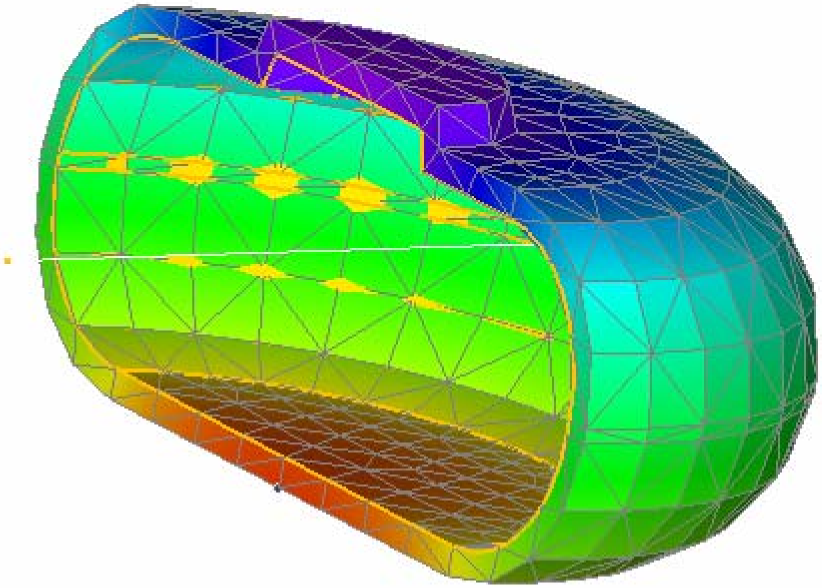
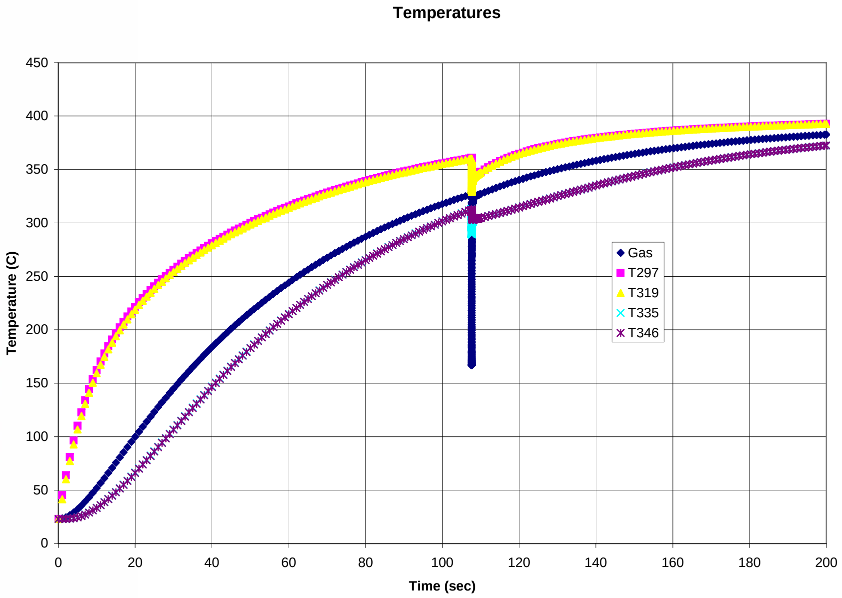
Air Bag Inflator Bonfire Test





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Modeling a Driver Side Air Bag Inflator Bonfire Test

Introduction

The DOT requires that all products shipped over interstate highways pass certain safety requirements. One requirement for pyrotechnic devices is that the do not explode in a fire. The test it performed by placing the devices in a matrix of oak staves that is ignited and the results videotaped. In the case of air bag inflators they are engineered to vent when heated, in some cases an auto-ignition material is present that will ignite the pyrotechnical material (propellant) and the air bag will vent in a normal manner.

In this present case we model a pressurized air bag inflator in a bonfire. There is no propellant. The vessel is pressurized with air and the ideal gas law is assumed. The air pressure at 23^{o}C is $2.7\text{x}10^{5}$ Pa. The bottle heats up until a burst disk ruptures at $5.5\ \text{x}10^{5}$ Pa, the bottle then vents rapidly through a nozzle. It is required that the temperatures in the areas of the vessel that contain the propellant be less than the melt temperature of the propellant at the time of the venting event.

Supersonic and Subsonic venting routines are used. Time steps are shortened just before the disk rupture in order to capture details of the venting. The time steps are restored after the gas has vented. The gas in the bottle is modeled by a single node. The inside bottle surfaces convect to this node with the convection coefficient h being the same for all conductors, h is increased by factor of 100 during venting to approximate the increased conduction due to the gas velocity, h is then decreased by a factor of 1000 after the venting event. Convection from the bonfire gases is applied to the bottom surfaces of the inflator at 400 ^{o}C and 380 ^{o}C. It takes 107.6 seconds under these conditions until the burst disk ruptures.

A more detailed model would include internal structure, heat transfer to the propellant and modeling of phase changes as the propellant melts and evaporates and heat transfer to any autoignition material if present.

Model Details

- Air is modeled as a single node
- Contact Segments used to connect air node and inside walls of inflator
- Gas pressure is calculated as heat is added until burst disk ruptures
- Convection is increased during venting

- Sonic and subsonic flow regimes are modeled

$$\dot{m}_{sub} = A\sqrt{2k\frac{p_1 p_2}{k-1}\left[\left(\frac{p_2}{p_1}\right)^{2/k} - \left(\frac{p_2}{p_1}\right)^{(k+1)/k}\right]}$$

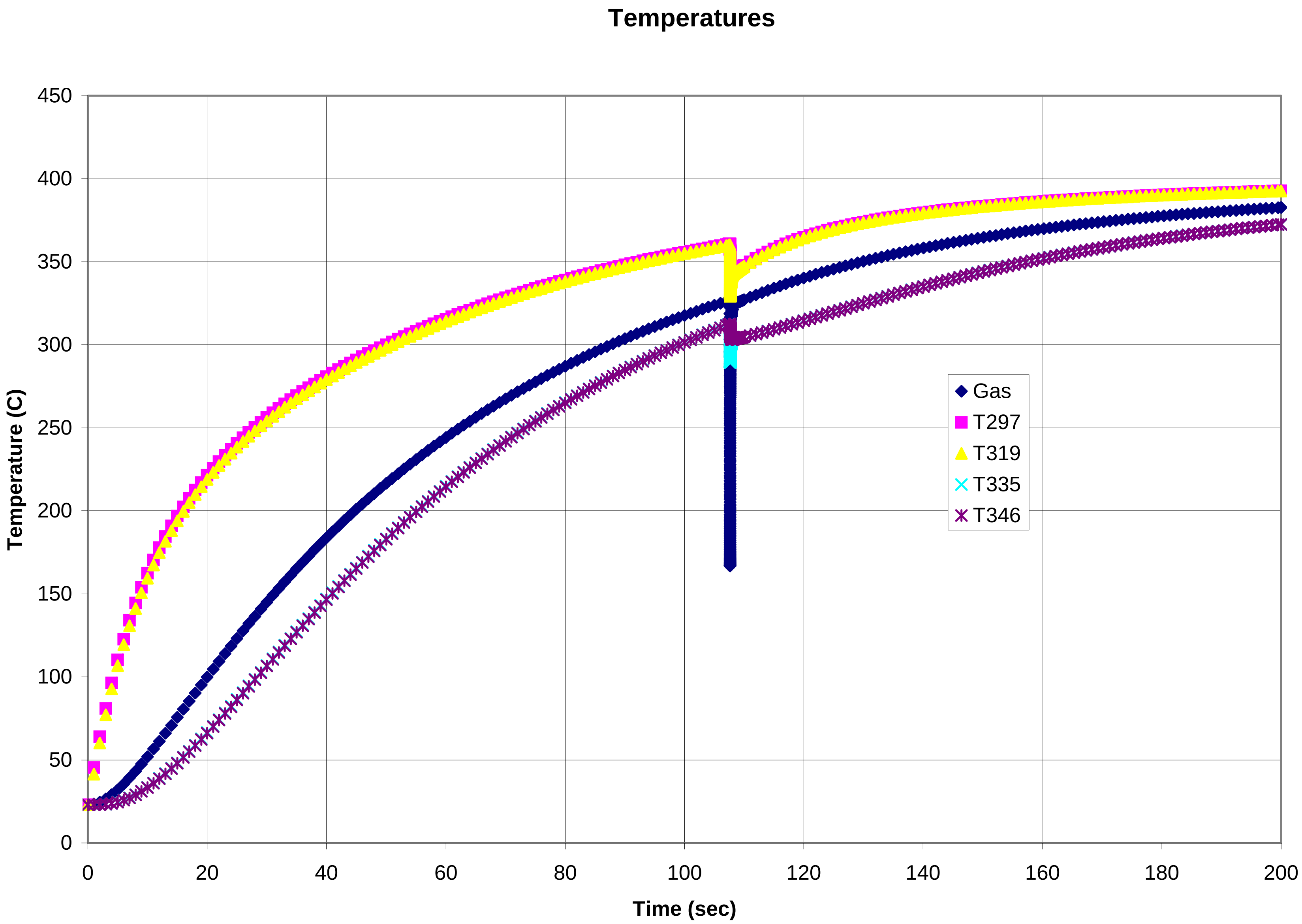
$$\dot{m}_{son} = \frac{Ap_1}{\sqrt{T}}\sqrt{\frac{k}{R}\left(\frac{2}{k+1}\right)^{(k+1)/(k-1)}}$$

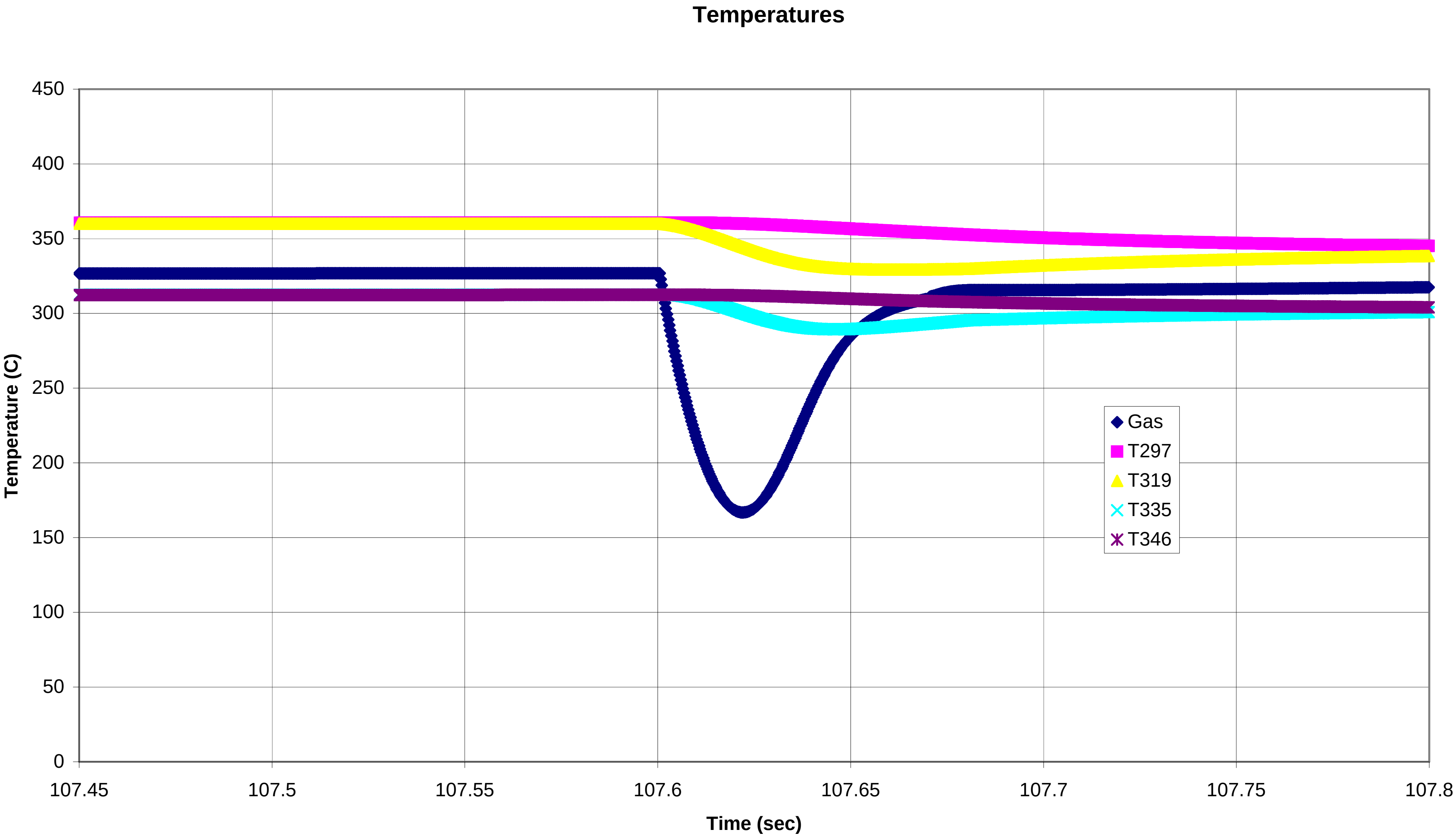
The Skeleton File

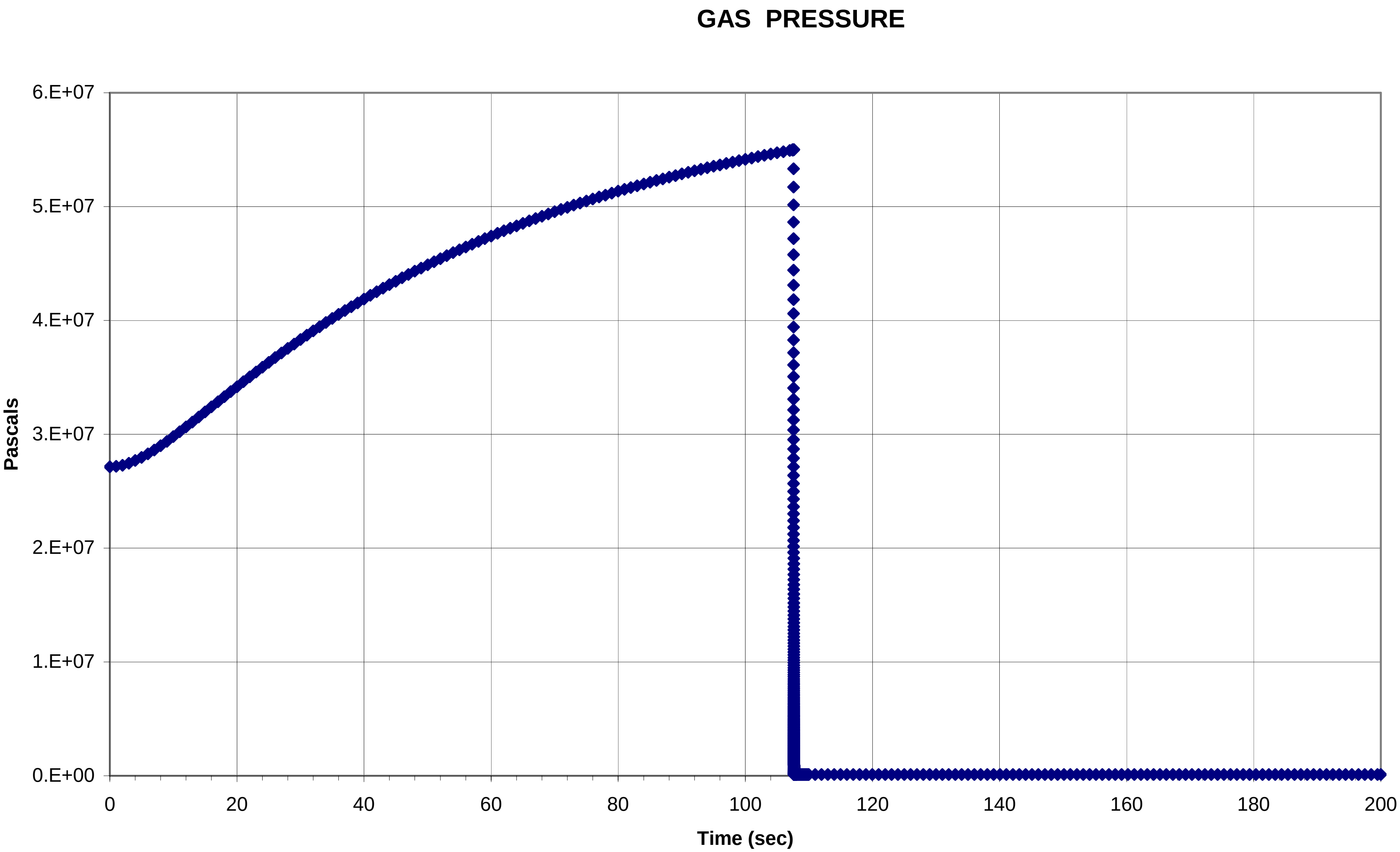
```
 BCD 3THERMAL LPCS PPP
     END
     BCD 3GLOBAL CONSTANTS DATA
M           CV = 716.0       $Thermal capacitance at constant volume for air
M           XMASS = 2.095E-2  $Initial mass of air in bottle
M           VOL = 6.5548E-5   $volume of bottle
M           AREA = 2.026E-5   $area of nozzle
M           RX = 286.8       $gas constant for air
M           PRESSURE = 0.0    $pressure in bottle
M           PO = 101330       $atmospheric pressure
M           VSONIC = 0.0      $speed of sound in gas
M           VSUBSQ = 0.0      $square of nozzle velocity in subsonic regime
M           XMDOT = 0.0       $mass flow through nozzle
M           DM = 0.0          $change in mass
M           DE = 0.0          $change in energy
```

```
 BCD 3VARIABLES 1

M       IF (PRESSURE .GT. 5.498E7) THEN
M         CSGFAC = 0.01 $modifying timestep
M         OUTPUT = DTIMEU
M       ENDIF

M        IF((PRESSURE .LT. 101600.0).AND.(NTEST .EQ. 1)) THEN
M           KTEST = KTEST + 1
M              IF(KTEST .GT. 500)   OUTPUT = 0.01
M              IF(KTEST .GT. 1000) OUTPUT = 0.1
M              IF(KTEST .GT. 1200) OUTPUT = 1.0
M        ENDIF
M        PRESSURE = (XMASS*RX*(T1+TMPZRO))/VOL
f       print*, pressure
f       pause
M        IF ((PRESSURE .LT. 5.5E 7) .AND. (NTEST .EQ. 0)) GOTO 100
M        NTEST = 1

C Routine to maintain bottle pressure at atmospheric P after venting
M       IF ((PRESSURE .LT. PO) .OR. (PRESSURE .EQ. PO))THEN
M            PRESSURE = PO
M            XMASS = (PO*VOL)/(RX*(T1+TMPZRO))
M            GOTO 100 $skip venting routines
M       ENDIF
```

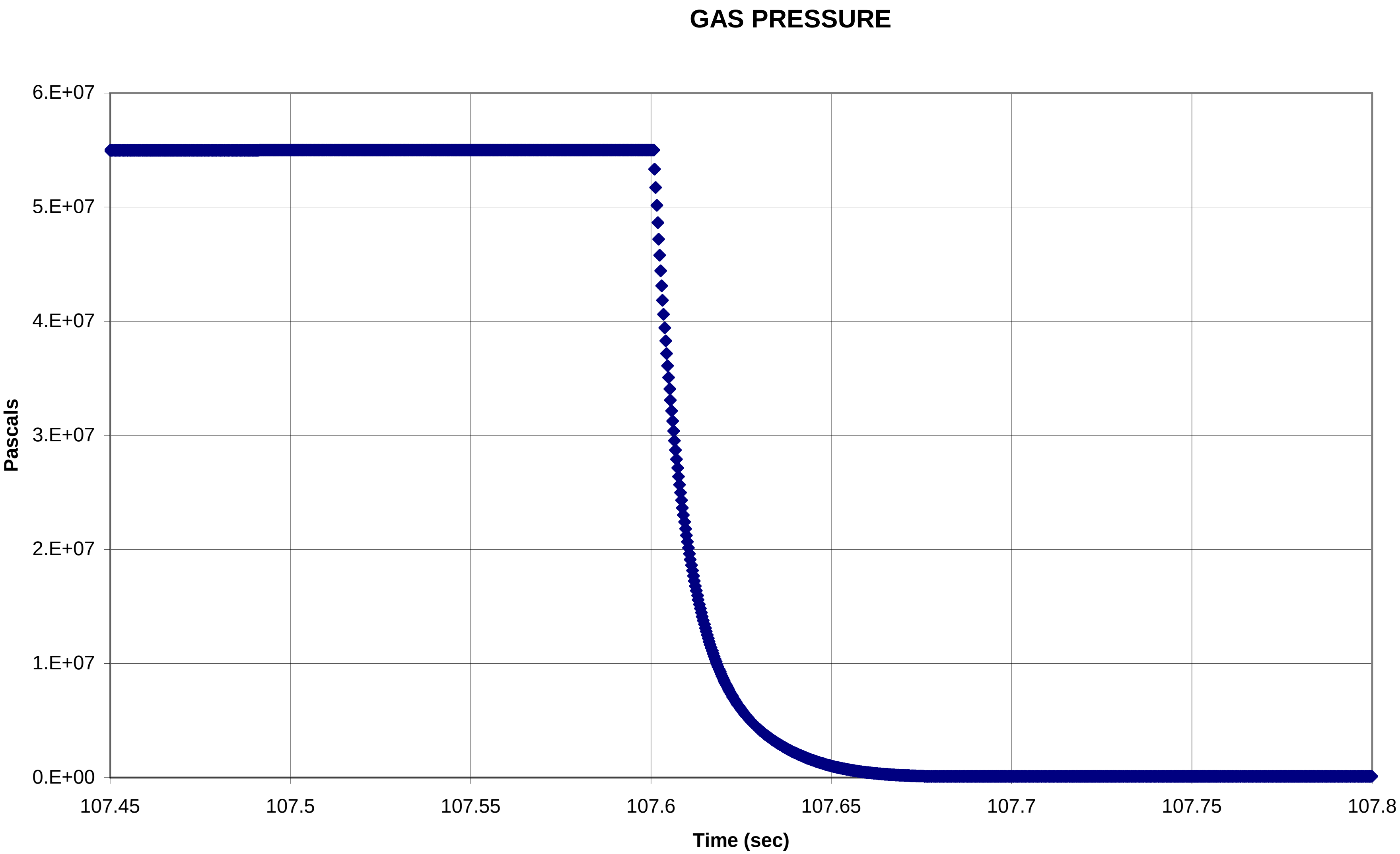
```
C    Subsonic venting
M          IF ((PRESSURE .LT. 1.89398*PO) .AND. (PRESSURE .GT. PO))
M    &          THEN $(1.9192E5 Pascals) at t=107.63sec
M               XMDOT = -AREA*PRESSURE*SQRT(7.0*((PO/PRESSURE)**
M    &          1.4286 - (PO/PRESSURE)**1.714)/(RX*(T1+TMPZRO)))
M                DM = XMDOT*DTIMEU
M                  XMASS = XMASS + DM
M                  VSUBSQ = RX*(T1+TMPZRO)*3.5*(1-(PO/PRESSURE)**0.28571) $V squared over 2
M                  DE = DM*VSUBSQ !energy removed from system by DM
M                Q1 = DE/DTIMEU    !add this energy to air node (Q1<0)
M               GOTO 100 $skip the sonic venting routine
M          ENDIF
M200       CONTINUE
C   Sonic Venting
M         XMDOT= -AREA*PRESSURE*(0.0404)/SQRT(T1+TMPZRO)
M          DM = XMDOT*DTIMEU
M          XMASS = XMASS + DM
M          VSONIC =  20.04*SQRT(T1+TMPZRO)
M          DE = 0.5*DM*VSONIC**2
M        Q1 = DE/DTIMEU
M100     CONTINUE $ compute gas capacitance
```

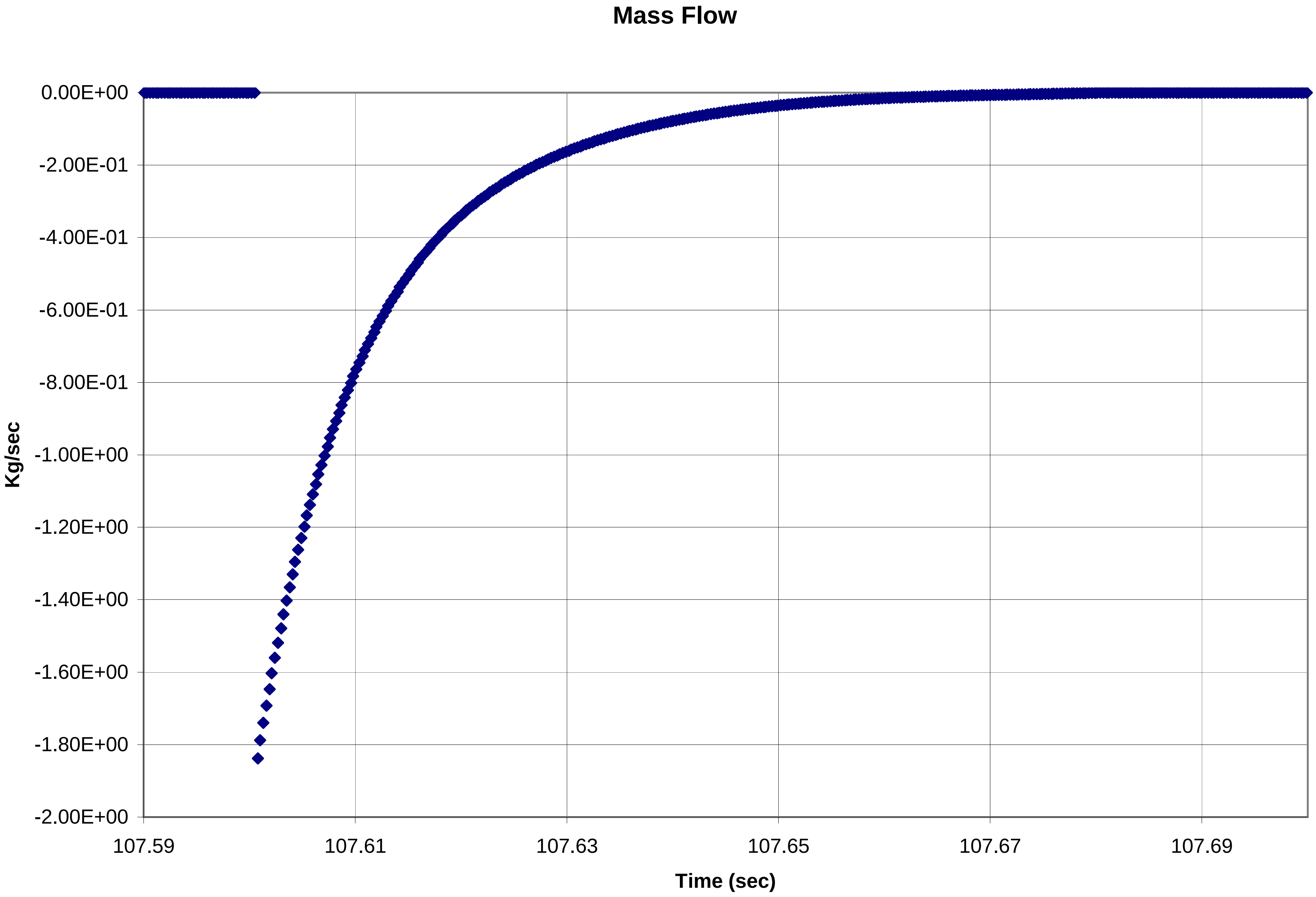

Temperatures
Temperature (C)
450
400
350
300
250
200
150
100
50
0
0
20
40
60
80
100
120
140
160
180
200
Time (sec)
Gas
T297
T319
T335
T346


Temperatures
450
400
350
300
250
200
150
100
50
0
Temperature (C)
107.45
107.5
107.55
107.6
107.65
107.7
107.75
107.8
Time (sec)
◆ Gas
■ T297
▲ T319
× T335
✱ T346

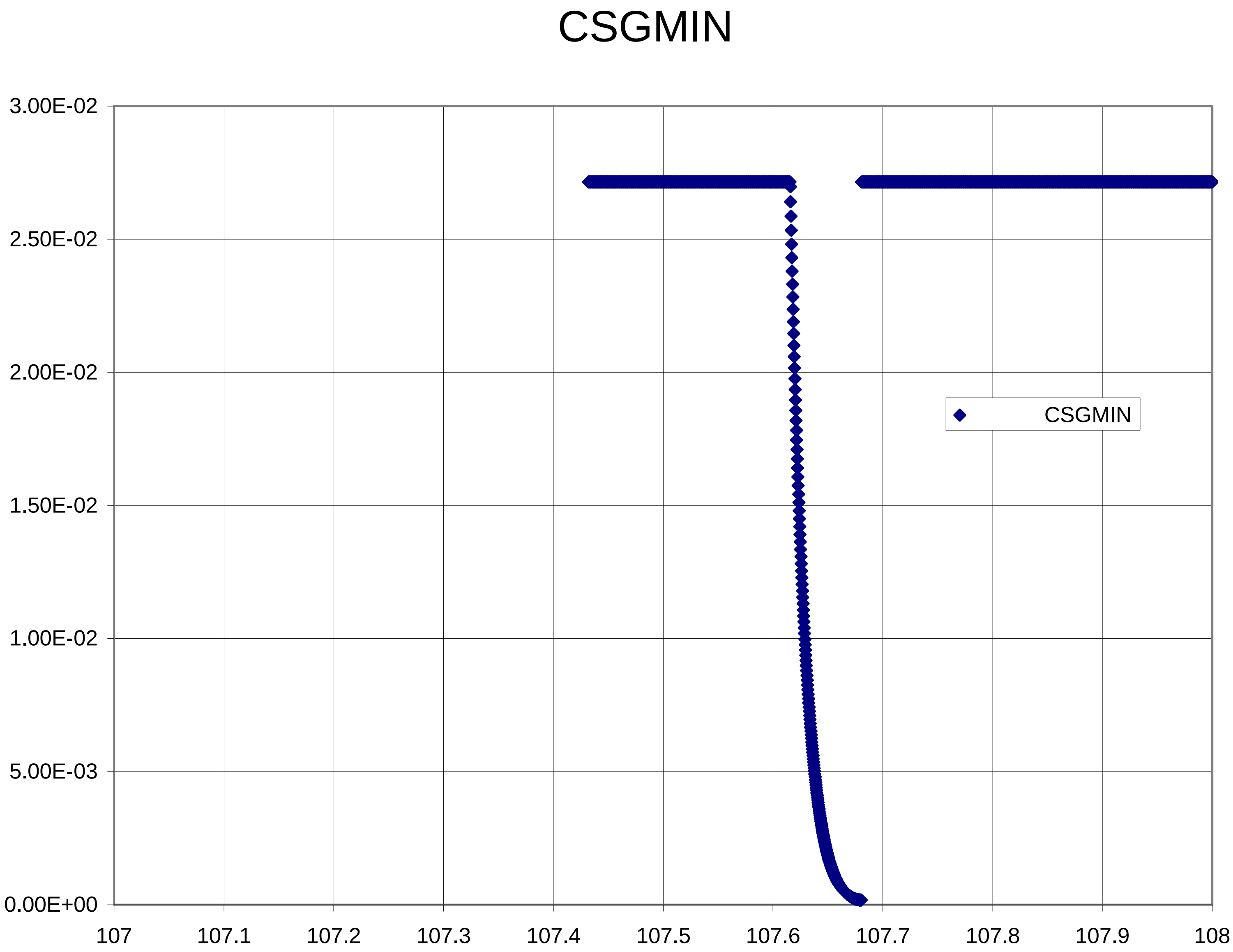


GAS PRESSURE
Pascals
6.E+07
5.E+07
4.E+07
3.E+07
2.E+07
1.E+07
0.E+00
0
20
40
60
80
100
120
140
160
180
200
Time (sec)


GAS PRESSURE
Pascals
6.E+07
5.E+07
4.E+07
3.E+07
2.E+07
1.E+07
0.E+00
107.45
107.5
107.55
107.6
107.65
107.7
107.75
107.8
Time (sec)



Mass Flow
Kg/sec
0.00E+00
-2.00E-01
-4.00E-01
-6.00E-01
-8.00E-01
-1.00E+00
-1.20E+00
-1.40E+00
-1.60E+00
-1.80E+00
-2.00E+00
107.59
107.61
107.63
107.65
107.67
107.69
Time (sec)


CSGMIN
3.00E-02
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
107
107.1
107.2
107.3
107.4
107.5
107.6
107.7
107.8
107.9
108
◆ CSGMIN