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Users' Guide to BREAK1, The Berkeley Algorithm for Breaking Window Glass in a Compartment Fire

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USER'S GUIDE TO BREAK1, The Berkeley Algorithm for Breaking Window Glass in a Compartment Fire

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Abstract

This is an instructional manual for the computer program BREAK1, the Berkeley Alogorithm for Breaking Window Glass in a Compartment Fire, version 1.0. The thermal response of window glass exposed to a compartment fire and its time to breakage are calculated. The following glass properties, treated here as constant, are required as input: thermal conductivity, thermal diffusivity, absorption length, breaking stress, Young's modulus, coefficient of linear thermal expansion and emissivity. In addition, the ambient temperature, the hot layer temperature, heat transfer coefficients and emissivities and the direct flame radiation histories are needed as input. The window geometry is also required. The output describes the evolution of the window temperature field, T(x,t), where x is the direction normal to the glass pane, culminating in the window breakage time, t_b. This manual contains a summary of the mathematical model, sample thermophysical and mechanical data tables, some worked examples and advice on using the program.

1. INTRODUCTION

Window glass breaking plays a key role in fire growth. Before breaking, the window acts as a wall and after breaking, as a vent. It is therefore necessary to know the time at which a window breaks in order to model a compartment fire. Windows break in a fire due to tensile stresses created in the portion of the glass shaded by the frame as the exposed central region heats up and expands [1]. Since glass has a low tensile strength, a reasonably small stress (~ 40 MPa) is enough to cause breakage. In **FIRST**[2], the code for fire simulation in a room, there is a provision for opening a vent (i.e. a window) at a specified time. This program provides the specified time, i.e., when the window breaks and becomes a vent, for any user specified flame radiation and layer temperature histories. The units for all the input and output are SI.

This document provides descriptions of the program **BREAK1**. The next section discusses the mathematical model and computer program. The third section describes the required input. The fourth section gives example sessions and the fifth explains the output.

2. MATHEMATICAL MODEL

The computer program **BREAK1** provides a solution to the transient problem of heating a window by exposing it to a fire and its hot products. The window glass absorbs direct radiation from the flame within its depth and is heated by radiation and convection from the surrounding hot gases while it loses heat to the cooler outside ambient atmosphere. In the shaded portion of the window glass within the frame, large tensile stresses develop. These tensile stresses are directly proportional to the average temperature difference between the shaded and the unshaded portion of the window glass. Figure 1 shows a schematic diagram of window glass exposed to a fire. L is the glass thickness, s is the length of the window shaded by the frame and H is the half-width or half-length of the window.

In a review of fire physics [3] at the Second International Symposium on Fire Safety Science, a simple strain criterion for the glass temperature increase ΔT required to break windows

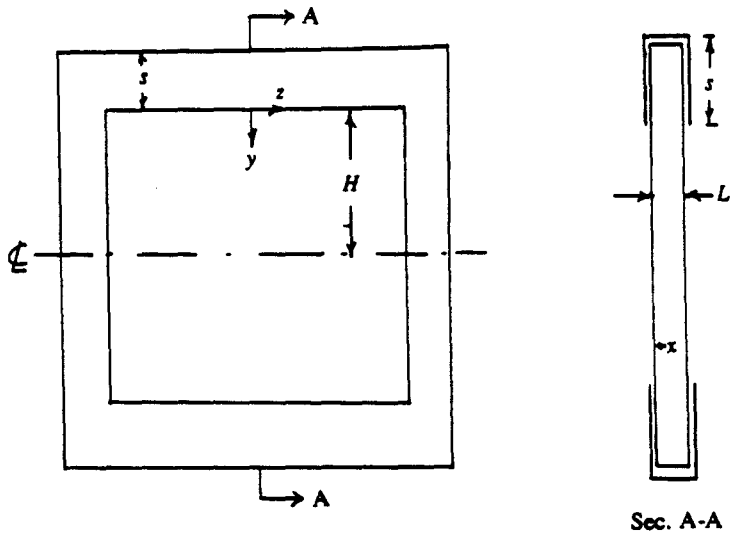

Fig. 1. Window Geometry

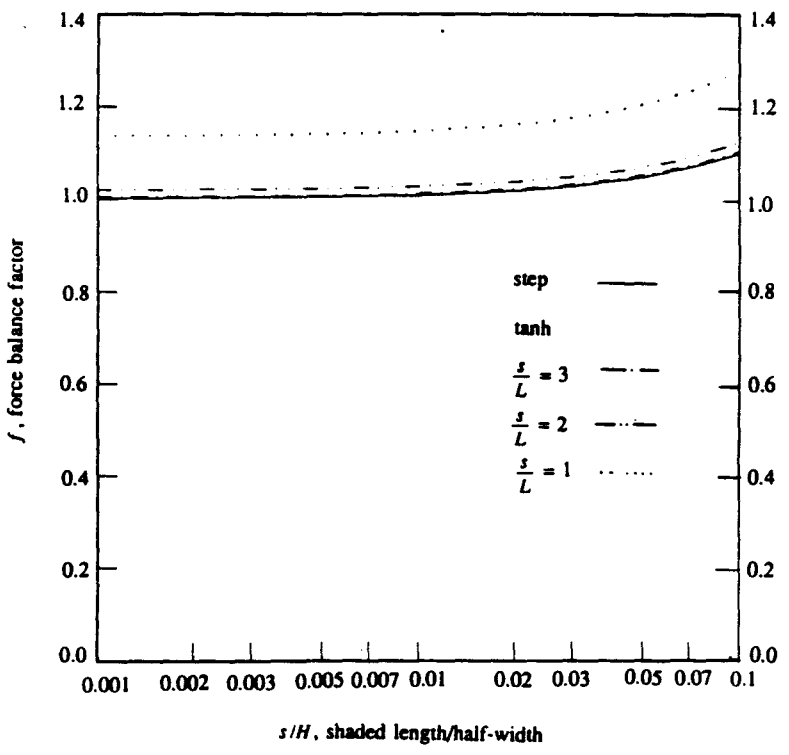

Fig. 2. Increase in temperature rise at breaking due to compression in the heated glass. For a step temperature profile, $f = 1+s/H$, for a hyperbolic tangent temperature profile, $f = 2/[tanh(s/L) + L/(s+H)(ln((cosh(H/L)/cosh(s/L)))]$.

in fires,

$$\beta \Delta T = \sigma_b / E, \tag{1}$$

was suggested, where β is the thermal coefficient of linear expansion, σ_b is the tensile strength at breakage and E is the Young's Modulus of the glass.

This relation was recently improved [4] to include a multiplying factor $g\,(\sim 1)$ on the right hand side of Eq. (1). to account for compression in the unshaded glass. The values for g in Fig. 2 are obtained from an over-all force balance in the plane of the pane. For large shading, $s/L \geq 2$, and fast heating, $\alpha t/s^2 \leq 1$, where $\alpha = k/\rho c$ is the thermal diffusivity of glass, the shaded edge of the window glass remains quite near the initial temperature, T_i. Hence, the temperature change ΔT at which breakage occurs is the increase in the average temperature of the central glass portion given by

$$\Delta T = (1/L)\int_0^L T(x,t)dx - T_i = g\,\sigma_b / E\,\beta. \tag{2}$$

Thus the goal here is to calculate the temperature in the large central section of the glass as a function of depth into the glass, x, and time, t. The time to initial window breakage is determined. The question of additional time required for all of the glass pieces to fall from the window frame [5] is not addressed. The governing equation for this system is

$$\rho c \frac{\partial T}{\partial t} = k \frac{\partial^2 T}{\partial x^2} + I(t) \frac{e^{-x/l}}{l}, \tag{3}$$

where $I(t)$ is the incident radiative flux directly from the fire which is at sufficiently short wavelengths that its distributed internal absorption needs to be included [6] and l is the decay length in the glass [7]. Radiation from the hot layer is included in the following boundary conditions

$$t = 0;\ \ T = T_i, \tag{4}$$

$$x = 0;\ \ -k\frac{\partial T}{\partial x} = h_2(t)(T_{2\infty}(t) - T(0,t)) + \varepsilon_{2\infty}(t)\sigma T_{2\infty}^4(t) - \varepsilon\sigma T^4(0,t) = q_2(t), \tag{5}$$

$$x = L;\ -k\frac{\partial T}{\partial x} = h_1(T(L,t)-T_{1\infty}) + \varepsilon\sigma T^4(L,t) - \varepsilon_{1\infty}\sigma T^4_{1\infty} = q_1(t). \tag{6}$$

Here, k is the thermal conductivity, ρ is the density, c is the specific heat, $h_2(t)$ and h_1 are the heat transfer coefficients on the exposed and unexposed sides respectively. $T_{2\infty}(t)$ is the compartment hot layer temperature and $T_{1\infty}$ is the ambient temperature, σ is the Stefan-Boltzmann constant, ε, $\varepsilon_{1\infty}$ and $\varepsilon_{2\infty}$ are the emissivities of glass, ambient and hot layer respectively.

The equations are nondimensionalized using the following variables

$$\xi = \frac{x}{L};\ \tau = \frac{\alpha t}{L^2};\ \gamma = \frac{l}{L};\ \theta = \frac{T-T_i}{T_c};\ T_c = \frac{\sigma_b}{E\beta};\ Bi_1 = \frac{h_1 L}{k};\ Bi_2 = \frac{h_2(t)L}{k} \tag{7}$$

The equations are solved using Laplace Transforms and Newton's method. An advantage of this technique [8], suggested by H. R. Baum, is that the inversions need be performed only at the boundaries for the surface temperatures.

We showed in Ref. 9 (Fig. 3 (steady parameter solution)) that the linear interpolation of temperature to obtain the average temperature underestimates the time to breakage. However, the linearity increases as τ increases. Then, a reasonable approximation for average temperature would be to obtain a function

$$\chi(\tau) = \frac{\int_0^1 \theta(\xi,\tau)d\xi}{\theta(0,\tau) + \theta(1,\tau)} \tag{8}$$

and approximate $\bar{\theta}(\xi,\tau) = \chi(\theta(0,\tau) + \theta(1,\tau))$. In the limit of a linear temperature profile, $\chi = 0.5$. Figure 3 shows the variation of χ with τ for the case of Fig. 3 in Ref. 9 and the fit $\chi = \frac{1}{2}erf(\sqrt{\tau})$ which appears to be reasonable. For $\tau \leq 0.05$, the semi-infinite unsteady temperature profile applies, while for $\tau > 1$, χ asymptotically approaches 0.5. In reality, the value of χ will be even smaller than that estimated from Eq. (8) i.e. the temperature profile will be even more nonlinear since unsteadiness usually increases heating causing a higher $\theta(0,\tau)$. Nevertheless, this variation of χ would still be better than the linear value of 0.5.

BREAK1 is written in FORTRAN 77. It has about 2200 lines of code including the comment statements. No description of the numerical procedure is provided (please refer to Pagni and Joshi [4]). However, an iterative procedure is utilized which checks the solutions by doubling or halving the time steps. If the difference is greater than the specified accuracy (default being $(soln(\Delta t)-soln((\Delta t)/2))/soln(\Delta t)\leq 10^{-4}$), the time step is halved again and the computations are repeated. Due to memory constraints, the number of time step reductions is restricted to 3 after which a message is displayed saying that the maximum allowable error is too small and the computations are stopped.

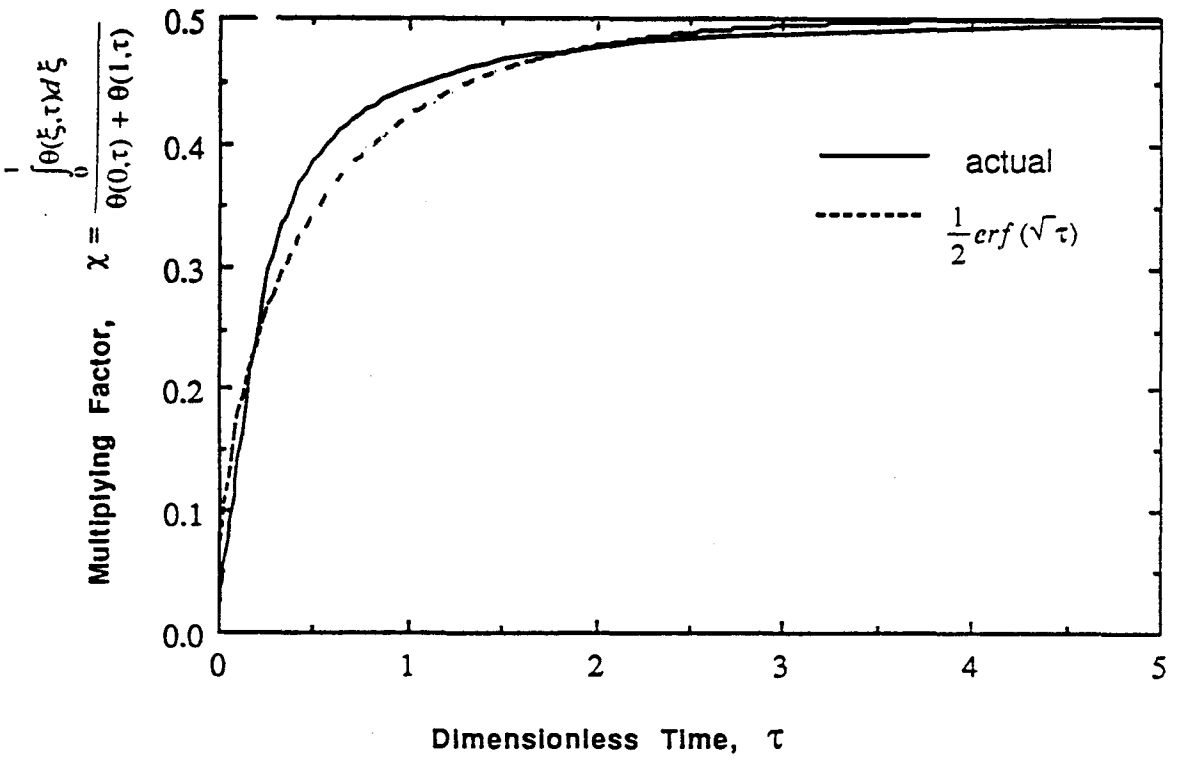

Figure 3. Variation of the multiplying factor $\chi = \dfrac{\int_0^1 \theta(\xi,\tau)d\xi}{\theta(0,\tau)+\theta(1,\tau)}$ as a function of τ for a constant parameter example of Fig. 3 of Ref. 9.

3. INPUT

The physical and mechanical properties and geometry of glass, fire parameters and numerical parameters required by the program are listed in Table 1 along with the input format and a suggested range of properties [10-13].

The hot layer temperature, the flame radiation, the heat transfer coefficient on hot layer side and emissivity of hot layer functions are entered at user specified time increments. The program then interpolates between the end points and builds a function. After the last entered time, the program assumes that the value remains constant.

There are two ways to input parameters. The first way is by changing default values and marking the altered file as an input file. The second one is by reading in data from a pre-existing file. Changes can be made to the input read from an input file using the following menu which enables the user to pick any desired area for alteration.

1) Change Properties of Glass
2) Change Geometry of Window
3) Change Coefficients
4) Change Flame Radiation
5) Change Gas Temperature
6) Change Heat Transfer Coefficient on Hot Layer Side
7) Change Emissivity of Hot Layer
8) Change Numerical Parameters

The program has been designed so that in the interactive mode, it reads the data in free format. After each entry the "carriage return" or "enter" key has to be hit. After changes are made in a particular section, the program shows the changed data on the screen and gives the user another chance to make changes in that section.

When typing input, if an error is made, e.g. instead of "y" a "t" is typed, or instead of a character, a number or *vice versa*, is typed, the question is re-asked. Also, if a number outside the permitted range is typed, the question is re-asked.

Table 1. Input

Name	Symbol	Units	Format	Normal Range
Thermal conductivity	k	W/mK	E12.4	0.6-1.3
Thermal diffusivity	α	m^2/s	E12.4	3.0-4.0 $\times 10^{-7}$
Absorption length	l	m	E12.4	0.9-1.5 $\times 10^{-3}$
Breaking stress	σ_b	N/m^2	E12.4	2.0-13.8 $\times 10^{7}$
Young's modulus	E	N/m^2	E12.4	7.0-7.25 $\times 10^{10}$
Thermal coefficient of linear expansion	β	$°C^{-1}$	E12.4	8.5-9.5 $\times 10^{-6}$
Thickness of the glass	L	m	F8.4	0.1-3.0 $\times 10^{-2}$
Shading thickness	s	m	F8.4	0.3-5 $\times 10^{-2}$
Half-width of the window	H	m	F8.4	0.05-5.0
Heat transfer coefficient on exposed side	$h_2(t)$	W/m^2K	F7.2	5.-80.
Heat transfer coefficient on unexposed side	h_1	W/m^2K	F7.2	3.-20.
Ambient temperature on unexposed side	$T_{1\infty}$	K	F7.1	270.-320.
Emissivity of glass	ε	-	F6.2	0.8-1.0
Emissivity of ambient	$\varepsilon_{1\infty}$	-	F6.2	0.1-1.
Emissivity of hot layer	$\varepsilon_{2\infty}(t)$	-	F6.2	0.1-1.
Time	t	s	F12.2	0.0-1500.
Flame radiation flux	$I(t)$	W/m^2	F12.2	0.0-10000.
Hot layer temperature	$T_{2\infty}(t)$	K	F12.2	300.-1300.
Time increment	Δt	s	F7.3	0.2-2
Maximum error allowed in solutions	ε_{max}	-	F7.2	10^{-4}–10^{-2}
Maximum run time	t_{max}	s	F8.2	100.-1500.
Output time interval	δt	s	F7.2	1.-100.

4. EXAMPLE SESSIONS IN INTERACTIVE MODE

This section shows several example sessions using different options. Execute a run by typing **BREAK1**. All the responses are either y, standing for yes, n, standing for no, numbers or a filename. End your entry by typing any two letters. All questions must be answered with some response or the computer will continue to wait for a response. Comments in parentheses do not appear on the screen; they are included to explain the options. Responses by the user are underlined. The input for the default example 4.1, was obtained by modeling a particular compartment fire with the program FIRST [9]. The data are shown in the output statement given in section 5. The compartment was large and the fire was far from the window so that $I(t) = 0$. The fire grew exponentially with a $30s$ doubling time. In example 4.2, you will interact with the program by changing a single input parameter. Example 4.3 is similar, but here you change an entire input field. In example 4.4, you recall the input file saved in example 4.1, modify it and use it as input. You have three options for changing values in input files: 1. using such files unchanged, 2. editing the input file with a separate editor and 3. editing the input file interactively. The latter technique is shown in example 4.4.

4.1. Default Run

This is the shortest session which is the default case. You will save your input as a file named ex1.in to be modified in example 4.4.

```
                    BREAK1- VERSION 1.0
              A. A. Joshi and P. J. Pagni
          Department of Mechanical Engineering
          University of California at Berkeley
                    Berkeley, CA 94720

 This program calculates the temperature history of the surfaces
 of a glass window for given fire parameters.
 The calculations are stopped when the glass breaks.

Hit RETURN to continue
```

```
*************************************************************
*  Warning: Read the disclaimer before using this program  *
*  ------------------------------------------------------  *
*  This program was developed under grants from the        *
*  National Institute of Standards and Technology, however *
*  no certification or applicability is implied.  Many     *
*  assumptions are made concerning the physical properties *
*  of glass and the phenomenology of breakage. Only you are*
*  responsible for your calculations with this program. Use*
*  should be restricted to predicting when ordinary  glass *
*  in ordinary windows may break under the assumptions in  *
*  your choice of input parameters.  Do not use the        *
*  program to calculate conditions under which glass  will *
*  not break.  The properties of a particular piece of     *
*  glass and the accuracy of each set of input are both    *
*  sufficiently uncertain that no confidence can be placed *
*  in any calculation which predicts that a window will    *
*  not break.                                              *
*************************************************************

 Please write 'y' for yes and 'n' for no
 for every question.
 --------------------

 Do you want to use the default values for properties, geometry,
 fire and numerical parameters?(y/n)
y    (y calculates the temperature histories for default values)
-    (n see example 4.2)

 Would you like to save your input data in a file?(y/n)
y
-
 What would you like to call it?(must be in DOS format)
ex1.in  (your choice, I'll choose ex1.in)
------
 Would you like to save the output in a file?(y/n)
y
-
 What would you like to call it?(must be in DOS format)
ex1.out  (your choice, I'll choose ex1.out)
-------
 Begin run
 (See the example output in section 5)
```

4.2. Change Input Parameters

In this run only the thickness of the glass is changed. The procedure for changing data in the areas COEFFICIENTS and NUMERICAL PARAMETERS is identical to the changes made in the area of GEOMETRY as in this run.

```
 Do you want to use the default values for properties, geometry,
 fire and numerical parameters?(y/n)
n
-
 Do you want to change the default values interactively or read in from
 a pre-existing file?(y/n)

 NOTE: To read in values from a file, you have to use a file saved in a
 previous run and if needed change the data according to the format specified in
 Table I of the manual.
 y=change default values interactively, n=read from a file
y   (y calls the default values in the program for any changes to be made)
-   (n reads data from a user specified file)
 To change the input in any of the following sections,enter the item number
 of your choice

 1)NO MORE CHANGES
 2)CHANGE PROPERTIES OF GLASS
 3)CHANGE GEOMETRY OF THE WINDOW
 4)CHANGE COEFFICIENTS
 5)CHANGE FLAME RADIATION
 6)CHANGE GAS TEMPERATURE
 7)CHANGE HEAT TRANSFER COEFF. ON HOT LAYER SIDE
 8)CHANGE EMISSIVITY OF HOT LAYER
 9)CHANGE NUMERICAL PARAMETERS

3
-
 GEOMETRY
 --------------------
 1.Glass thickness [m]=  0.0063
 2.Shading thickness [m]=  0.0150
 3.Half-width [m]=  0.5000

 Write item numbers and values you wish to change separated by comma.
 Hit the RETURN or ENTER key after entering each pair. End your entry series
 by typing any 2 characters. (e.g. 1,.00635 RETURN 2,.02 RETURN EN)
1,.005
------
EN
--
```

```
 GEOMETRY
 --------------------
 1.Glass thickness [m]=  0.0050
 2.Shading thickness [m]=  0.0150
 3.Half-width [m]=  0.5000

 Would you like to make any more changes in this section?(y/n)
n  (y asks to enter numbers again)
-  (n returns to the menu)

 To change the input in any of the following sections,enter the item number
 of your choice

 1)NO MORE CHANGES
 2)CHANGE PROPERTIES OF GLASS
 3)CHANGE GEOMETRY OF THE WINDOW
 4)CHANGE COEFFICIENTS
 5)CHANGE FLAME RADIATION
 6)CHANGE GAS TEMPERATURE
 7)CHANGE HEAT TRANSFER COEFF. ON HOT LAYER SIDE
 8)CHANGE EMISSIVITY OF HOT LAYER
 9)CHANGE NUMERICAL PARAMETERS

1
-
 Would you like to save your input data in a file?(y/n)
y
-
 What would you like to call it?(must be in DOS format)
ex2.in  (your choice, I'll choose ex2.in)
------
 Would you like to save the output in a file?(y/n)
y
-
 What would you like to call it?(must be in DOS format)
ex2.out  (your choice, I'll choose ex2.out)
-------
 Begin run
```

4.3. Change Input Fields

This session describes the case of a fire next to the window. Hence, changes are made in the area FLAME RADIATION. In the default run the flux from the fire is equal to zero. If the run time is greater than the last entry, the flux stays constant until the maximum run time. The procedure for changing the GAS TEMPERATURE, HEAT TRANSFER COEFFICIENT ON HOT LAYER SIDE and EMISSIVITY OF HOT LAYER is identical to that for changing FLAME RADIATION.

```
To change the input in any of the following sections,enter the item number
of your choice

1)NO MORE CHANGES
2)CHANGE PROPERTIES OF GLASS
3)CHANGE GEOMETRY OF THE WINDOW
4)CHANGE COEFFICIENTS
5)CHANGE FLAME RADIATION
6)CHANGE GAS TEMPERATURE
7)CHANGE HEAT TRANSFER COEFF. ON HOT LAYER SIDE
8)CHANGE EMISSIVITY OF HOT LAYER
9)CHANGE NUMERICAL PARAMETERS

5
-

FLAME RADIATION
-------------------

This program can handle time varying flame radiation flux. The flux
is specified with values at discrete intervals of time. The program
then linearly interpolates the flux between time intervals.
-------------------
Values for flux are
    point #     time [s]            flux [W/m^2]
        1           0.                   0.
        2        1000.00                 0.


What type of change would you like to make?
1. Add time/s
2. Alter data
3. Enter new data
3
-
```

```
 Enter time in secs and flux in W/m^2 separated by a comma.
 Hit the "RETURN" or "ENTER" key after entering each pair. End your
 entry series by typing any 2 characters. (e.g. 0,10000. RETURN EN)
0,0
---
200,10000
---------
500,3000
--------
en
--
     point #     time [s]              flux [W/m^2]
         1           0.                     0.
         2         200.00               1000.00
         3         500.00               3000.00

 Would you like to make any more changes in this section?(y/n)
n  (y asks to change values again)
-  (n returns to the menu)

 To change the input in any of the following sections,enter the item number
 of your choice

 1)NO MORE CHANGES
 2)CHANGE PROPERTIES OF GLASS
 3)CHANGE GEOMETRY OF THE WINDOW
 4)CHANGE COEFFICIENTS
 5)CHANGE FLAME RADIATION
 6)CHANGE GAS TEMPERATURE
 7)CHANGE HEAT TRANSFER COEFF. ON HOT LAYER SIDE
 8)CHANGE EMISSIVITY OF HOT LAYER
 9)CHANGE NUMERICAL PARAMETERS

1
-

 Would you like to save your input data in a file?(y/n)
y
 What would you like to call it?(must be in DOS format)
ex3.in  (your choice, I'll choose ex3.in)
------
 Would you like to save the output in a file?(y/n)
y
-
 What would you like to call it?(must be in DOS format)
ex3.out  (your choice, I'll choose ex3.out)
-------
 Begin run
```

4.4. Input Files

This sample uses the file saved in the previous run of example 4.1 as the input. The input file can either be edited by using the editor on the computer or by changing values interactively. In this case, numerical parameters and the gas temperature history are changed interactively.

```
 Do you want to use the default values for properties, geometry,
 fire and numerical parameters?(y/n)
n
-
 Do you want to change the default values interactively or read in from
 a pre-existing file?(y/n)

 NOTE: To read in values from a file, you have to use a file saved in a
 previous run and if needed change the data according to the format specified in
 Table I of the manual.
 y=change default values interactively, n=read from a file
n
-
 Please write the file name (must be in DOS format)
ex1.in
------
 Would you like to change any input data?(y/n)
y
-

 To change the input in any of the following sections,enter the item number
 of your choice

 1)NO MORE CHANGES
 2)CHANGE PROPERTIES OF GLASS
 3)CHANGE GEOMETRY OF THE WINDOW
 4)CHANGE COEFFICIENTS
 5)CHANGE FLAME RADIATION
 6)CHANGE GAS TEMPERATURE
 7)CHANGE HEAT TRANSFER COEFF. ON HOT LAYER SIDE
 8)CHANGE EMISSIVITY OF HOT LAYER
 9)CHANGE NUMERICAL PARAMETERS

9
-
 NUMERICAL PARAMETERS
 --------------------
 1.Maximum fractional error in soln=  0.000100
 2.Size of time step [s]=  1.000
 3.Maximum run time [s]=  250.00
 4.Time interval for output [s]=  10.00
```

```
 Write item numbers and values you wish to change separated by comma.
 Hit the RETURN or ENTER key after entering each pair. End your entry series
 by typing any 2 characters (e.g. 1,1.e-4 RETURN EN)
1,.001
------
en
--
 NUMERICAL PARAMETERS
 --------------------
 1.Maximum fractional error in soln=  0.001000
 2.Size of time step [s]=  1.000
 3.Maximum run time [s]=  250.00
 4.Time interval for output [s]=  10.00

 Would you like to make any more changes in this section?(y/n)
n
-

 To change the input in any of the following sections,enter the item number
 of your choice

 1)NO MORE CHANGES
 2)CHANGE PROPERTIES OF GLASS
 3)CHANGE GEOMETRY OF THE WINDOW
 4)CHANGE COEFFICIENTS
 5)CHANGE FLAME RADIATION
 6)CHANGE GAS TEMPERATURE
 7)CHANGE HEAT TRANSFER COEFF. ON HOT LAYER SIDE
 8)CHANGE EMISSIVITY OF HOT LAYER
 9)CHANGE NUMERICAL PARAMETERS

6
-
 GAS TEMPERATURE
 --------------------

 This program can handle time varying hot ambient temperature. The
 temperature is specified with values at discrete intervals of time.
 The program then linearly interpolates the temperature between time
 intervals.
 Values for hot layer temp are
     point #     time [s]              temperature [K]
         1            0.                   300.00
         2           10.00                 303.30
         3           20.00                 303.96
         4           30.00                 304.60
         5           40.00                 305.57
         6           50.00                 306.85
         7           60.00                 308.20
         8           70.00                 310.09
         9           80.00                 312.64
        10           90.00                 315.50
        11          100.00                 319.56
        12          110.00                 325.19
        13          120.00                 331.73
        14          140.00                 353.71
        15          160.00                 388.29
        16          180.00                 437.97
        17          200.00                 831.07
```

```
 What type of change would you like to make?
 1. Add time/s
 2. Alter data
 3. Enter new data
3
-
 Enter time in [s] and temperature in [K] separated by a comma.
 Hit the "RETURN" or the "ENTER" key after entering each pair.
 End your entry series by typing any 2 characters. (eg. 0.,300. RETURN EN)
0,300
-----
10,400
------
20,600
------
30,700
------
40,750
------
en
--
     point #      time [s]              temperature [K]
         1            0.                     300.00
         2           10.00                   400.00
         3           20.00                   600.00
         4           30.00                   700.00
         5           40.00                   750.00

 Would you like to make any more changes in this section?(y/n)
n
-

 To change the input in any of the following sections,enter the item number
 of your choice

 1)NO MORE CHANGES
 2)CHANGE PROPERTIES OF GLASS
 3)CHANGE GEOMETRY OF THE WINDOW
 4)CHANGE COEFFICIENTS
 5)CHANGE FLAME RADIATION
 6)CHANGE GAS TEMPERATURE
 7)CHANGE HEAT TRANSFER COEFF. ON HOT LAYER SIDE
 8)CHANGE EMISSIVITY OF HOT LAYER
 9)CHANGE NUMERICAL PARAMETERS

1
-

 Would you like to save your input data in a file?(y/n)
n
-
 Would you like to save the output in a file?(y/n)
n
-
 Begin run
```

5. OUTPUT

The output appears either on the screen in the form of numbers and can be written to files if desired by the user. File names must be provided by the user in order to save either output. The file name must be in DOS format. The program deletes any pre-existing files with the same name. Thus to save all the runs, different file names must be used for each run.

When saved in a file, the output begins with a listing of all the input variables. Properties of glass appear first, followed by geometry, coefficients, flame radiation, gas temperature, heat transfer coefficient on hot layer side, emissivity of hot layer and numerical parameters. Following the input variables is a table of the time, the temperature of the side exposed to fire, the temperature of the side away from the fire, the dimensionless average temperature obtained approximately as $\theta_{av} = \frac{1}{2}(\theta(0)+\theta(1))*erf(\sqrt{\tau})$, and dimensionless time. On the screen, there is no listing of the input variables and the output begins with the table shown below in the example. After the table, the breakage time or a statement that breakage did not occur within the maximum run time is given. Below this statement, the definitions of dimensionless time and dimensionless temperature and the values of the characteristic time, characteristic temperature and the compression factor, g appear along with the values of average initial temperature, the average temperature increase at breakage and the average temperature at breakage. The example output that follows is for the default run.

```
PHYSICAL AND MECHANICAL PROPERTIES OF GLASS

1.Thermal conductivity [W/mK]=  0.7600e+00
2.Thermal diffusivity [m^2/s]=  0.3600e-06
3.Absorption length [m]=  0.1000e-02
4.Breaking stress [N/m^2]=  0.4700e+08
5.Youngs modulus [N/m^2]=  0.7000e+11
6.Linear coefficient of expansion [/deg C]=  0.9500e-05

GEOMETRY

1.Glass thickness [m]=  0.0063
2.Shading thickness [m]=  0.0150
3.Half-width [m]=  0.5000
```

COEFFICIENTS

1.Heat transfer coeff, unexposed [W/m^2-K]= 10.00
2.Ambient temp, unexposed [K]= 300.0
3.Emissivity of glass = 1.00
4.Emissivity of ambient (unexposed) = 1.00

FLAME RADIATION

Number of points used for flux input: 2

point #	time [s]	flux [W/m^2]
1	0.	0.
2	1000.00	0.

GAS TEMPERATURE

Number of points used for temperature input: 17

point #	time [s]	temperature [K]
1	0.	300.00
2	10.00	303.30
3	20.00	303.96
4	30.00	304.60
5	40.00	305.57
6	50.00	306.85
7	60.00	308.20
8	70.00	310.09
9	80.00	312.64
10	90.00	315.50
11	100.00	319.56
12	110.00	325.19
13	120.00	331.73
14	140.00	353.71
15	160.00	388.29
16	180.00	437.97
17	200.00	831.07

HEAT TRANSFER COEFF. ON HOT LAYER SIDE

Number of points used for heat transfer coeff input: 2

point #	time [s]	h2 [W/m^2-K]
1	0.	50.00
2	1000.00	50.00

EMISSIVITY OF HOT LAYER

Number of points used for emissivity input: 2

point #	time [s]	emissivity
1	0.	1.00
2	1000.00	1.00

NUMERICAL PARAMETERS

1.Maximum fractional error in soln= 0.000100
2.Size of time step [s]= 1.000
3.Maximum run time [s]= 250.00
4.Time interval for output [s]= 10.00

TEMPERATURE HISTORY

Time (s)	Exposed T(K)	Unexposed T(K)	Theta (Average)	Tau
0.	300.0	300.0	0.	0.
10.0	300.3	300.0	0.001	0.089
20.0	300.6	300.0	0.002	0.179
30.0	300.8	300.1	0.004	0.268
40.0	301.1	300.2	0.006	0.357
50.0	301.4	300.4	0.008	0.446
60.0	301.8	300.5	0.012	0.536
70.0	302.3	300.7	0.016	0.625
80.0	302.9	301.0	0.021	0.714
90.0	303.7	301.2	0.028	0.804
100.0	304.6	301.6	0.036	0.893
110.0	305.9	302.0	0.047	0.982
120.0	307.5	302.6	0.061	1.071
130.0	309.7	303.3	0.080	1.161
140.0	312.6	304.2	0.105	1.250
150.0	316.4	305.4	0.138	1.339
160.0	321.1	307.0	0.180	1.428
170.0	327.2	309.0	0.235	1.518
180.0	334.7	311.6	0.304	1.607
190.0	366.5	314.6	0.536	1.696
200.0	434.9	320.3	1.033	1.786
201.0	442.7	321.2	1.092	1.795

Window breaks at time = 201.00 [s]

tau = t/tc, tc = 112.0 s, Avg. theta = (Tav-Ti)/Tc, Tc = 70.7 K
g = 1.039
Avg. T init = 300.0 K, Avg. Delta T = 77.2 K, Avg. T break = 377.2 K

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11. ABSTRACT (A 200-WORD OR LESS FACTUAL SUMMARY OF MOST SIGNIFICANT INFORMATION. IF DOCUMENT INCLUDES A SIGNIFICANT BIBLIOGRAPHY OR LITERATURE SURVEY, MENTION IT HERE.)

This is an instructional manual for the computer program BREAK1, the Berleley Alogorithm for Breaking Window Glass in a Compartment Fire, version 1.0. The thermal response of window glass exposed to a compartment fire and its time to breakage are calculated. The following glass properties, treated here as constant, are required as input: thermal conductivity, thermal diffusivity, absorption length, breaking stress, Young's modulus, coefficient of linear thermal expansion and emissivity. In addition, the ambient temperature, the hot layer temperature, heat transfer coefficients and emissivities and the direct flame radiation histories are needed as input. The window geometry is also required. The output describes the evolution of the window temperature field, T(x,t), where x is the direction normal to the glass pane, culmiinating in the window breakage time, t_b. This manual contains a summary of the mathematical model, sample thermophysical and mechanical data tables, some worked examples and advice on using the program.

12. KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS)
computer models; fire models; glass; mathematical models; radiation; thermal stresses; vents

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