBETA,12X,6HGTHETA,10X,5HGSIMP) FORMAT(3X,6HTERM A,10X,6HTERM B,10X,8HSERIES A,8X,8HSERIES B, 1 8X,5HGAMNA,11X,4HBETA,12X,6HGTHETA,10X,5HGSIMP) FORMAT(1X,8E16,8] FORMAT(1X,8E16,8] FORMAT(1X,12HTEMPERATURE=E16,8,10X,E16,8) NG=NANS(1) NB=NANS(2) IF(JPRINT(17).GE.2) WRITE(6,3) SERIA=0.000 SERIB=0.000 DO 400 IB=1,NB	009520 009530 009540 009540 009560 009560 009580 009580 009600 009610 009620 009630 009640 009650 009640 009650 009660 009660 009680 009680 009710 009720 009730 009750 009760 009760

		Contrails	
-		REG1=B2=BSNFCS([G,P)	009830
C		TERNA=ARBA(IG,IB)+REG1+EXP(-ALPHO+BAYTOS(IG,IB)++2+TIME)	009840 009850
		CALL GTIME(TIME,BAYTOS(IG,IB),GSIMP) TERMB= ARBG(IG,IB)=REGI=(-GTHETA+GSIMP)	009860 009870
С			009880
		SERIA=SERIA+TERMA SERIB=SERIB+TERMB	009890 009900
С			009910
		IF(JPRINT(17).GE.2) 1 WRITE(6.4) TERMA,TERMB,SERIA,SERIB,GAMMOS(IG),BAYTOS(IG,IB),	009920 009930
		2 GTHETA, GSIMP	009940
С	400	CONTINUE	009950 009960
v		CALL VLINE(KR,KP,R,P,XR,YP,STEADY,7,25,S)	009970
		HEAT=SERIA+SERIB +GTHETA=S If(JPRINT(17).ge.1) write(6,5) heat,s	009980 009990
		HEAT=ATRAN(HEAT)	010000
	500	WRITE(6,5) HEAT Return	010010 010020
		END	010030
51	BFTO	C STATE SUBROUTINE STATE	010040 010050
		DOUBLE PRECISION T1, T2, T3, T4	010060
		CONMON/ACAB/FARE1(200),FARE2(200),FPHI1(200),FPHI2(200),DUME(1000) COMMON/CCAB/STO1(25),STO2(7),STO3(7),STO4(7),STO5(25),STO6(25),	010070 010080
	1	1 DUNY (804)	010090
		COMMON/CKOUT/NANS(10) COMMON/ECAB/GAMMOS(30),EPILON(30),DUM(870)	010100 010110
		COMMON/GCAB/ARE(2), AREARE(200)/HCAB/PHI(2), PHIPHI(200)	010120
		COMMON/OCAB/STEADY(7,25),XR(7),YP(25),KR,KP COMMON/RCAB/AL(2,2),AK(2,2)	010130 010140
		COMMON/Z01/JPRINT(35)	010150
		EQUIVALENCE (KR,NR) EQUIVALENCE (KP,NP)	010160 010170
		FORMAT(6H0 T1,13X,2HT2,14X,2HT3,14X,2HT4,14X,13HSTEADY(IR,IP),	010180
		1 10X,2H1R,8X,2HIP) FORMAT(1X,5E16.8,2110)	010190 010200
C	• ·		010210
		NG=NANS{7} NP=NANS{6}	010220 010230
		NR=NANS(5)	010240
		DO 100 IP=1,NP DO 100 IR=1,NR	010250 010260
		STEADY(IR, IP)=0.0	010270
с	100	CONTINUE	010280 010290
-		N=1	010300
		CALL GAMEPS(N,NANS(7),GAMMOS) N=2	010310 010320
		CALL GAMEPS(N, NANS(7), EPILON)	010330
С		DO 4000 IG=1.NG	010340 010350
		CALL COECOE(IG,CP,CL,CQ,CW)	010360
		DO 300 IP=1.NP STOL(IP)=BSNFCS(IG.YP(IP))	010370 010380
		N=3	010390
		STD5([P)=X1([G,YP(]P),N) N=4	010400 010410
		STO6(IP)=XI(IG,YP(IP),N)	010420
с	300	CONTINUE	010430 010440
•		DO 400 IR=1,NR	010450
		N=1 STO2([R)=XI([G,XR([R),N)	010460 010470
		N=2	010480

Contrails

STD3(IR)=XI(IG+XR(IR)+N)	010490
STO4(IR)=AMSAFC(IG,XR(IR))	010500
400 CONTINUE	010510
C IF(IG.EQ.NG.OR.JPRINT(18).GE.1) WRITE(6.13)	010520 010530
DO 3000 $IP=1,NP$	010540
DO 3000 [R=1,NR	010550
T1=CP+ST01([P)+ST02(1R)	010560
T2=CL+STO1([P)+STO3(]R) T3=CQ+STO4(]R)+STO5(]P}	010570
T4=CW+ST04(1R)+ST06(1P)	010580 010590
STEADY(IR, 1P)=STEADY(IR, 1P)+T1+T2+T3+T4	010600
IF(IG.EQ.NG.OR.JPRINT(18).GE.1) WRITE(6,14) T1,T2,T3,T4,	010610
1 STEADY(IR,IP),IR,IP 3000 CONTINUE	010620
400G CONTINUE	010630 010640
	010650
NPT=NANS(3)	010660
NRI#NANS(4) 1544 () Oktober Oktober Oktober () IN-CEERON() IN- E-EADER	010670
IF(AL(1,2)+AK(1,2).EQ.2.0) STEADY(1,1)=STEADY(1,1)+.5#FARE1 1 .5#FPHI1	
IF(AL(1,2)+AK(2,2).EQ.2.0) STEADY(1,NP)=STEADY(1,NP)+.5+FAF	
1 +.5*FPH	HI2(1) 010710
IF(AL(2,2)+AK(1,2).EQ.2.0) STEADY(NR,1)=STEADY(NR,1)+.5+FAR	
1 +'.5*FP+ IF(AL(2,2)+AK(2,2).EQ.2.0) STEADY(NR,NP)=STEADY(NR,NP)+	HII(NP.I) 010730 010740
1 .5+FARE21NPI1+.5+FPHI2{NRI}	010750
C	010760
RETURN	010770
END	010780
SIBFTC XI FUNCTION XI(IG, MANBOUND)	010790
COMMON/ECAB/GAMMOS(30),EPILON(30),DUM(870)	010810
COMMON/GCAB/ARE(2), AREARE(200)/HCAB/PHI(2), PHIPHI(200)	010820
COMMON/RCAB/AL(2,2),AK(2,2),	010830
COMMON/UTILTY/RIOR2,R2OR1,AR1OR2,AR2081,AR1,AR2 COMMON/Z01/JPRINT(35)	010840 010850
DOUBLE PRECISION D1+D2+D3+D4	010860
1 FORMAT(49HIJOB TERMINATED, DO NOT PUT FLUX AT ALL BOUNDRIES	
1 (8E16.8)) 2 EORMATINE 2001-E16 8 EV. 8000000000 20 715	010880
2 FORMAT(1X,3HXI=€16.8,5X, 8HBOUNDARY,2X,II) C	010890 010900
GO TO(100,2000,3000,4000),NBOUND	010910
C	010920
	010930
C AT BOUNDARY R1 C	010940 010950
100 CONTINUE	010960
IF(GANHOS(IG).NE.0.) GO TO 1000	010970
IF(AL(1,2).EQ.O.) GD TO 200 IF(AL(2,2).EQ.O.) GD TO 8800	010980
XI=ALOG(V/ARE(2))/AR10R2	010990 011000
GO TO 8900	011010
200 IF(AL(2,2).EQ.0.) GO TO 9000	011020
XI=ARE(1)+ALOG(V/ARE(2)) G0 T0 8900	011030
	011040 011050
1000 CONTINUE	011060
D1=(V/ARE(1))++(-GAMMOS(IG))	011070
D2=(R1OR2++GAMMDS(IG))+((V/ARE(2))++GAMMOS(IG)) D4= R1OR2++(2.0+GAMMOS(IG))	011080 011090
IF(AL(1,1).EQ.0.) GO TO 1050	011100
D3=-(GANMOS(IG)/ARE(1))	011110
D4=D4+(-D3)	011120
GD TO 1100 1050 CONTINUE	011130 011140
	ATTTA

Contrails

	D3=1.0D0	011150
1100	CONTINUE	011160
	IF(AL(2,2).EQ.0.0) GO TO 8700	011170
	D3=-D3	011180
	D1=-D1	011190
_	GO TO 8700	011200
C		011210
	BOUNDARY R2	011220
C	CONTINUE	011230
2000	CONTINUE 1F{GAMMOS(1G].NE.O.) GO TO 2800	011240 011250
	IF(AL(1,2),EQ.0.) GO TO 2030	011260
	IF(AL(2,2).EQ.0.) GD TO 2020	011270
	XI#ALOG(V/ARE(1))/AR2OR1	011280
	GD TO 8900	011290
2020	CONTINUE	011300
	XI=ARE(2)+ALDG(V/ARE(1))	011310
	GO TO 8900	011320
2030	CONTINUE	011330
	IF(AL(2,2).EQ.0.) GO TO 9000	011340
~	GO TO 8800	011350
C	CONTINUE	011360
2800	D1=(R10R2==GAMMOS(IG))+(V/ARE(1))++(-GAMMOS(IG))	011370 011380
	D2=(V/ARE(2))++GAMMDS(IG)	011390
	D3=R10R2++(2,+GAMMDS(IG))	011400
	IF(AL(2,1),EQ.()) GO TO 2835	011410
	D3=-(GAMMOSLIG)/ARE(2))+D3	011420
	D4=GAMMOS(IG)/ARE(2)	011430
	GO TO 2880	011440
2835	CONTINUE	011450
	04=1.0D0	011460
2880	CONTINUE	011470
	IF(AL(1,2).EQ.0.) GO TO 8700	011480
	D1=-D1	011490
	D3=-D3 G0 T0 8700	011500 011510
c	60 10 8100	011520
	BOUNDRY P1	011530
č		011540
3000	CONTINUE	011550
	IF(EPILON(IG).NE.O.) GO TO 3705	011560
	IF(AK(1,2).EQ.0.) GO TO 3010	011570
	IF(AK(2,2).EQ.0.) GO TO 8800	011580
	XI=PH1(2)+Y	011590
1010	GD TO 8900 Continue	011600
2010	IF(AL(2,2).EQ.0.) GO TO 9000	011610 011620
	XI=V-PHI(2)	011630
	GO TO 8900	011640
С		011650
3705	CONTINUE	011660
	DI=EXP(-EPILON(IG)+V)	011670
	D2=EXP(-EPILON([G)+(2.*PHI(21-V))	011680
	D4=EXP(-2.+EPILON(1G)+PHI(2))	011690
	IF(AK(1,1).NE.O.) GD TO 3815	011700
	D3=1.0D0 G0 T0 3860	011710
3815	CONTINUE	011720 011730
2019	D3= +EPILON(IG)	011740
	D4=D4+EPILON(IG)	011750
3860	CONTINUE	011760
	IF(AK(2,2).EQ.0.) GO TO 8700	011770
	01=-01	011780
	D3=-D3	011790
~	GO TO 8700	011800
C AT	BOUNDARY P2	011810
C		011820 011830
•		011030

Contrails

4000	CONTINUE	011840
	IF(EPILON(IG).NE.0.) GO TO 5000	011850
	IF(AK(1,2).EQ.0.) GO TO 4025	011860
	IF(AK(2,2).EQ.D.) GO TO 4016	011870
	X[=¥/PHI(2)	011880
	GO TO 8900	011890
4016	CONTINUE	011900
		011910
4075	GO TO 8900 [F(AK(2,2).Eq.0.) GD TO 9000	011920
4025	GO TO 8800	011930 011940
с		011950
-	CONTINUE	011960
2000	D1=EXP(-EPILON(IG)+(PHI(2)+V))	011970
	D2=EXP(EPILON(1G)+(V-PHI(2)))	011980
	D3= EXP(-2.+FPI)ON(IG)+PHI(2))	011990
	IF(AK(2,1).EQ.0.) 60 TO 5046	012000
	D3=-D3+EP1LON(IG)	012010
	D4=EPILON(IG)	012020
E 6 4 4		012030 012040
3040	CONTINUE D4=1.000	012050
6000	CONTINUE	012060
0000	IF(AK(1.2).EQ.O.) GO TO 8700	012070
	D1=-D1	012080
	D3=-D3	012090
С		012100
8700	XI=(01+02)/(D3+D4)	012110
	GO TO 8900	012120
С		012130
	XI=1.0	012140
C	CONTINUE	012150
8900	CONTINUE IF(JPRINT(19).EQ.1) WRITE(6,2) XI,NBOUND	012160 012170
	RETURN	012180
с		012190
č		012200
9000	CONTINUE	012210
	WRITE(6.1) AL,AK	012220
	STOP	012230
	END	012240
\$IBFT(		012250
	SUBROUTINE FFP(1G, B, F, FP)	012260
	DOUBLE PRECISION D1,D2	012270 012280
	DOUBLE PRECISION T-TP DIMENSION T(4),TP(4),C(4),P(4)	012290
	COMMON/ECAB/GAMMDS(30), BAYTDS(30,30)	012300
	COMMON/GCAB/ARE(2), AREARE(200)/HCAB/PHI(2), PHIPHI(200)	012310
	COMMON/RCAB/AL(2,2), AK(2,2)	012320
	COMMON/ZD1/JPRINT(35)	012330
14	FORMAT(1X,2HK=12,5X,5HC(K)=E16.8,5X,5HP(K)=E16.8,5X,5HT(K)=E16.8,	012340
	1 5X,6HTP(K)=E16.8,E16.8)	012350
20	FORMAT(3H X=E16.8,3X,2HY=E16.8,3X,3HYP=E16.8,3X,6HGAMMA 12)	012360
	BR=B+ARE(1)	012370 012380
	REG1= ((GAMMOS(1G)+=2)/BR) -BK A=AL(1,1)	012390
	D=AL(1,2)	012400
	R=ARE(1)	012410
	CALL ABES(B, ARE(1), GAMMOS(IG), C(1), P(1), C(2), P(2))	012420
	CALL ABES(B, ARE(2), GAMMOS(IG), C(3), P(3), C(4), P(4))	012430
	DO 13 K=1,4	012440
	01=A=P(K)	012450
	DZ=D+C(K)	012460
	T(K)=D1+D2	012470
	D1=A+C(K)+REG1 D2=R=D=P(K)/P	012480
	D2≖R+D+P(K)/B	012490

Contrails

TP(K)=D1+D2	012500
IF(K.EQ.1) GO TO 13	012510
A=AL[2,1]	012520
D=AL(2,2)	012530
BR=B+ARE{2}	012540
REG1= ({GAMMDS{[G}++2}/BR} -BR	012550
R=ARE(2)	012560
13 IF(JPRINT(20).GE.2) WRITE(6,14) K,C(K),P(K),T(K),TP(K),REG1	012570
F=T(1)+T(2)+T(3)	012580
FP=T(1]=TP(4)-T(2)=TP(3)+TP(1)+T(4)+TP(2)+T(3)	012590
IF(JPRINT(20).GE.1) WRITE(6,20) B.F.FP,IG	012600
RETURN	012610
END	012620

5	1 BFT(	CARBCOE	012630
		SUBROUTINE ARBCOE	012640
		COMMON/ACAB/ARBA(30,30),ARBG(30,30)	012650
		COMMON/CKOUT/NANS(10)	012660
		COMMON/ECAB/GAMMOS(30),BAYTOS(30,30)	012670
		COMMON/GCAB/ARE(2),AREARE(200)/HCAB/PHI(2),PHIPHI(200)	012680
		COMMON/OCAB/STEADY(7,25),XR(7),YP(25),KR,KP	012690
		COMMON/PCAB/DZERO(7,25),XRD(7),YPD(25),LR,LP	012700
		COMMON/SPACE/STO1(200),STO2(200)	012710
		COMMON/SPACE1/A1(200),A2(200),A3(200),A4(200)	012720
		COMMON/Z01/JPRINT(35)	012730
	1	FORMAT( 8H A(I,J)=E16.8,5X, 7HG(1,J)=E16.8,5X,3HI= I3,3X,3HJ= I3)	012740
c			012750
		NG=NANS(1)	012760
		NB=NANS(2)	012770
		NR=NANS(9)	012780
		NP=NANS(8)	012790
С			012800
		CALL SIZE(PHIPHI,NP,PHI(1),PHI(2))	012610
		CALL SIZE (AREARE + NR + ARE(1) + ARE(2))	012820
C			012830
		DXR=AREARE(2)-AREARE(1)	012840
		DXP=PHIPHI(2)-PHIPHI(1)	012850
с			012860
		CALL GAMEPS(1,NANS(1),GAMMOS)	012870
		CALL WURZEL	012860
С			012890
		DQ 500 IG=1,NG	012900
		CALL DENON(IG, DEHON)	012910
С			012920
-		DO 91 I=1.NP	012930
		STOL(I)=BSNFCS(IG,PHIPHI(I))	012940
	91	CONTINUE	012950
c			012960
-		DO 500 [B=1.NB	012970
		CALL ENDM (IG, IB, EHOM)	012980
C		STO2 IS FILLED IN ENON	012990
-		D0 300 IP=1,NP	013000
		DD 200 IR=1.NR	013010
		CALL VLINE(LR, LP, AREARE(IR), PHIPHI(IP), XRD, YPD, DZERD, 7, 25, D)	013020
		D=TRAN(D)	013030
		CALL VLINE(KR,KP,AREARE(IR),PHIPHI(IP),XR,YP,STEADY,7,25,S)	013040
		REG=ST01([P)+ST02(IR)	013050
		A1(IR)=D+REG	013060
		A2(IR)=S+REG	013070
	200	CONTINUE	013080
		CALL SIMP(NR, DXR, A1, A)	013090
		A3(IP)=A	013100
		CALL SIMP (NR, DXR, A2, B)	013110
		A4(IP)=B	013120
	300	CONTINUE	013130
		CALL SIMP (NP, DXP, A3, V1)	013140
		CALL SIMP (NP, DXP, A4, V2)	013150

Contrails

C O	13160
REG=EHOM+DEHOM 0	13170
ARBA(IG,IB)=V1/REG 0	13180
ARBG(IG,IB)=V2/REG 0	13190
C	13200
IF(JPRINT(21).EQ.1) WRITE(6,1) ARBA(IG,IB),ARBG(IG,IB),IG,IB	13210
	13220
RETURN	13230
END	13240

SIBFTC TRAN	013250
FUNCTION TRAN(V)	013260
COMMON/XCAB/XTRAN(50),YTRAN(50),MAXMAX	013270
COMMON/YCAB/BEE,SEE/ZBCAB/ICASE	013280
COMMON/ZO1/JPRINT(35)	013290
50 FORMAT(1X,17H+TRANSFORM ERROR+)	013300
51 FORMAT(1X,14H+TRAN+ CASE= 13,3X,4HBEE=E16.8,5X,4HSEE=E16.8,5X,	013310
1 2HV=EL6.8 / 1X,2HQ=EL6.8,5X,5HREG1=EL6.8,5X,5HREG2=EL6.8,5X,	013320
2 5HREG3=E16.8 / 1X,5HREG4=E16.8,5X,5HREG5=E16.8,5X,5HTRAN=E16.8}	013330
C SET ICASE EQUAL TO THE CASE NUMBER OF THE DESIRED TRANSFORM	013340
REG1=0.	013350
REG2=0.	013360
REG3=0.	013370
REG4=0.	013380
REG5=0.	013390
Q=0.	013400
GO TO (1,2,3,4,5,6,7),ICASE	013410
1 TRAN=1.0/BEE-EXP(-BEE=V)/BEE	013420
C CASE 1	013430
GO TO 100	013440
2 IFISEE.LE.O.) GO TO 9997	013450
C CASE 2	
	013460
REG1=4. +SEE-BEE+BEE	013470
Q=REG1	013480
REG2=2.+SEE+V	013490
IF(REG1)11,12,13	013500
11 REG1=SQRT(-REG1)	013510
REG3=REG2/(BEE+REG1)	013520
REG4=REG2/(BEE+REG1)	013530
REG5=(REG3+1.)/(REG4+1.)	013540
IF(REG5-LE-0-) GD TD 9997	013550
TRAN=ALOG(REG5)/REG1	013560
G0 T0 100	013570
12 REG3=REG2+BEE	
	013580
TRAN=2./BEE-2./REG3	013590
GO TO 100	013600
13 REG1=SQRT(REG1)	013610
REG3=REG2+BEE	013620
REG4=ATAN2(REG3,REG1)	013630
REG5=ATAN2{BEE,REG1}	013640
TRAN=2.+(REG4-REG5)/REG1	013650
GO TO 100	013660
3 REG1=1.+BEE+V	013670
C CASE 3	013680
IF(REG1.LE.OOR.BEE.EQ.O.) GO TO 9997	013690
TRAN=ALOG(REG1)/BEE	013700
GO TO 100	013710
4 TRAN=V+BEE+V+V/2.	
C CASE 4	013720
	013730
GO TO 100	013740
5 CONTINUE	013750
C CASE 5	013760
6 TRAN=V	013770
C CASE 6	013780
GO TO 100	013790
7 CALL CLINE(MAXMAX,V,XTRAN(1),YTRAN(1),TRAN)	013800

Contrails	
C CASE 7	013810
GD TD 100	013820
9997 WRITE(6,50)	013830
STOP	013840
100 IF(JPRINT(22).EQ.1) WRITE(6,51) ICASE,BEE,SEE,V,	013850
1 Q.REG1,REG2,REG3,REG4,REG5,TRAN	013860
RETURN	013860
END	013880

\$IBFTC BSNFCS	013890
FUNCTION BSNFCS(IG,P)	013900
COMMON/ECAB/GAMMOS(30), DUM(900)	013910
COMMON/ZECAB/BSUB(30),FSUB(30)	013920
COMMON/ZOL/JPRINT(35)	013930
1 FORMAT(1X,7HBSNFCS=E16.8)	013940
A=GAMMOS(IG)+P	013950
IF(BSUB(IG)+EQ+0+) GO TO 100	013960
RL=BSUB(IG)+SIN(A)	013970
GO TO 200	013980
100 R1=G.	013990
200 IF(FSUB(1G).EQ.0.) GO TO 300	014000
R2=FSUB(IG)*CDS(A)	014010
GO TO 400	014020
300 R2=0.	014030
400 BSNFCS=R1+R2	014040
IF(JPRINT(23).EQ.1) WRITE(6,1) BSNFCS	014050
RETURN	014060
END	014070

\$IBFT(	C COECOE	014080
	SUBROUTINE CDECDE(IG,CP,CL,CQ,CW)	014090
	COMMON/ACAB/FARE1(200),FARE2(200),FPHI1(200),FPHI2(200),A1(200),	014100
1	1 A2(200), DUMY(600)	014110
	COMMON/CROUT/NANS(10)	014120
	COMMON/ECAB/GAMMOS(30), EPILON(30), DUM(870)	014130
	COMMON/GCAB/ARE(2),AREARE(200)/HCAB/PHI(2),PHIPHI(200)	014140
	COMMON/ZO1/JPRINT(35)	014150
1	FORMAT(1X,6HCP([)=E16.8,5X,6HCL([)=E16.8,5X,6HCQ([)=E16.8,5X,	014160
	1 6HCW([]=E16.8.5X.3HI= 15)	014170
C		014180
	CALL DENOM(IG,DEHOM)	014190
	NTERVL=NANS(3)	014200
	DD 500 INN=1+NTERVL	014210
	B=BSNFCS(IG,PHIPHI(INN))	014220
	A1(INN)=FARE1(INN)+B	014230
	A2(INN)=FARE2(INN)+B	014240
500	CONTINUE	014250
	CALL SIMP(NTERVL, PHIPHI(2)-PHIPHI(1), A2, AREA2)	014260
	CALL SINP (NTERVL, PHIPHI(2)-PHIPHI(1), AI, AREA1)	014270
	CP=AREA1/DEHOM	014280
	CL=AREA2/DEHOM	014290
C		014300
C		014310
	NTERVL=NANS(4)	014320
	CALL CENDM(IG,CEHOM)	014330
	DO 1000 INN=1,NTERVL	014340
	B=AMSAFC(IG,AREARE(INN))/AREARE(INN)	014350
	Al(INN)=FPHI1(INN)=B	014360
	A2(INN)=FPHI2(INN)+B	014370
1000	CONTINUE	014380
	CALL SINP(NTERVL,AREARE(2)-AREARE(1),AI,AREA1)	014390
	CALL SIMP(NTERVL,AREARE(2)-AREARE(1),A2,AREA2)	014400
	CQ=AREA1/CEHON	014410
	CW=AREA2/CEHOM	014420

	Contrails	
C	IF{JPRINT(24).EQ.1) WRITE(6,1) CP,CL,CQ,CW,IG Return End	014430 014440 014450 014460
\$IBFT	C CENDM	014470
	SUBROUTINE CENOM(IG,CEHOM)	014480
	DIMENSION A(2),X(2)	014490
	COMMON/ECAB/DUM(30),EPILON(30),DUMY(870) COMMON/GCAB/ARE(2),AREARE(200)	014500 014510
	COMMON/RCAB/AL(2,2),AK(2,2)	014520
	COMMON/UTILTY/R10R2,R20R1,AR10R2,AR20R1,AR1,AR2	014530
	COMMON/WCAB/AM(30), AF(30)	014540
1	COMMON/ZO1/JPRINT(35) Format( 7H Cehom=E16.8,5X,7HAM(IG)=E16.8,5X,4HIG= I5}	014550 014560
c `		014570
	T1=0.0	014580
	T2=0.0	014590
c	T3≖0.0	014600 014610
ũ	IF(EPILON(IG).EQ.0.) GO TO 7600	014620
	REGL=SIN(EPILON(IG)+AR1)	014630
	REG2=CDS(EPILON(IG)+AR1)	014640
	UNDER=AL(1,1)=EPILON(IG)=REG2/ARE(1)=AL(1,2)=REG1 IF(UNDER_E0.0.) GO TO 4000	014650 014660
	AH(IG)=(AL(1,1)+EPILON(IG)+REG1/ARE(1) -AL(1,2)+REG2)/UNDER	014670
	AF(IG)=1.0	014680
40 <b>00</b>	GO TO 4065 Continue	014690 014700
4000	AM(IG)=1.0	014710
	AF(1G)=0.0	014720
C		014730
4065	CONTINUE X(1)=EPILON(IG)+AR1	014740 014750
	$X(2) \neq EPILON(IG) \neq AR2$	014760
C		014770
	IF(AM(IG).EQ.0.) GO TO 4800	014780
c	IF(AF(IG).EQ.0.) GO TO 5200	014790 014800
Ť	D0 4300 I=1+2	014810
	A(I)=.5+SIN(X(I))++2	014820
4300	CONTINUE T3={2.0+AM(IG)/EPILON(IG)}+{A(2}-A{1})	014830 014840
c	13-12.0-AR(16)/CF1L04(16)/-(A(2)-A(1))	014850
4800	CONTINUE	014860
	DO 4850 I=1,2	014870
4850	A(I)=X(I)/2.0+SIN(2.0+X(I))/4.0 CONTINUE	014880 014890
4030	T2*(A(2)-A(1))/EPILON(IG)	014900
С		014910
6200	IF(AM(IG).EQ.O.) GO TO 6123 CONTINUE	014920 014930
5200	00 5256 I=1,2	014940
	A(1)=X(1)/2.0-SIN(2.0+X(1))/4.0	014950
5256	CONTINUE	014960
c	T1=(AM(IG)++2)+{A(2)-A(1)}/EPILON(IG)	014970 014980
	CONTINUE	014990
	CEHOM=T1+T2+T3	015000
<i>c</i>	GO TO 8653	015010
C 7600	CONTINUE	015020 015030
	AH(IG)=0.0	015040
	AF(IG)=1.0	015050
	CEHON=AR2OR1	015060
C 8653	CONTINUE	015070 015080
	IF(JPRINT(25).EQ.1) WRITE(6,1) CEHOM,AM(IG),IG	015090
	RETURN	015100
	END	015110

Contrails

\$IBFTC ATRAN	015120
FUNCTION ATRAN(T)	015130
COMMON/XCAB/XTRAN(50),YTRAN(50),HAXMAX	015140
COMMON/YCAB/BEE, SEE/ZBCAB/ICASE	015150
COMMON/ZO1/JPRINT(35)	015160
50 FORMAT(1X,17H=INVERSION ERROR=) 51 FORMAT(1X,14H=ATRAN= CASE= I3,3X,4HBEE=E16.8,5X,4HSEE=E16.8,5X,	015170 015180
1 2HT=E16.8 / 1X, 2HQ=E16.8,5X,5HREG1=E16.8,5X,5HREG2=E16.8,5X	015190
2 5HREG3=E16.8 / 1X,5HREG4=E16.8,30X,6HATRAN=E16.8)	015200
C SET ICASE EQUAL TO THE CASE NUMBER OF THE DESIRED INVERSION	015210
REGI=0.	015220
REG2=0.	015230
REG3=0.	015240
REG4=0.	015250
Q=0.	015260
GO TO (1,2,3,4,5,6,7), ICASE	015270
1 REG1=1T#BEE	015280
C CASE 1	015290
IF(REG1.LE.O.) GO TO 9997 Atran=-Alog(Reg1)/Bee	015300 015310
GO TO 100	015320
2 IF(SEE.EQ.0.) GO TO 9997	015330
C CASE 2	015340
REG1=4.+SEE-BEE+BEE	015350
Q=REG1	015360
IF(REG1)11,12,13	015370
11 REG1#SQRT(-REG1)	015380
REG2=EXP(REG1+T)+(BEE-REG1)/(BEE+REG1)	015390
ATRAN={{BEE+REG}}+REG2-BEE+REG1}/{2.+SEE+{1REG2}}	015400
GO TO 100	015410
12 ATRAN#BEE+T/(4.#SEE/BEE-2.#SEE+T) GO TO 100	015420 015430
13 REG1=SQRT(REG1)	015440
REG2=BEE/REG1	015450
REG3=REG1+T/2.	015460
REG3=SIN(REG3)/COS(REG3)	015470
REG4=REG3+REG2	015480
TWOSEE=2.+SEE	015490
ATRAN=REG1+(REG2+REG3)/(TWDSEE-TWDSEE+REG4)-BEE/TWDSEE	015500
GO TO 100	015510
3 IF(BEE.EQ.O.) GO TO 9997 C CASE 3	015520 015530
ATRAN=(EXP(BEE+T)-1.)/BEE	015540
G0 T0 100	015550
4 REG1=1.+2.*BEE*T	015560
C CASE 4	015570
1F(REG1.LT.O.) GO TO 9997	015580
ATRAN=(-1.+SQRT(REG1))/BEE	015590
GO TO 100	015600
5 CONTINUE	015610
C CASE 5	015620
6 ATRAN=T C CASE 6	015630
GO TO 100	015640 015650
7 CALL CLINE(MAXMAX,T,YTRAN(1),XTRAN(1),ATRAN)	015660
C CASE 7	015670
IF(ATRAN.GT.XTRAN(MAXMAX)) GO TO 9997	015680
GO TO 100	015690
9997 WRITE(6,50)	015700
STOP	015710
100 IF(JPRINT(26).EQ.1) WRITE(6,51) ICASE, BEE, SEE, T,	015720
1 Q.REG1,REG2,REG3,REG4,ATRAN	015730
RETURN	015740
END	015750

Contrails

er de tr	C DENOM	015760
*LDF1	SUBROUTINE DENOM(IG,DEHOM)	015770
с	SUBRUCIAL DERCHAINVDEHONV	015780
C	DIMENSION A(2),X(2)	015790
	COMMON/ECAB/GAMMOS(30),DUM(900)	015800
	COMMON/HCAB/PHI(2), PHIPHI(200)	015810
	COMMON/RCAB/AL(2+2)+AK(2+2)	015820
	COMMON/ZECAB/BSUB1301.FSUB(30)	015830
	COMMON/201/JPRINT(35)	015840
1	FORMAT(7H DEHOM=E16.8,5X,9HBSUB(IG)=E16.8,5X,4HIG= I5)	015850
c Î		015860
Ŭ	IF(GAMMOS(IG).EQ.0.) GO TO 8011	015870
С		015880
U	T3=0.0	015890
	T2=0.0	015900
	T1=0.0	015910
с		015920
÷	X(1)=GAMMOS([G)+PH1(1)	015930
	X(2)=GAMMOS(IG)+PHI(2)	015940
	REGI=COS(X(1))	015950
	REG2=SIN(X(1))	015960
	UNDER=AK(1,1)+GAMMOS(IG)+REG1+AK(1,2)+REG2	015970
	IF(UNDER.EQ.0.) GO TO 106	015980
	BSUB(IG)=(-AK(1,2)*REG1+AK(1,1)*GAHMOS(IG)*REG2)/UNDER	015990
	FSUB(IG)=1.0	016000
	GO TO 150	016010
106	CONTINUE	016020
	BSUB(IG)=1.0	016030
	FSUB(IG)=0.0	016040
150	CONTINUE	016050
	IF(BSUB(IG).EQ.0.) GO TO 3000	016060
	IF(FSUB(IG).EQ.0.) GO TO 1000	016070
	DO 400 I=1,2	016080
	A(I)=BSUB(IG)*(SIN(X(I)))**2/GAMMOS(IG)	016090
400	CONTINUE	016100
	T2=A(2)-A(1)	016110
1000		016120 016130
	B=BSUB(IG)==2/2.0	016140
	G=2.0+GAMMOS(IG)	016150
	DO 1002 [=1,2 A(1)=B*PHI(1)-B*SIN(2.0*X(1))/G	016160
1082	CONTINUE	016170
1005	T1=A(2)-A(1)	016180
	IF(FSUB(IG).EQ.0.) GD TO 7000	016190
3000	CONTINUE	016200
2000	G=4.0+GAMMOS(IG)	016210
	DO 3800 I=1+2	016220
	A(1)=PHI(1)/2.0 +SIN(2.0+X(1))/G	016230
3800	CONTINUE	016240
	T3=A(2)-A(1)	016250
7000	CONTINUE	016260
	DEH0M=T1+T2+T3	016270
	GO TO 8900	016280
С		016290
8011	CONTINUE	016300
	BSUB(1G)=0.0	016310
	FSUB(IG)=1.0	016320
	DEHOM=PH1(2)-PH1(1)	016330
С		016340
8900	CONTINUE	016350
	IF(JPRINT(27),EQ.1) WRITE(6,1) DEHOK, BSUB(IG), IG	016360
	RETURN	016370
	END	016380

Contrails

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SIRATO	5 Parts - 1 <b>7</b>	016390
	SUBROUTINE INPUT	016400
C		016410
	COMMON/ACAB/FARE([200],FARE2(200),FPHI1(200),FPHI2(200),DUME(1000)	016420
	COMMON/CKOUT/NANS(10)	016430
	COMMON/CONTIM/XLAMDA(50), GLANDA(50), NLAMDA	016440
	COMMON/GCAB/ARE(2), AREARE(200)/HCAB/PHI(2), PHIPHI(200)	016450
	COMMON/UCAB/STEADY(7,25),XR(7),YP(25),KR,KP	016460
	COMMON/PCAB/DZER0(7,25),XRD(7),YPD(25),LR,LP	016470
	COMMON/RCAB/AL(2,2),AK(2,2)	016480
	COMMON/SPACE/DUM (200), R (200)	016490
	COMMON/TORIAN/STOOD, ONLY, SNOW	016500
	COMMON/UTILTY/RIOR2, R2OR1, ARIOR2, AR2OR1, AR1, AR2	016510
	COMMON/VCAB/ALPHG	016520
	COMMON/XCAB/XTRAN(50),YTRAN(50),MAXMAX	016530
1	COMMON/YCAB/BEE, SEE	016540
1	COMMON/ZBCAB/ICASE	016550
	COMMON/ZCCAB/AZERD	016560
	EQUIVALENCE (R.P)	016570
С		016580
1	FORMAT(6F10.0)	016590
2	FORMAT(A5,5X,110,4F10.0)	016600
3	FORMAT(A5,5X,2110,A6)	016610
4	FDRMAT(A5,5X,A5,5X,I10,A2)	016620
5	FORMAT(12A6)	016630
	FORMAT(1H112A6)	016640
8	FORMAT( 6H0INPUT/ 9H GEOMETRY/1X,3HR1=E16.8,5X,3HR2=E16.8/ 1X,	016650
-	3HP1=E16.8,5X,3HP2=E16.8, 5X,9H(RADIANS))	016660
-	FORMAT(27HOTHERMO PHYSICAL PROPERTIES)	016670
	FORMAT(1X,11HPDINT DATA,3X,12,12H POINT PAIRS / (4E20.8))	016680
	FORMAT(1X, 6HALPHA=E16.8,5X, 6HKZERO=E16.8)	016690
	FORMAT(1X,26HEVALUATE POLYNOMIAL FROM E16.8,3X,5HTD E16.8)	016700
	FORMAT(29H TRANSFORM ACCORDING TO CASE 11,3H,B=E16.8,3X,2HC=E16.8)	
	FORMAT(34HOINITIAL TEMPERATURE DISTRIBUTION )	016720
	FORMAT(1X,12HPOINT DATA, 12,1HX,12,18H, VALUES OF F(R,P))	016730
	FORMAT(3X,5E20.8)	016740
-	FORMAT(44HOERROR IN INPUT, PROBLEM UNABLE TO CONTINUE ,10X,112)	016750
	FORMAT(1H0,20HBOUNDRY CONDITIONS )	016760
-	FORMAT(1X,7HAT R1, ,A6,3X,4HL11=F10.2,3X,4HL12=F10.2)	016770
	FORMAT(1X,7HAT R2, ,46,3X,4HL21=F10.2,3X,4HL22=F10.2)	016780
	FORMAT(1X,7HAT P1, ,A6,3X,4HK11=F10.2,3X,4HK12=F10.2)	016790
	FORMAT(1X,7HAT P2, ,46,3X,4HK21=F10.2,3X,4HK22=F10.2)	016800
	FORMAT(1X,11HPDINT DATA,3X,12,43H EVENLY SPACED ORDINATES BETWEEN	016810 016820
	R1 AND R2 / (6E20.0)) Format{1x.11hpoint data.3x.12.43h evenly spaced ordinates between	016830
	PI AND P2 / (6E20.8))	016840
-	FORMAT(14HOTIME FUNCTION)	016850
	FORMAT(44HOSTEADY STATE SOLUTION IS BEING INPUT )	016860
	FORMAT(1H1)	016870
	FORMAT(7F10.0)	016880
	CALL ATHRUZ(PLY, 6HPOLY )	016890
	CALL ATHRUZ (CACE, 6HCASE )	016900
	CALL ATHRUZ(PONT, 6HPOINT )	016910
	CALL ATHRUZ (SNON, 6HND )	016920
	CALL ATHRUZ (PHLUX, 6HFLUX )	016930
	CALL ATHRUZ (FEVER, 6HTEMP )	016940
	CALL ATHRUZ (DNLY, 6HDN )	016950
	CALL ATHRUZISSOP, 6HTRANSF)	016960
	0=L	016970
C TITL		016980
	READ(5,5) (R(1),I=1,12)	016990
	WRITE(6,6) (R(1),I=1,12)	017000
C		017010
	IETRY, AREARE	017020
	READ(5,1) ARE	017030
	R10R2=ARE(1)/ARE(2)	017040
	R2OR1=ARE(2)/ARE(1)	017050
	AR1ORZ=ALOG(R1OR2)	017060
	ARZOR 1=ALOG(RZOR 1)	017070

Contrails

		AR1=ALOG(ARE(1))	017080
		AR2=ALOG(ARE(2))	017090
С	PHI		017100
~	<b>0</b> T	READ(5,1) PHI	017110
L	PHI	IS INPUT IN DEGREES AND FRACTIONS DO 18 I#1,2	017120 017130
	18	PH1(1)=PH1(1)+.01745329	017140
		WRITE(6,8) ARE,PHI	017150
		IF(ARE(1).LE.0.0.OR.ARE(2).LE.0.0.OR.PHI(1).NE.0.0.OR.PHI(2).LE.0.	017160
_		10) GO TO 900	017170
ç	THE	NO DUNCICAL DRODEDTIES TRAN	017180 017190
Ľ	INC	RMO PHYSICAL PROPERTIES, TRAN WRITE(6,9)	017200
		READ(5+2) WHAT,N+A+B+C+D	017210
		IF(N.GT.50) GO TO 19	017220
		IF(WHAT.EQ.PONT) GO TO 20	017230
		IF(WHAT.EQ.PLY) GO TO 30	017240
	10	IF(WHAT-EQ-CACE) GD TO 40 J≠1	017250 017260
	.,	GO TO 900	017270
	20	ALPHO=A	017280
		AZERO≠B	017290
		READ(5,1) (XTRAN(1),DUM(1),I=1,N)	017300
		MAXMAX=N WRITE(6,10) MAXMAX,(XTRAN(I),DUM(I),I=1,MAXMAX}	017310 017320
		WRITE(6,11) A,B	017330
		GD TO 35	017340
	30	ALPHO=C	017350
		AZERO=D	017360
		MAXMAX=50 CALL SIZE{XTRAN,MAXMAX,A,B]	017370 017380
		CALL POLYGN(XTRAN,DUM,MAXMAX,N)	017390
		WRITE(6,12) A,B	017400
		WRITE(6,11) C,D	017410
	35	ICASE=7	017420
C		CALL WOOFER	017430 017440
С		CALL NODFER	017450
-		GO TO 60	017460
	40	ICASE=N	017470
		BEE=A	017480
		SEE≖B ALPHO≖C	017490 017500
		AZERO=D	017510
		WRITE(6,13) N, BEE, SEE	017520
		IF(ICASE.GT.7) GO TO 19	017530
~		WRITE(6,11) C,D	017540
C	TNT	TIAL TEMPERATURE DISTRIBUTION, DZERD(IR, 1P)	017550 017560
v		WRITE(6,14)	017570
		READ(5,3) WHAT,N.M	017580
		IF(WHAT.EQ.PLY) GO TO 90	017590
		IF(N.GT.7.OR.M.GT.25) GO TO 68 IF(WHAT.EQ.PONT) GO TO 70	017600 017610
	68	J=2	017620
	••	GO TO 900	017630
	70	CALL SIZE(XRD,N,ARE(1),ARE(2))	017640
		CALL SIZE(YPD, M, PHI(1), PHI(2))	017650
		WRITE(6,15) N₂M DO 75 J≠1₂N	01766 <b>0</b> 017670
		L=M-J+L	017680
		READ(5,10000) (DZERD(I,L),I=1,N)	017690
	75	WRITE(6,16) (DZERD(I,L),I=1,N)	017700
			017710
		LP=M GO TO 95	017720
	90	NTERMS=N	017740
		LR=7	017750
		LP=25	017760

Contrails

	CALL SIZE(XRD, LR, ARE(1), ARE(2))	017770
	CALL SIZE(YPD,LP,PHI(1),PHI(2))	017780
	CALL POLYH(DZERO,XRD,YPD,LR,LP,NTERMS)	017790
С		017800
	UNDARY CONDITIONS, FARE1(PHI),AL(1,1),AL(1,2)	017810
	5 WRITE(6,4000)	017820
10	D READ(5,4) X, WHAT, N, STOOD	017830
	IF(X.EQ.FEVER) GO TO 110	017840
	IF(X.EQ.PHLUX) GO TO 120	017850
	J=3 G0 T0 900	017860
11	GU 10 900 D AL(1.1)=0.	017870 017880
11	AL(1,2)=1.	017890
	GO TO 130	017900
12	0 AL(1,1)=-1	017910
	AL(1,2)=0.	017920
13	0 WRITE(6,4001) X,AL(1,1),AL(1,2)	017930
	IF(STODD.EQ.SNDW) GO TO 160	017940
	IF(N.GT.200) GO TO 135	017950
	CALL SIZE(PHIPHI,NANS(3),PHI(1),PHI(2))	017960
	CALL SIZE(AREARE,NANS(4),ARE(1),ARE(2))	017970
	CALL SIZE(XR, NANS(5), ARE(1), ARE(2))	017980
	CALL SIZE(YP,NANS(6),PHI(1),PHI(2))	017990
	NP=NANS(3)	018000
	NR=NANS(4)	018010
	IF(WHAT.EQ.PONT) GO TO 140 IF(WHAT.EQ.PLY) GO TO 150	018020 018030
13	5 J=4	018040
	GO TO 900	018050
14	0 READ(5,10000) (DUM(I),I=1,N)	018060
-	WRITE(6,4006) N. (DUM(I), I=1.N)	018070
	CALL SIZE (P, N, PHI(1), PHI(2))	018080
	DO 145 IP=1,NP	018090
14	5 CALL CLINEIN, PHIPHI(IP), P, DUM, FARE1(IP))	018100
	GO TO 155	018110
	O CALL POLYGN(PHIPH1,FARE1,NANS(3),N)	018120
15	5 IF(AL(1,2).EQ.1.0) GO TO 157	016130
	DO 156 $IP=1$ , NP	018140
15	FARE1([P)= FARE1(IP)/AZERO 6 CONTINUE	018150
12	GO TO 160	018160 018170
15	7 CONTENUE	016180
	DO 158 IP=1+NP	018190
	FAREL(IP) = TRAN(FAREL(IP))	018200
15	8 CONTINUE	018210
C		018220
	RE2(PH1),AL(2,1),AL(2,2)	018230
16	O READ(5,4) X,WHAT,N	018240
	IF(X.EQ.FEVER) GO TO 170	018250
	IF(X.EQ.PHLUX) GO TO 180 J=5	018260
	J=5 G0 T0 900	018270
17	0 AL(2,1)=0.	018280 018290
•••	AL(2+2)=1.	016300
	GO TO 190	018310
18	O AL(2,1)=1.	018320
	AL(2,2)=0.	018330
19	0 WRITE(6,4002) X,AL(2,1),AL(2,2)	018340
	IF(STOOD-EQ.SNOW) GD TO 220	018350
	IF(N.GT.200) GO TO 195	018360
	IF(WHAT.EQ.PONT) GO TO 200	018370
	IF(WHAT.EQ.PLY) GO TO 210	018380
19	5 J=6	018390
20	GO TO 900 A READIE 100001 (DUM(1) Tel NI	018400
201	0 READ(5,10000) {DUM([],[=1,N} WRITE(6,4006) N,{DUM([],[=1,N)	016410
	CALL SIZE(P+N,PHI(1),PHI(2))	016420
	DO 205 IP=1,NP	018430 018440
20	5 CALL CLINE(N, PHIPHI(IP), P, DUM, FARE2(IP))	018450
		~~~~~

Contrails

GO TO 211	
210 CALL POLYGN(PHIPHI,FARE2,NP,N)	
211 IF(AL(2,2).EQ.1.0) GO TO 213 DO 212 IP=1.NP	
FARE2(IP)=FARE2(IP)/AZERO	
212 CONTINUE	
GO TO 220 213 continue	
DO 214 IP=1,NP	
FARE2(IP)=TRAN(FARE2(IP))	
214 CONTINUE C	
G FPHI1(ARE),AK(1,1),AK(1,2)	
220 READ(5,4) X, WHAT,N	
IF(X.EQ.FEVER) GO TO 230	
IF(X.EQ.PHLUX) GO TO 240 J=7	
GO TO 900	
230 AK(1,1)=0.	
AK(1,2)=1.	
GO TO 250 240 AK(1+1)=-1	
AK(1,2)=0.	
250 WRITE(6,4003) X; AK(1,1); AK(1,2)	
IF(STOOD.EQ.SNOW) GO TO 280	
IF(N.GT.200) GD TO 255 IF(WHAT.EQ.PONT) GD TO 260	
IF(WHAT.EQ.PLY) GO TO 270	
255 J=8	
GO TO 900 260 READ(5,10000) (DUM(I),I=1,N)	
WRITE(6,4005) N. (DUM(I), I=1,N)	
CALL SIZE(R,N,ARE(1),ARE(2))	
DO 265 IR±1.NR	
265 CALL CLINE(N+AREARE(IR)+R+DUM+FPH11(IR GO TO 271	• •
270 CALL POLYGN(AREARE, FPHIL, NR, N)	
271 IF(AK(1,2).EQ.1.0) GO TO 273	
DO 272 IR=1,NR	
FPHI1(IR) = AREARE(IR) + FPHI1(IR)/AZERO 272 CONTINUE	
GO TO 280	
273 CONTINUE	
DO 274 IR=1+NR FPHI1(IR)=TRAN(FPHI1(IR))	
274 CONTINUE	
C	
C FPHI2(ARE), AK(2,1), AK(2,2)	
260 READ(5,4) X,WHAT,N IF(X.EQ.FEVER) GO TO 290	
IF(X.EQ.PHLUX) GO TO 300	
J=9	
GO TO 900 290 AK(2,1)=0.	
AK(2,2)=1.	
GO TO 310	
300 AK(2,1)=1.	
AK(2,2)=0. 310 WRITE(6,4004) X,AK(2,1),AK(2,2)	
IF(STOOD.EQ.SNOW) GO TO 360	
IF(N.GT.200) GD TO 315	
IF(WHAT.EQ.PONT) GO TO 320 IF(WHAT.EQ.PLY) GO TO 330	
315 J=10	
GO TO 900	
320 READ(5,10000) (DUM(I),I=1,N)	
WRITE(6,4005) N,(DUM(I),I=1,N) CALL SIZE(R,N,ARE(1),ARE(2))	
DO 325 IR=1,NR	

018460
018470 018480 018490
018500 018510 018520
018530 018540 018550
018560 018570 018580
018590 018600
018610 018620 018630
018640 018650 018660
018670 018680 018690
018700 018710 018720
018730 018740 018750
018760 018770 018780
018790 018800 018810
018820 018830
018840 018850 018860
018870 018880 018890
018900 018910 018920
018930 018940 018950
018960 018970 018980
018990 019000 019010
019020 019030 019040
019050 019060
019070 019080 019090
019100 019110 019120
019130 019140

Contrails

	325	CALL CLINE(N, AREARE(IR), R, DUM, FPHI2(IR))		019150
		GO TO 331		019160
		CALL PDLYGN(AREARE, FPHI2, NR, N)		019170
	331	IF(AK(2,2).EQ.1.0) GO TO 333		019180
		DO 332 IR=1,NR		019190
		FPHI2(IR) = AREARE(IR) + FPHI2(IR) / AZERO		019200
	352	CONTINUE GD TO 400		019210 019220
	333	CONTINUE		)19230
		00 334 IR=1+NR		019240
		FPHI2(IR) #TRAN(FPHI2(IR))		019250
	334	CONTINUE		019260
		GO TO 400		19270
C			(	019280
С		NDY STATE INPUT OPTION		19290
	360	WRITE(6,4009)		019300
		READ(5,3) WHAT,N,M,X		019310
		IF(WHAT.EQ.PLY) GO TO 380 IF(N.GT.7.OR.M.GT.25) GO TO 365		19320
		IF(WHAT.EQ.PONT) GO TO 370		019330 019340
	365	J=11		019350
		GD TD 900		019360
	370	WRITE(6,15) N.M		019370
		DO 375 J=1,M		019380
		L=H-J+1	(	019390
		READ(5,10000) (STEADY(I,L),I=L,N)		019400
	375	WRITE(6,16) (STEADY(I,L),I=1,N)		019410
		CALL SIZE(XR,N,ARE(1),ARE(2))		019420
		CALL SIZE(YP,M,PHI(1),PHI(2)) KR=N		019430
		KR=N KP=M		019440 019450
		GO TO 390		019460
	380	KR=7		19470
		KP=25		019480
		CALL SIZE(XR,KR,ARE(1),ARE(2))	(	019490
		CALL SIZE(YP,KP,PHI(1),PHI(2))	t	19500
		NTERMS=N		019510
		CALL POLYH(STEADY, XR, YR, KR, KP, NTERMS)		019520
	390	IF(X.NE.SSOP) GO TO 400		019530
		DO 395 IR=1,KR		019540
	305	DO 395 IP=1+KP STEADY(IR,IP)=TRAN{STEADY{IR,IP)}		019550 019560
с	377	STERDITIN JIP /- TRAILSTERDITIN JIP / T		019570
	T LME	FUNCTION		019580
-		READ(5,2) WHAT,N,B		019590
		A=0.0	(	19600
		WRITE(6,4007)	(	019610
		IF(WHAT.EQ.PONT) GO TD 420		019620
		IF(WHAT.EQ.PLY) GO TO 430		019630
	410	J=12		019640
	4 30	GO TO 900		019650
	420	NLAMDA=N IF(NLAMDA-GT-50) GO TO 410		019660 019670
		READ(5,1) (XLAMDA(1),GLAMDA(1),I=1,N)		19680
		WRITE(6.10) N. (XLANDA(1).GLANDA(1).I=1.N)		19690
		GO TO 440		)19700
	430	NLAMDA=50		19710
		CALL SIZE (XLAMDA, NLAMDA, A, B)		19720
		CALL POLYGN(XLAMDA, GLAMDA, NLAMDA, N)		019730
		WRITE(6,12) A,B		19740
	44U	NRITE(6,4010)		019750
c	ERRO	RETURN		)19760 )19770
•		WRITE(6,1000) J		19780
		STOP		19790
		RETURN		19800
		END		19810

Contrails

	010020
\$IBFTC SIMP SUBROUTINE SIMP(NT,DX,V,AREA)	019820 019830
C EQUALLY SPACED POINTS	019840
C EVEN NO. OF INTERVALSSIMPSONS RULE	019850
C UDD NO FIRST N-1 INTERVALS-SIMPSONS LAST INTERVAL-TRAPEZOI	
DIMENSION V(1)	019870
C DIMENSION V(1)	019880
AREA=0.0	019890
IF(NT-1)47,50,47	019900
47 IF((NT/2)+2-NT)28,29,28	019910
29 NOD=1	019920
Nl=NT-1	019930
GO TO 32	019940
28 N1=NT	019950
NOD=0	019960
32 AREA1=0.0	019970
IF(N1-1)35,35,445	019980
445 J=N1-1	019990
00 33 I=2,J,2	020000
33 AREA=V(I)+AREA	020010
IF{N1-3}446,446,7447	020020
7447 J=N1-2	020030
DO 34 I=3+J+2	020040
34 AREA1=V(I)+AREA1	020050
446 AREA =.33333333+(V(1)+V(N1)+2.0+AREA1+4.0+AREA)	020060
IF(NOD) 35, 36, 35	020070
35 AREA= AREA +.5+(V(N1)+V(N1+1))	020080
36 AREA= DX+AREA	020090
50 RETURN END	020100
END	020110
\$LBFTC ATHRUZ	020120
SUBROUTINE ATHRUZ (A. B)	D20130
DIMENSION A(1), B(1)	020140
DO 25 I = 1, 22	020150
A(1) = B(1)	020160
C = COMPL(B(I+1))	020170
IFI C .EQ. O.) RETURN	020180
25 CONTINUE	020190
RETURN	020200
END	020210
SIBFTC CLINE	020220
SUBROUTINE CLINE(N,X,A,B,Y)	020230
DIMENSION A(1), B(1)	020240
C DIMENSION A(1), B(1)	020250
IF (N) 100,100,101	020260
101 DO 102 J=2,N	020270
]=J	020280
IF (X-A(J)) 103,103,102	020290
102 CONTINUE	020300
103 Y = B(I-1) + (X+A(I-1)) + (B(I)-B(I-1))/(A(I)-A(I-1))	020310
RETURN 100 y×0.0	020320
RETURN	020330
END	020340
	020350

Contrails

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# APPENDIX C

# DESCRIPTION OF SUBROUTINES

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APPENDIX C

Contrails

#### DESCRIPTION OF SUBROUTINE

Independent intermediate print is available for many of the subroutines and subprograms. Each routine has been assigned a sequence number. This sequence number corresponds to a column number of card B in the input data (see Section IIIB). Hence, a particular column i of card B controls the intermediate print of the routine or subprogram which has been assigned the sequence number i. A description of this resulting intermediate print for a particular routine is given in the discussion of that routine.

The routines and their associated sequence numbers are as follows:

	Sequence		Sequence
Routine	No.	Routine	No.
	4	GEDIEG	17
MAIN	1	SERIES	17
BES	2	STATE	18
РØLYH	3	XI (function)	19
VLINE	4	FFP	20
LEFT	5	ARBCØE	21
SIZE	6	TRAN (function	22
WØØFER	7	BSNFCS (function)	23
PØLYGN	8	CØECØE	24
ENØM	9	CENØM	25
GAMEPS	10	ATRAN (function)	26
GTIME	11	DENØM	27
WURZEL	12	INPUT	28
BRIDGE	13		
ABES	14	ATHRUZ )	
GAMMA	15	SIMP ) System ro	utines
AMSAFC (function)	16	CLINE )	

1. MAIN (Sequence Number 1)

MAIN is the control point for the program. It sets up the order in which the program will execute.

MAIN reads in the fixed input and in the times and locations at which answers are requested. The remainder of the input data is handled in subroutine INPUT.

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The fixed input in MAIN consists of the two leading cards A and B of the input data. Card A contains the mathematical options for the program which are stored in an array called NANS. Card B contains the intermediate print options for the program which are stored in an array called JPRINT. The following are the mathematical options:

NANS(1)	=	the number of gammas used for a solution (30 max)
NANS(2)	=	the number of betas used for a solution (30 max)
NANS(3)	=	the number of intervals for phi integration in STATE (200 max)
NANS(4)	Ŧ	the number of intervals for r integration in STATE (200 max)
NANS(5)	=	the number of lattice points in the r direction in STATE
		(7 max)
NANS(6)	=	the number of lattice points in the phi direction in STATE
		(25 max)
NANS(7)	=	the number of gammas/epsilons used in STATE (30 max)
NANS(8)	=	the number of intervals for phi integration in ARBCØE
		(200 max)
NANS(9)	=	the number of intervals for r integration in $ARBC \phi E$ (200 max)

Each subscript of NANS is a multiple of a five column span on card A. Thus, the number of  $\beta$ 's, NANS(2), would appear in columns 6 through 10, and it must be right adjusted in its field with no decimal point, as must all of the entries on cards A and B.

Intermediate print for MAIN consists of a printout of the image of card A, and the lattice network in r and  $\phi$ , if applicable.

A detailed flow diagram of MAIN is given in Appendix D.

2. BES (Sequence Number 2)

Subroutine BES is one of the two subroutines used in a previous program (Reference 4). This subroutine calculates Bessel functions of the form  $J_{\gamma}(\beta r)$  and  $J'_{\gamma}(\beta r)$ . The arguments for this routine are A, X, Y, B, and BP, which correspond to  $\beta$ , r,  $\gamma$ ,  $J_{\gamma}(\beta r)$  and  $J'_{\gamma}(\beta r)$ .

This subroutine uses series solution and recursion formulas similar to those used in ABES. (See References 6 and 7).

3. PØLYH (Sequence Number 3)

Subroutine PØLYH is a utility subroutine of subroutine Input. PØLYH reads in an evaluates a polynominal of ten or less terms where each term is of the form:

 $AX^{B}Y^{C}$ .

The restrictions on A, B, and C are those imposed by the computer in raising a number to a power. In general it should be noted that a computer error usually occurs when

Contrails

or

 $|C| \ln Y > 88.02$ 

 $|B| \ln X > 88.02$ 

(A negative X or Y also causes a computer error, but the X's and Y's used in this program correspond to r and  $\phi$ , and these cannot be negative without voiding the solution).

 $P \not O LYH$  automatically prints out the polynomial that was input.

The argument list for PØLYH is Z, X, Y, NX, NY, and NTERMS where:

- Z = the name of the array where the evaluations of the polynomial will be stored
- X = an independent variable array
- Y = an independent variable array
- NX = the number of points in X where the polynomial is to be evaluated

NY = the number of points in Y where the polynomial is to be evaluated NTERMS = the number of terms comprising the polynomial

A 1 placed in column 3 of card B will produce intermediate print of the arrays X, Y, and Z.

4. VLINE (Sequence Number 4)

Subroutine VLINE linearly interpolates on a doubly subscripted array Z(X,Y). The arguments for VLINE are NX, NY, XIN, YIN, XARRAY, YARRAY, L, M, and ZØUT, where:

- NX = the number of points in the X direction
- NY = the number of points in the Y direction
- XIN = the value X at which the value for Z(X,Y) is desired
- YIN = the value Y at which a value for Z(X,Y) is desired
- XARRAY = the name of the singularly subscripted array containing the X independent variable
- YARRAY = the name of the singularly subscripted array containing the Y independent variable
- ZARRAY = the name of the doubly subscripted array containing the Z dependent variable

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L and M = the dimensions on the Z array, where the Z array is of the form Z(L,M) Note: L and M must agree with the dimensions given for the Z array in the calling program. ZØUT = the interpolated value of the dependent variable.

VLINE was especially designed for the lattice networks of the steady state solution and the initial temperature distribution which are stored as double subscripted variables in the program.

5. LEFT (Sequence Number 5)

Subroutine LEFT was created to avoid unnecessary rewriting of a short set of instructions. It simply moves an X, Y, and Z prime into their appropriate storage areas. LEFT is used in subroutines WURZEL and BRIDGE.

6. SIZE (Sequence Number 6)

Subroutine SIZE divides an interval into a given number of constant size increments. The arguments for size are:

A, MAX, AMIN, and AMAX

where

A = the array name where the increments are to be stored
MAX = the number of increments plus one
AMIN = the lower limit of the interval
AMAX = the upper limit of the interval

7. WØØFER (Sequence Number 7)

A 1 placed in column 7 of card 8 will produce intermediate print of the arrays XTRAN (real temperature) and YTRAN (transform temperature). The input thermophysical property data is always printed out.

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## 8. PØLYGN (Sequence Number 8)

Subroutine PØLYGN performs the same basic function as subroutine PØLYH but for one independent variable instead of two; i.e., PØLYGN reads and evaluates a polynominal whose terms are of the form

$$y = Ax^B$$

(See Subroutine PØLYGH).

The arguments for PØLYGN are X, Y, NY, and NTERMS, where:

- X = the independent variable
- Y = the dependent variable array
- NY = the number of points at which the polynomial is to be evaluated,

NTERMS = the number of terms comprising the polynominal.

The polynomial evaluated by POLYGN is automatically printed out.

A 1 placed in column 8 of card B will produce intermediate print of the arrays X and Y.

9. ENØM (Sequence Number 9)

Subroutine ENØM solves three related expressions:

$$C_{\gamma\beta} = \frac{-\ell_{11} Y'_{\gamma} (\beta r_{1}) - \ell_{12} Y_{\gamma} (\beta r_{1})}{\ell_{11} J'_{\gamma} (\beta r_{1}) + \ell_{12} J_{\gamma} (\beta r_{1})}$$

$$EH \not O M = \int_{r_{1}}^{r_{2}} r \left[ C_{\gamma\beta} J_{\gamma} (\beta r) + Y_{\gamma} (\beta r) \right]^{2} dr$$

$$ST \phi 2 = \left[ C_{\gamma\beta} J_{\gamma}(\beta r) + Y_{\gamma}(\beta r) \right] r.$$

 $ST\emptyset^2$  is actually an array of expressions. It is evaluated at a number of r's and stored in common for use in subroutine ARBC $\emptyset$ E.

The arguments for ENOM are IG, IB, and EHØM where:

IG = the index number of an angular eigenvalue (y)

Contrails

IB = the index number of a radial eigenvalue  $(\beta)$ 

EHOM = the name of the location where the value of the integral EHOM is stored

A 1 in column 9 of card B produces intermediate print of EHØM and  $C_{\nu\beta}.$ 

10. GAMEPS (Sequence Number 10)

Subroutine GAMEPS solves for the eigenvalues  $\gamma$  and  $\epsilon$ . The subroutine evaluates Equations (46) through (51) to obtain  $\gamma$ 's and a similar set to obtain  $\epsilon$ 's.

The arguments for GAMEPS are ISEEK, MANY, and VALUES, where:

ISEEK = the selection indicator for  $\gamma$ 's or  $\epsilon$ 's MANY = the number of eigenvalues desired VALUES = the array name where the eigenvalues will be stored.

A 1 in column 10 of card B (above) produces intermediate print in GAMEPS of the arguments, the eigenvalues, and some of the indicators and constants used by GAMEPS.

11. GTIME (Sequence Number 11)

Subroutine GTIME solves the expression

GSIMP = 
$$\alpha \beta^2 \int_0^{\theta} g(\lambda) e^{-\alpha \beta^2 (\theta - \lambda)} d\lambda$$

and also obtains

$$\mathbf{GTHETA} = \mathbf{g}(\mathbf{\theta})$$

where  $g(\theta)$  is the time function which is input by the program user, and  $\theta$  is a time at which program answers are being computed.

The arguments for GTIME are: TIME, BETA, and GSIMP, where:

TIME =  $\theta$ BETA =  $\beta$ GSIMP = the name of the location where the evaluation of the integral GSIMP (above) will be stored.

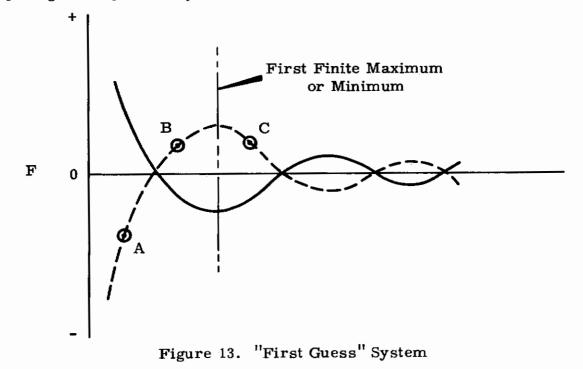
Intermediate print is not furnished for GTIME since GSIMP and GTHETA are part of the intermediate print of subroutine SERIES.

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12. WURZEL (Sequence Number 12)

Subroutine WURZEL is a root searching routine which works in conjunction with subroutines FFP and BRIDGE. Its method, one of trial and error, is based on limiting root spacing of Equation (52)<sup>†</sup>.

WURZEL makes continuous guesses at an abscissa value and calls subroutine FFP to get a corresponding ordinate value of Equation (53) and slope of Equation (54). The relationship of the signs of Equations (53) and (54) on the first guess, determines whether the direction of the continued search should be forward or backward. This scheme is illustrated in Figure 13. A first guess at point A would initiate a forward search. A first guess at point B would initiate a backward search. The scheme, however, does not provide recovery from a first guess past the first finite maximum or minimum such as point C, and would subsequently miss the first root. Accordingly, an educated first guess is required. As programmed, a first guess of  $0.25\alpha/r_1*$  is used as the first guess for the first two y's. The first guesses for the remainder of the given set of  $\gamma$ 's is based on the spacing of the previously determined first roots.



<sup>\*</sup> For  $\gamma$  equals zero, the first guess is  $1/r_2 - r_1$ .

† The root spacing approaches  $\pi/r_2 - r_1$  as  $\beta$  approaches infinity.

#### 13. BRIDGE (Sequence Number 13)

Subroutine BRIDGE is a direct application of Newton's method of successive approximations (Reference 11) and the regula falsi method (Reference 2) used in root searching. The regula falsi method is applied in the coarse search phase, until it obtains two points in the immediate vicinity of, and boardering a root. Newton's method of successive approximations is then applied in the fine search phase to obtain the root within a desired accuracy.

Contrails

The arguments for BRIDGE are:

IB, XH, YH, SH, XL, YL, SL, and IG

where

- IB = the index number of the desired radial eigenvalue ( $\beta$ ).
- (XH, YH and SH) = the coordinates and slope respectively of a point forward of the  $\beta$ .
- (XL, YL and SL) = the coordinates and slope respectively of a point behind the  $\beta$ .
  - IG = the index number of an angular eigenvalue (y)

14. ABES (Sequence Number 14)

Subroutine ABES solves for Bessel functions of the second kind of the form  $Y_{\gamma}(\beta r)$  and  $Y'_{\gamma}(\beta r)$ . It also obtains Bessel functions of the first kind of the form  $J_{\gamma}(\beta r)$  and  $J'_{\gamma}(\beta r)$  by a call to subroutine BES.

The arguments for ABES are B6, R6, C6, A6, AP6, Y6, and YP6, which correspond to

$$\dot{\beta}$$
, r,  $\gamma$ ,  $J_{\gamma}$  ( $\beta$ r),  $J'_{\gamma}$  ( $\beta$ r),  $Y_{\gamma}$  ( $\beta$ r), and  $Y'_{\gamma}$ ( $\beta$ r).

If the desired functions are of non-integer order, an explicit expression for Bessel functions of the second kind, in terms of Bessel functions of the first kind, is used. This expression is

$$Y_{\gamma}(\beta r) = \frac{1}{\sin \gamma \pi} \left[ \cos (\gamma \pi) J_{\gamma}(\beta r) - J_{-\gamma}(\beta r) \right]$$

Integer order functions are obtained by calculating  $Y_1$  and  $Y_2$  from the following equations and using recurrence formulas (see Reference 6 or 7)

Contrails

to obtain  $Y_n$  and  $Y'_n$ . The use of recurrence formulas avoids the need of special expressions for high orders and provides a scheme for obtaining the derivatives. The derivative is required by WURZEL and ENOM.

For small arguments

$$\pi Y_{\gamma} (\beta \mathbf{r}) = 2J_{\gamma} (\beta \mathbf{r}) \left[ \ell n \frac{\beta \mathbf{r}}{2} + \sigma \right] - \sum_{\mathbf{r}=0}^{\infty} (-1)^{\mathbf{r}} \frac{(\beta \mathbf{r}/2)^{\gamma+2\mathbf{r}}}{\mathbf{r}!(\gamma+\mathbf{r})!}$$
$$\times \left[ \sum_{\mathbf{m}=1}^{\gamma+\mathbf{r}} \mathbf{m}^{-1} + \sum_{\mathbf{m}=1}^{\mathbf{r}} \mathbf{m}^{-1} \right]$$
$$- \frac{\gamma \sum_{\mathbf{r}=0}^{-1}}{\mathbf{r} \sum_{\mathbf{r}=0}^{\gamma-1} (\beta \mathbf{r}/2)^{-\gamma+2\mathbf{r}} \frac{(\gamma-\mathbf{r}-1)!}{\mathbf{r}!}}$$

where  $\sigma$  is Euler's constants.

For larger arguments ( $\beta$ r)

$$\pi Y_{\gamma}(\beta r) \sim \left(\frac{2\pi}{\beta r}\right)^{\frac{1}{2}} \sin \left(\beta r - \frac{1}{2}\gamma \pi - \frac{1}{4}\pi\right) \sum_{m=0}^{\infty} \frac{(-1)^{m} f_{\gamma}(\gamma, 2m)}{(2\beta r)^{2m}} + \cos \left(\beta r - \frac{1}{2}\gamma \pi - \frac{1}{4}\pi\right) \sum_{m=0}^{\infty} \frac{(-1)^{m} f_{\gamma}(\gamma, 2m+1)}{(2\beta r)^{2m+1}}$$

where

$$f_{\gamma}(a,b) = \frac{\Gamma(a+b+\frac{1}{2})}{b!\Gamma(a-b+\frac{1}{2})}$$

15. GAMMA (Sequence Number 15)

Subroutine GAMMA is the other of the two routines used in Reference 4. GAMMA calculates GAMMA functions for use in Subroutine BES.

The arguments for GAMMA are X and Y where

 $Y = \Gamma(X).$ 

16. AMSAFC (Sequence Number 16)

Function subprogram AMSAFC solves the expression

AMSAFC =  $M_{\epsilon} \sin (\epsilon \ln r) + F_{\epsilon} \cos (\epsilon \ln r)$ 

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The arguments for AMSAFC are IG and V,

where,

IG = the index number of the  $\epsilon$ 

V = r

the values of  $M_{\epsilon}$ ,  $F_{\epsilon}$ , and  $\epsilon$  are stored in common. A 1 placed in column 16 of card B will print the expression AMSAFC as intermediate print.

17. SERIES (Sequence Number 17)

Subroutine SERIES solves the equation

 $T(\theta, r, \phi) = TERMA + TERMB + g(\theta) \times f(r,\phi)$ 

where TERMA is defined by the double summation of Equation (44) and TERMB is defined by the double summation of Equation (83).

The arguments for SERIES are: TIME, R, and P, which correspond to  $\theta$ , r, and  $\phi$ .

The intermediate print for SERIES is in two forms. A 1 in column 17 of card B prints  $T(\theta, r, \phi)$ , before it is inverted, and the corresponding steady state solution  $f(r, \phi)$ .

A 2 placed in the same column prints the same information as for a 1, as well as the terms in the series, the time function, the eigenvalues, and the partial sums.

18. STATE (Sequence Number 18)

Subroutine STATE solves the steady state portion of the problem. In particular, it solves the equation

 $f(\mathbf{r}, \phi) = \Sigma T_1 + \Sigma T_2 + \Sigma T_3 + \Sigma T_4$ 

where

 $T_1 = \text{term defined in (100)}$  $T_2 = \text{term defined in (110)}$ 

$$T_3 = term defined in (120)$$

 $T_4 = term defined in (132).$ 

The intermediate print in STATE is obtained by placing a 1 in column 18 of card B.

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The printout consists of  $T_1$ ,  $T_2$ ,  $T_3$ ,  $T_4$  and the partial sum of the four series for each eignevalue.

19. XI (Sequence Number 19)

Function subprogram XI solves for the  $\xi$  expressions in Equations (101), (111), (122), and (133) in the steady state solution. For example, at boundary  $r_1$ , XI solves Equation (101). However, special cases in Equation (107), (108), and (109) can be obtained by setting

$$\xi_{r1} = 1.0,$$
  
 $\xi_{r1} = ln(r/r_2) / lnr_1/r_2,$ 

or

$$\xi_{r1} = r_1 \ln (r/r_2).$$

depending upon the boundary condition indicators.

The arguments for XI are: IG, V, and NBØUND,

where

- IG = the index number of an eigenvalue
- V = either r or φ depending upon which boundary is being requested
- NBOUND = the number of the boundary being requested (1, 2, 3, or 4 for boundaries  $r_1$ ,  $r_2$ ,  $\phi_1$ , or  $\phi_2$ , respectively).

A 1 in column 19 of card B will produce intermediate print of the value of  $\xi$  and the boundary which has been evaluated.

20. FFP (Sequence Number 20)

Subroutine FFP calculates the functions

$$\mathbf{F} = \begin{vmatrix} \mathbf{T}_1 & \mathbf{T}_2 \\ \mathbf{T}_3 & \mathbf{T}_4 \end{vmatrix}$$
(53)

Contrails

 $\mathbf{and}$ 

$$\frac{\partial \mathbf{F}}{\partial \beta} = \mathbf{F} \mathbf{P} = \begin{vmatrix} \mathbf{T}_{1} & \mathbf{T}_{2} \\ \frac{\partial \mathbf{T}_{3}}{\partial \beta} & \frac{\partial \mathbf{T}_{4}}{\partial \beta} \end{vmatrix} + \begin{vmatrix} \frac{\partial \mathbf{T}_{1}}{\partial \beta} & \frac{\partial \mathbf{T}_{2}}{\partial \beta} \\ \mathbf{T}_{3} & \mathbf{T}_{4} \end{vmatrix}$$
(54)

for a particular value of the independent variable  $\beta$  for a given  $\gamma$ . Subroutine WURZEL and BRIDGE use this subroutine (FFP) in searching for roots of equation (52).

The arguments for FFP are: IG, B, F, and FP

where:

IG = the index number of the angular eigenvalue  $(\gamma)$ .

B = the independent variable in equation (53) and (54).

 $F \sim$  defined above in equation (53)

 $FP \sim$  defined above in equation (54)

Intermediate print in FFP is of two forms:

- 1 A 1 in column 20 of card B (above) prints out B, F, FP, and IG.
- 2 A 2 in column 20 of card B prints out the elements of the determinant F, and their derivatives and the Bessel functions necessary for these computations as well as B, F, FP, and IG.

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#### 21. ARBCØE (Sequence Number 21)

Subroutine ARBC $\not{O}$ E solves the equations for A<sub> $\gamma\beta$ </sub>, Equation (62), and G<sub> $\gamma\beta$ </sub>, Equation (80). A<sub> $\gamma\beta$ </sub> and G<sub> $\gamma\beta$ </sub> are the arbitrary coefficients of the transient solution. Special cases of the arbitrary coefficients emerge automatically in ARBC $\not{O}$ E due to the evaluation of composite expressions in supporting subroutines and subprograms.

A 1 in column 21 of card B produces intermediate print of the arbitrary coefficients.

22. TRAN (Sequence Number 22)

Function subprogram TRAN transforms a variable according to the special cases of Table I.

The single argument of TRAN is V which is the variable to be transformed according to Equation (11).

A 1 in column 22 of card B produces intermediate print of the variable V, the transform variable T, and the constants and intermediate expressions used in the transform calculations.

23. BSNFCS (Sequence Number 23)

Function subprogram BSNFCS solves the expression

BSNFCS =  $B_v \sin(\gamma \phi) + F_v \cos(\gamma \phi)$ 

The arguments of BSNFCS are IG and P

#### where

IG = the index number of an eigenvalue  $(\gamma)$ 

 $P = \phi$ 

 $B_{v}$  and  $F_{v}$  are obtained through common.

A 1 in column 23 of card B produces intermediate print of the expression BSNFCS.

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## 24. CØECØE (Sequence Number 24)

Subroutine CØECØE solves Equations (102), (112), (123) and (134) for the arbitrary coefficients of the steady state solution,  $P_{\gamma}$ ,  $L_{\gamma}$ ,  $Q_{\epsilon}$ + and  $W_{\epsilon}$ , respectively. Special cases of the arbitrary coefficients resulting from  $B_{\gamma}$  or  $M_{\epsilon}$  being infinite, or  $\gamma$  or  $\epsilon$  being zero, are incorporated in CØECØE through supporting subroutines and subprograms.

The arguments for CØECØE are: IG, CP, CL, CQ, and CW where: IG = the index number of an eigenvalue, and CP, CL, CQ, and CW correspond to  $P_{v}$ ,  $L_{v}$ ,  $Q_{\epsilon}$  and  $W_{\epsilon}$  respectively.

Intermediate print for COECOE consists of printout of the arbitrary coefficients calculated in each case, and it is obtained by placing a 1 in column 24 of card B.

### 25. CENØM (Sequence Number 25)

Subroutine CENØM solves the integral:

$$CEH \not OM = \int_{r_1}^{r_2} \left[ M_{\epsilon} \sin(\epsilon \ln r) + F_{\epsilon} \cos(\epsilon \ln r) \right]^2 \frac{dr}{r}$$

which has special cases of

$$CEH \not OM = \left[\frac{\ell n r}{2} - \frac{1}{4\epsilon} \sin \left(2\epsilon \ell n r\right)\right]_{r_1}^{r_2}$$

for an infinite  $M_{\epsilon}$ , and

$$CEHOM = In(r_2/r_1)$$

when  $\epsilon$  equals zero.

Subroutine CENØM also solves Equation (124) for  $M_{\epsilon}$  and sets  $F_{\epsilon}$  equal to zero for special cases.

The arguments to CENØM are: IG, and CEHØM where

IG = the index number of an eigenvalue and

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CEHOM = the name of the location where the value of the integral CEHOM above will be stored.

The values of  $M_{\epsilon}$  and  $F_{\epsilon}$  are stored in common.

A 1 in column 25 of card B produces intermediate print of IG, CEH $\phi$ M, and M<sub>e</sub>.

26. ATRAN (Sequence Number 26)

Function subprogram ATRAN is the inversion routine which corresponds to the transformation routine TRAN. (See function subprogram TRAN.)

The single argument of ATRAN is T which is the transform variable to be inverted to real temperature.

A 1 in column 26 of card B produces print similar to the intermediate print of function subprogram TRAN.

27. DENØM (Sequence Number 27)

Subroutine DENØM solves the integral:

$$DEHOM = \int_{\phi_1}^{\phi_2} \left[ B_{\gamma} \sin(\gamma \phi) + F_{\gamma} \cos(\gamma \phi) \right]^2 d\phi$$

which has special cases of:

DEH
$$\phi$$
M =  $\left[\frac{\phi}{2} - \frac{1}{4\gamma}\sin(2\gamma\phi)\right]_{\phi_1}^{\phi_2}$ 

for  $\mathbf{B}_{\mathbf{v}}$  of infinity and

DEHØM = 
$$\phi_2 - \phi_1$$

for  $\gamma$  equal to zero

DENØM also solves Equation (60) for  $B_{\gamma}$  and sets  $F_{\gamma}$  equal to zero for special cases.  $F_{\gamma}$  is similar to  $F_{\varepsilon}$  in subroutine CENØM.

The arguments for DENØM are IG and DEHØM

where:

- IG = the index number of an eigenvalue and
- DEHOM = the name of the location where the value of the integral DEHOM above will be stored.

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The values of  $B_{\gamma}$  and  $F_{\gamma}$  are stored in common. Intermediate print in DENØM consists of the values of DEHØM, IG, and  $B_{\gamma}$ . To obtain this print a 1 is placed in column 27 of card B.

28. INPUT (Sequence Number 28)

Subroutine INPUT reads in and prints out the problem description and the necessary supporting data for a problem solution. It also serves the needs of the other subroutines by putting raw data in a form usable to the transformation of the thermophysical properties, and each of the boundary condition functions is done by subroutine INPUT. Communication from INPUT to the remainder of the program is accomplished through COMMON.

Subroutine INPUT checks all of the input data for such things as sequence, mode, form, and limits. Together with the computer FORTRAN monitor, this provides a good level of assurance to the program user that computer time will not be expended on an erroneous problem. However, this is by no means complete protection.

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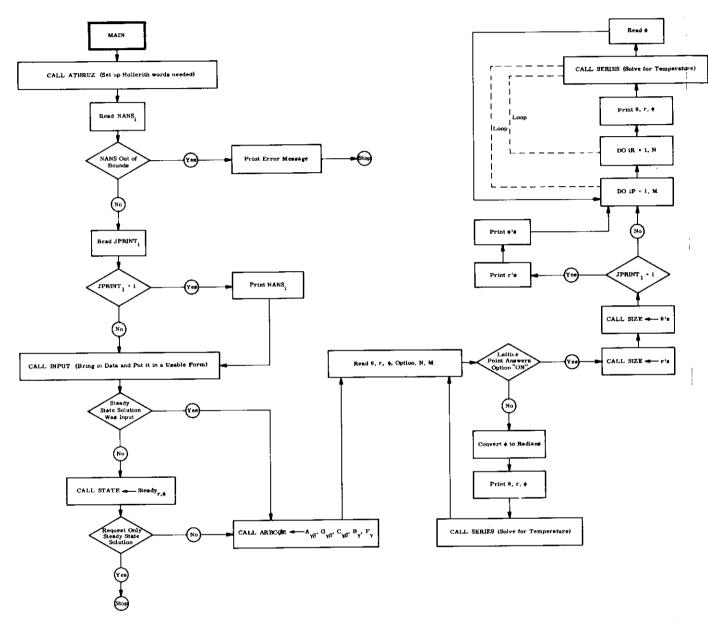
## APPENDIX D

# FLOW DIAGRAMS

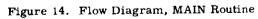
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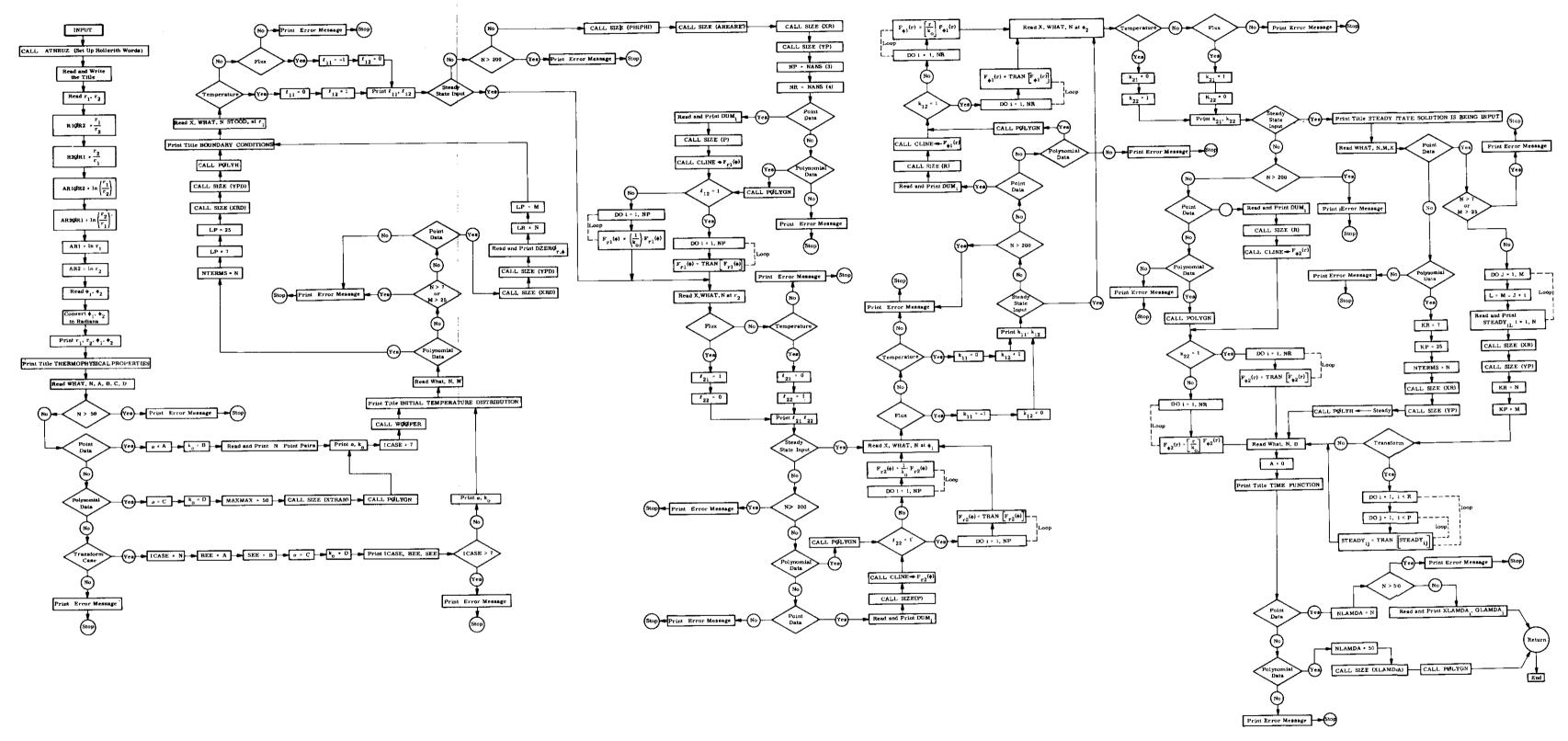


Figure 15. Flow Diagram, Subroutine INPUT

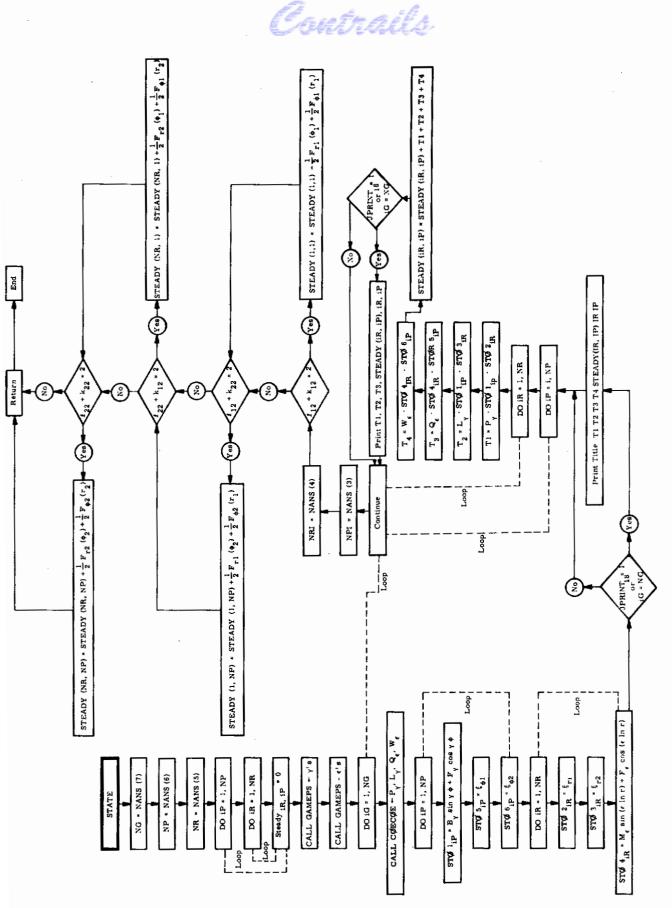


Figure 16. Flow Diagram, Subroutine STATE

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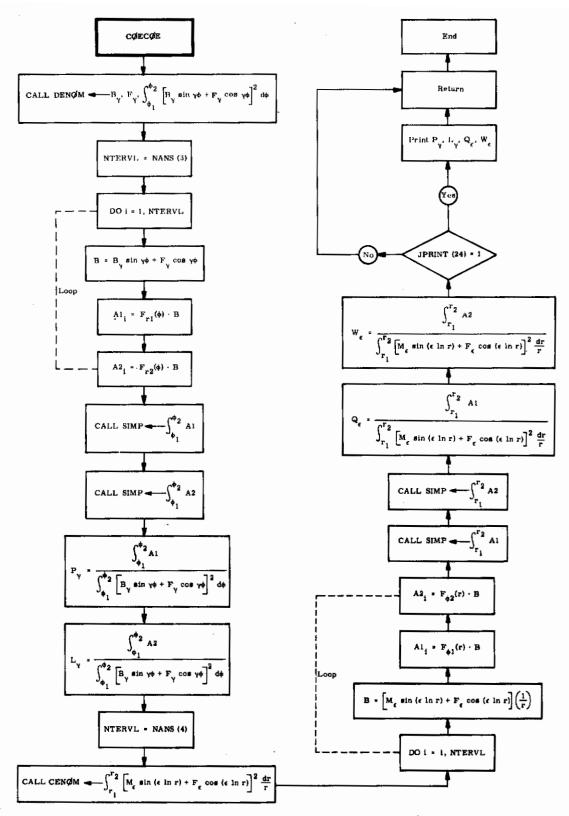


Figure 17. Flow Diagram, Subroutine  $C \phi E C \phi E$ 

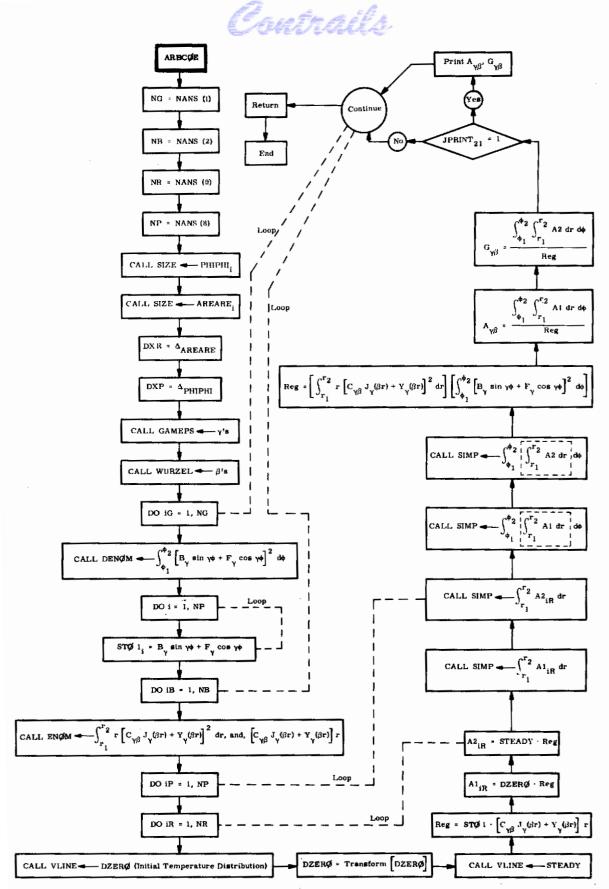


Figure 18. Flow Diagram, Subroutine ARBCØE



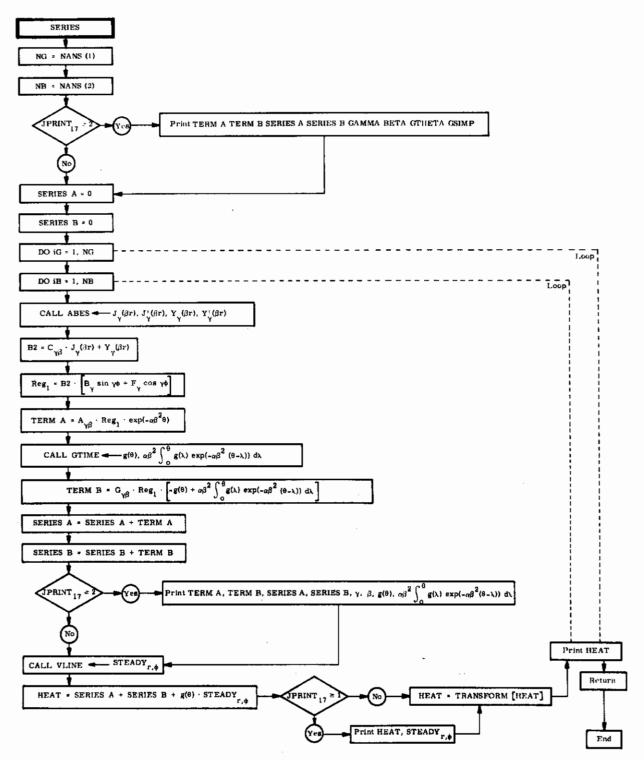


Figure 19. Flow Diagram, Subroutine SERIES



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## APPENDIX E

SAMPLE TEST PROBLEM

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#### APPENDIX E

### SAMPLE TEST PROBLEM

In addition to the sample problems presented in preceding sections, a series of 12 test problems were run on the computer at Wright-Patterson Air Force Base. Similar problems were calculated for comparison using the Thermal Analyzer Computer program (Reference 13).

This appendix presents a typical test problem and a comparison between the two programs. The specific problem is the determination of the temperature response of the center radial line in a 60 degree sector with zero initial temperature distribution, a temperature of 100 sin 60 at the surface  $r_2$ , and the remaining surfaces insulated. Print out of the input and solution obtained with the computer program developed in this report is shown in Table VII. Data from both programs is shown in Figure 20.

#### TABLE VII

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#### Program Printout, Sample Test Problem

SP 8 INPUT **GEOME TRY** RI= 0.5000000E 00 Pl= 0. R2= 0.80000000E 00 P2= 0.10471974E 01 (RADIANS) THERMO PHYSICAL PROPERTIES TRANSFORM ACCORDING TO CASE 4,8= 0.99999999E-02 ALPHA= 0.40000000E-04 KZERO= 0.23100000E-04 C= 0. INITIAL TEMPERATURE DISTRIBUTION POLYNOMIAL DATA, 1 TERMS )(R++ 1(P== ٥. ٥. \$ BOUNDRY CONDITIONS AT RI, FLUK L11= -1.00 L12= ( POLYNOMIAL DATA, I TERMS, X=DUMMY VARIABLE { 0. }}(X=0 0-0. AT R2, TEMP L21= 0. L22= 4 POLYNDMIAL DATA, 5 TERMS, X=DUMMY VARIABLE { 0.30000000E 03}(X++ 1.00 1.00 1.0000) ( -0.45000000E 03)(X=+ ( 0.20250000E 03)(X=+ ( -0.43499999E 02)(X=+ ( 0.53999999E 02)(X=+ 3.0000) 5.0000) 7-0000) 9.00001 K11= -1.00 K12= ٥. AT PL. FLUX POLYNOMIAL DATA, 1 TERNS, X-DUMMY VARJABLE ( 0. )[X++ 0. AT PZ, FLUX K21= 1.00 K22= ( 0. POLYNOMIAL DATA, 1 TERMS, X-DUMMY VARIABLE ( 0. ) 1X++ 0. 1 TIME FUNCTION POLYNOMIAL DATA, 1 TERMS, X=DUMMY VARIABLE ( 0.09999999E 01)(X++ 0. EVALUATE POLYNOMIAL FROM 0. UNDRFLOW AT 32300 IN AC AND NQ. UNDRFLOW AT 32300 IN AC AND MQ. TO 0.3000000E 03 STEADY(18+1P) 0+80600750E 02 11 **T4** IR 19 11 -0.34710202E-08 -0. -0.20258909E-06 0. -0. ٥. 1 -0. 0.78605650E 02 -0-2 -0.14559225E-04 C.72564872E 02 3 -0-٥. -Ó. -0. 0. 0. 0. -0.70479304E-03 0. -0.24570825E-01 -0. 0.61232409E 02 0.41449883E 02 -0-45 Ł -0. 1 -0.64933278E 00 -0. 0.42467164E 01 6 -0--0--0.602735656-09 -0. C.82528167E 02 1 C.81044332E 02 0.76626717E 02 -0--0.351791876-07 0. -0-2 2 -0.25281800E-05 -0--0-0. 3 2 -0.12238588E-03 -0. 0.68704513E 02 Ā 2 -0. 0. 0. -0. -0.42666741E-02 -0. C.56426386E 02 5 -0. -0.11275532E-00 -0. C.40783387E 02 6 Ż 0.32616926E-08 -0. ٥. 0.87343854E 02 1 2 3 a. 0.19037150E-06 0.87071547E 02 0. ٥. 0.13681198E-04 0. -0. 0.86345201E 02 3 3 -0. C-85354899E 02 0-84583668E 02 ٥. 0.66228892E-03 0. 45 3 0.230890276-01 -0. ٥. 3 ō. 0.61017331E 00 -0. 0.85270080E 02 3 6 1 0.17355084E-08 -0. 0.92716964E 02 4 ٥. 0. 0.10129444E-06 0.72796056E-05 -0. ۰. C.93705983E 02 2 4 0.96675146E 02 0. 0. 3 444 ō. 0.35239618E-03 0. -0. 0.10209414E 03 ã, 0. 0. 0. 0.122854016-01 -0. 0.11085305E 03 5 ٥. 0.32466608E-00 -0. -0.26589575E-08 -0. ۰. 0.12407698E 03 6 4555 0.96173427E 02 0.97932601E 02 -0. 1 2 -0. -0.155192356-06 0. -0. -0.111530216-04 0. -0. C.10311360E 03 3 -0.53990316E-03 0. -0.18822357E-01 -0. -0. 0.11225347E 03 0.12641241E 03 5 45 -0.49741811E-00 o. 0.14672273E 03 6 5 -0. -0. -0.26589534E-08 -0. ٥. C.96185058E 02 6 -0-15519211E-06 C-97944140E 02 -0. ٥. -0-2 6 6 0.10312445E 03 -U.11153004E-04 0. -0. -0. 3 -0. -0.539902316-03 0. 0.11226215E 03 45 -0. 6 -0.18822327E-01 -0. 0. C.12641680E 03

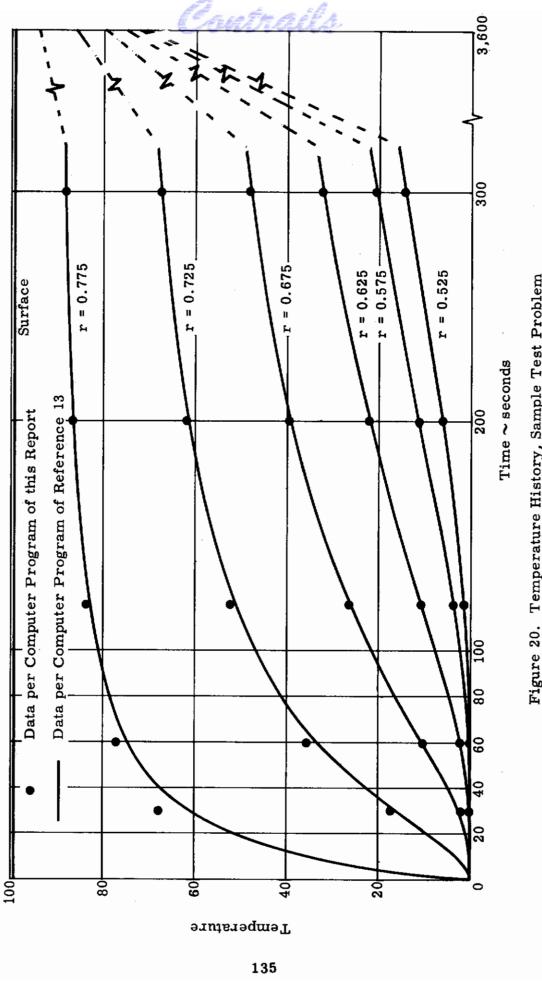
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6777778888889999999000000 100000

-0.	-0.49741732E-00 -0.	0.	0.14672258E 03	4
0.	0.173551346-08 -0.	0.	0.92751843E 02	6
ŏ.	0.101294736-06 0.		0.937411856 02	1
ŏ.		-0.		2
ŏ.	0.72796263E-05 0. 0.3523971#E-03 0.	-0-	C.96709935E 02	3
<b>0.</b>	0.12205435E-01 -0.	-0. 0.	0-10212471E 03	4
ŏ.			0.11087208E 03	5
	0.32466700E-00 -0.	0.	C-12407804E 03	6
0.	0.326169028-08 -0.	0-	C.87400795E 02	1
0.	0-19037136E-06 0-	-0.	C-87130707E 02	2
0.	0-13681188E-04 0.	-0-	C.86409051E 02	3
0.	0.662288448-03 0.	-0.	C-85421223E 02	4
0. 0.	U.23089010E-01 -0. 0.61017287E 00 -0.	0.	C.84641580E 02 C.85295413E 02	5
-0-	-4.602741872-09 -0.	0. 0.	C.82602119E 02	6
-0.	-0.351795498-07 0.	-0.	0.81123461E 02	1
-0.	-0.25202060E+05 0.	-6.	C.76720396E 02	2
-0.	-0.12238714E-03 0.	-0.	C.68821730E 02	4
-0-	-0.42667181t-02 -0.	ċ.	0.565725786 02	5
-0.	-0.11275648E-00 -0.	0.	0.40928707E 02	6
-0.	-0.347102026-08 -0.	ö.	C.80681277E 02	1
-0.	-0.20258909E-06 0.	-0.	C+78692923E 02	ź
-0-	-0.14559225E-04 0.	-0.	C.72672613E 02	3
-0.	-0.70479304E-03 0.	-0.	C-61380392E 02	4
-0.	-0.24570825E-01 -0.	0.	C.41679476E 02	5
-0-	-0.64933278E 00 -0.	0.	0-46839292E 01	6
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T [ HE=	0.30000000E 02 R= 0.52500000E 00 TEMPERATURE= 0.73015690E-02	PH [ =	0.52359870E 00 (RADIANS)	
TIME=	0.599999996 02 R= 0.5250C000E 00 TEMPERATURE= 0.31241775E-01	PH1 =	0.5235987GE 00 (RADIANS)	
T LME=	0.12000000E 03 R= 0.52500000E 00 TEMPERATURE= 0.99881590E 00	PH [=	0.52359870E 00 (RADIANS)	
T I ME =	0.20000000E 03 R= 0.5250C000E 00 TEMPERATURE= 0.59490845E 01	PH1=	0.5235987CE 00 (RADIANS)	
TIME=	0.30000000E 03 R= 0.52500000E 00 TEMPERATURE= 0.14803585E 02	P# [ =	0.5235987CE 00 (RADIANS)	
TIME=		PHI=	0.52359870E 00 (RADIANS)	
TIME=	0.59999999E 02 R= 0.57500000E 00 TEMPERATURE= 0.56388974E-01	PH (=.	0-52359870E 00 (RADIANS)	
T LME=	0.12000000E 03 R= 0.57500000E 00 TEMPERATURE= 0.32958269E 01	PHI=	0.52359870E 00 (RADIANS)	
TINE=	0.20000000E 03 R+ 0.57500000E 00 TEMPERATURE= 0.11141579E 02	PH1=	0-52359870E 00 (RADIANS)	
TIME=	0.30000000E 03 R= 0.57500000E 00 TEMPERATURE= 0.20094477E 02	PH1=	0.5235987CE 00 (RADIANS)	
TIME=	0.30000000E 02 R= 0.62500000E 00 TEMPERATURE= -0.39322674E-00	PH[=	0.52359870E 00 (RADIANS)	
TIME=	0.59999999E 02 R= 0.62500000E 00 TEMPERATURE= 0.14172167E 01	PH [ =	0.5235987CE 00 (RADIANS)	
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T IME=	0.599999999E 02 R= 0.67500000E 00 TEMPERATURE= 0.10009040E 02	PH1=	0.52359970E 00 (RADIANS)	
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TINE*		R= 0.67500000E 0.48302764E 02	00	PH[=	0.52359870E	00 (RADIANS)
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TI#E≠		R= 0.72499999E D.35588296E 02	00	PH1=	0.52359870E	00 (RADIANS)
TIME≖		R= 0.72499999E 0.52197002E 02	00	PHI≖	0.52359870E	00 (RADIANS)
	0.20000000E 03 TEMPERATURE=	R= 0.72499999E 0.61719963E 02	00	PH[=	0.52359870E	00 (RADIANS)
TIME=		R= 0.72499999E 0.67554465E D2	00	PHE=	0.52359870E	00 (RADIANS)
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13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

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