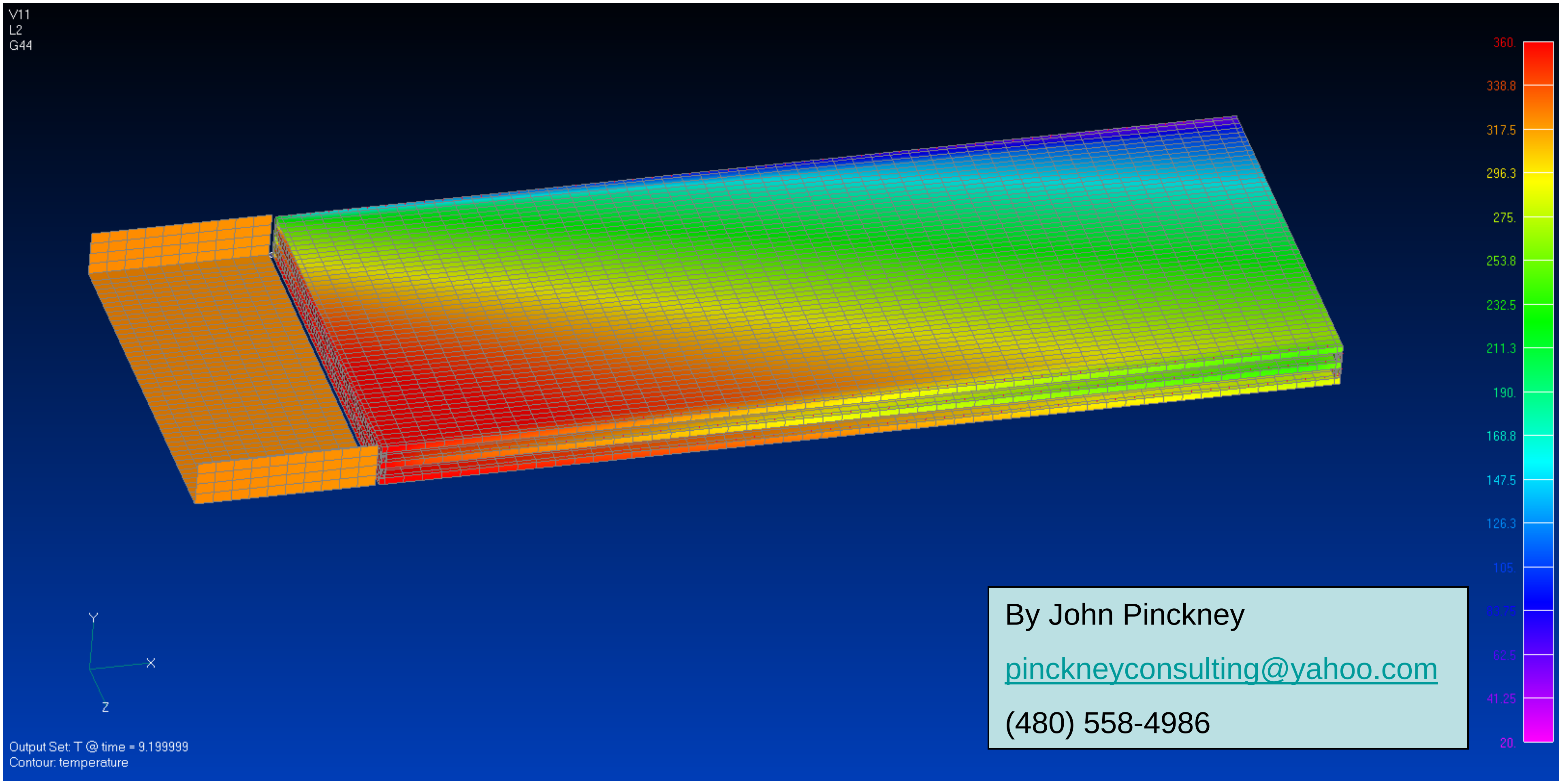
Transient Thermal Analysis of Compact Cross Flow Heat Exchanger for Aviation Application

- Pulsed hot air operation
- Modeled using innovative technique of applying fin equations within *SINDA/G for Femap*
- Results used for performance and thermal stress analysis



By John Pinckney

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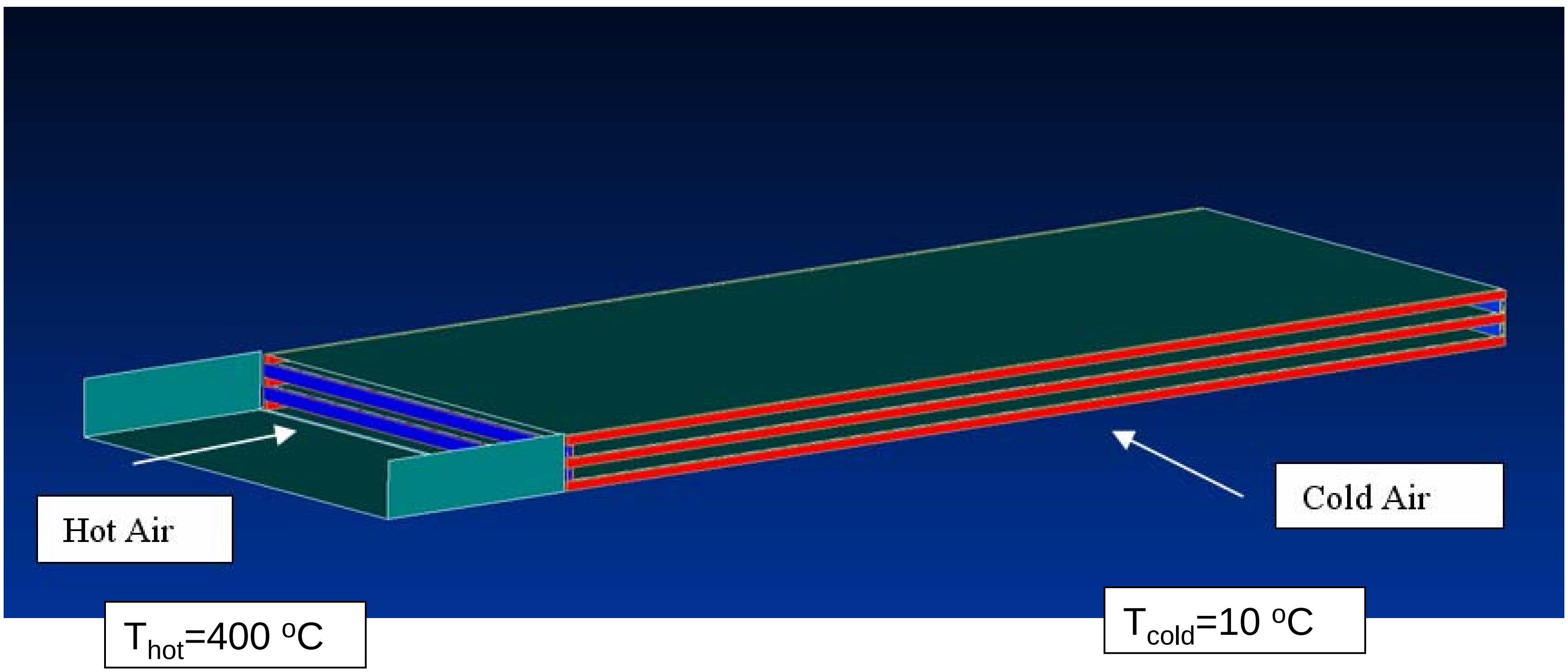
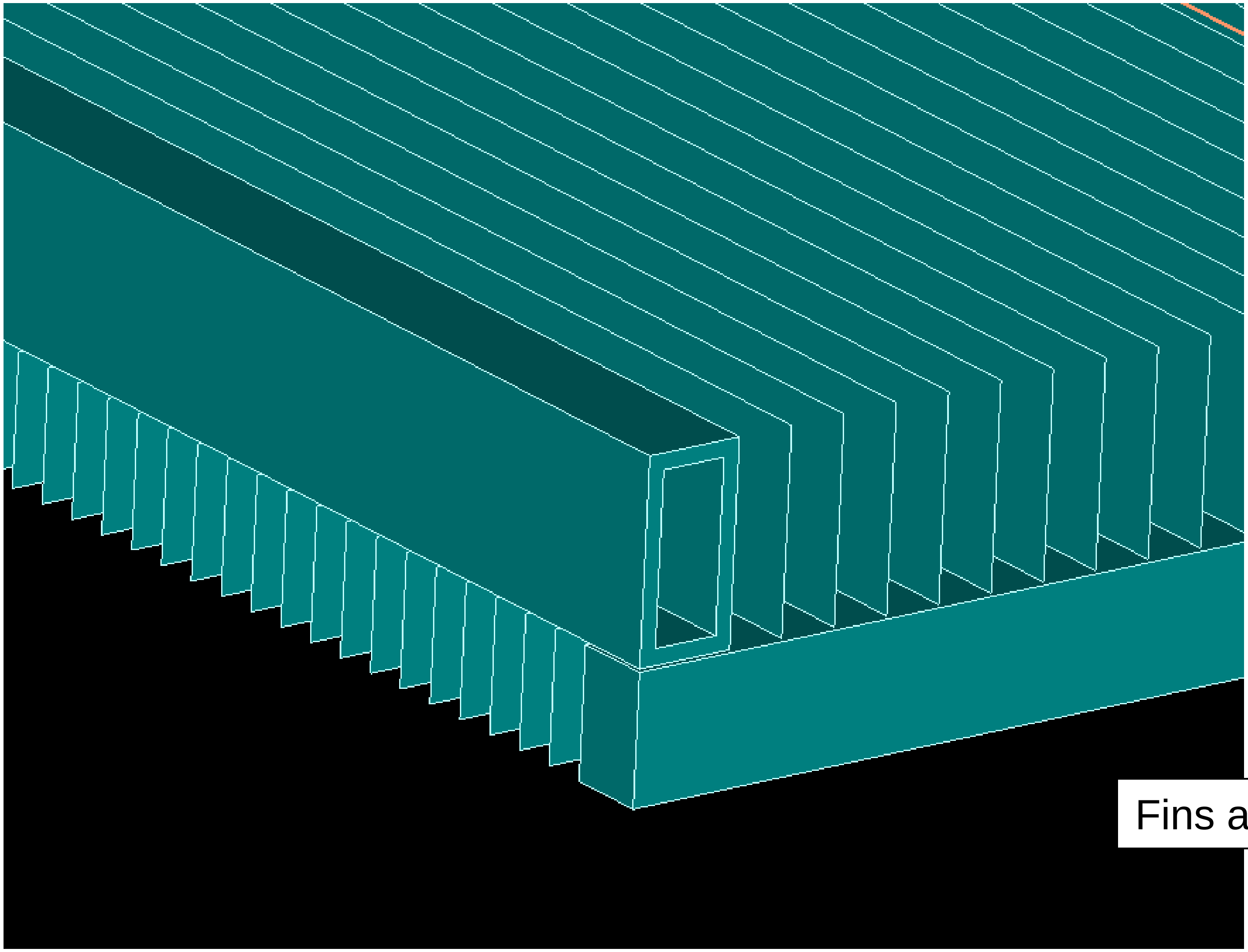
The heat exchanger is of a compact cross-flow finned and plate type consisting of n layers. Each layer consists of parallel parting sheets with parallel and evenly spaced fins placed perpendicular to the parting sheets. The layers are closed on two opposing edges by closure bars. The fins run in perpendicular directions in alternating layers. Hot air and cold air enter the heat exchanger in alternating layers resulting in perpendicular flow vectors.

Five Layers were modeled.



Close up of a Hot and Cold Layer



Fin spacing is 1.44 mm for the hot layers and 1.8mm for the cold layers. The cold closure bars are hollow. (The fins were not in the actual *Femap* model.)

Fins are 0.05 mm thick.

Super Fins

For modeling purposes fins were grouped into “Super Fins” and fin factors calculated for these Super Fins.

Fins per meter

$\eta_{FinHot} := \frac{148}{0.214}$ $\quad \eta_{FinHot} = 6.91589 \times 10^{2}$

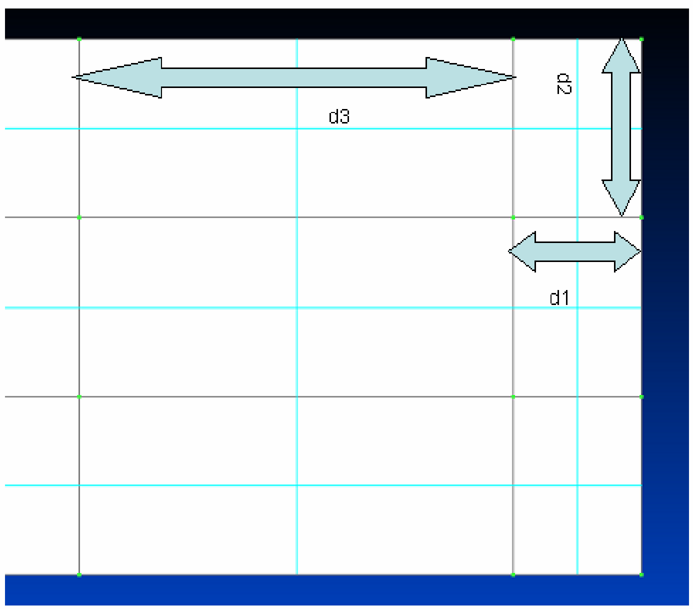
$\delta := 0.00005$

$\frac{1}{\eta_{FinHot}} = 1.44595 \times 10^{-3}$

$\eta_{FinCold} := \frac{290}{0.533}$ $\quad \eta_{FinCold} = 5.4409 \times 10^{2}$

$\frac{1}{\eta_{FinCold}} = 1.83793 \times 10^{-3}$

Hot Parting



What fraction of parting surfaces covered by fins?

$\eta_{FinHot} \cdot \delta = 3.45794 \times 10^{-2}$

$\eta_{FinCold} \cdot \delta = 2.72045 \times 10^{-2}$

What fraction of parting surfaces covered by fins?

$\eta_{FinHot} \cdot \delta = 3.45794 \times 10^{-2}$

$\eta_{FinCold} \cdot \delta = 2.72045 \times 10^{-2}$

$d_{hot1} := 0.0030988$

$d_{hot2} := 0.0041784$

$d_{hot3} := 0.010536$

$Fin_{factorhot1} := \eta_{FinHot} \cdot \frac{d_{hot2}}{2}$

$Fin_{factorhot2} := \eta_{FinHot} \cdot d_{hot2}$

$Fin_{factorhot1} = 1.44487 \times 10^{0}$ $\quad Fin_{factorhot2} = 2.88973 \times 10^{0}$

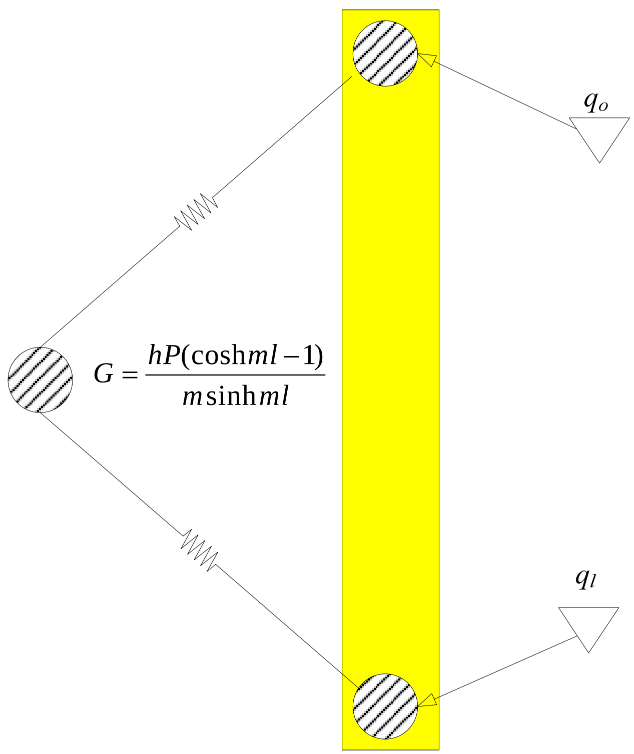
$A_{hot2} := \frac{d_{hot1} \cdot d_{hot2}}{4}$ $\quad d_{hot3} \cdot d_{hot2} = 4.40236 \times 10^{-5}$

Super Fin sections modeled as three nodes with two conductors and two heat terms.

$$q_l = \frac{hP}{m \sinh ml}\left(\Theta_o \cosh ml - \Theta_l\right)$$

$$q_o = \frac{hP}{m \sinh ml}\left(\Theta_o - \Theta_l \cosh ml\right)$$

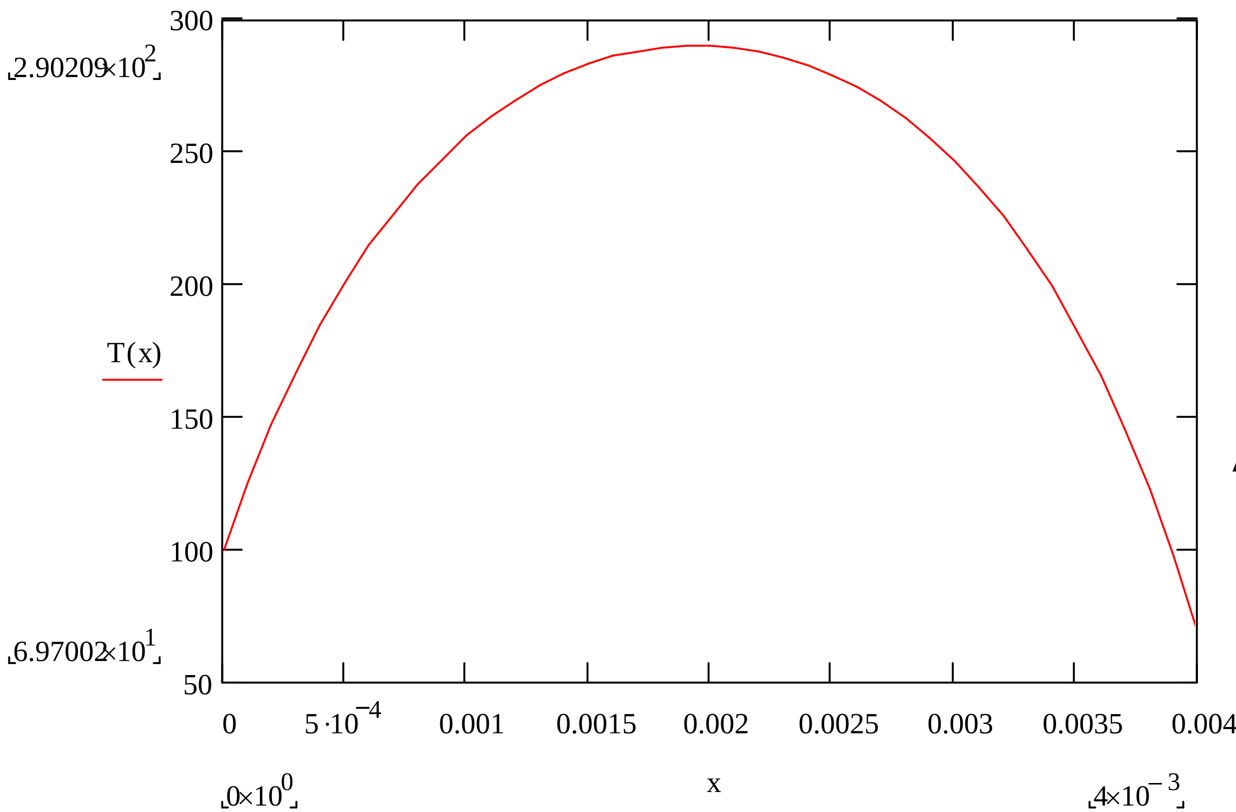
$$q_{con} = \frac{hP(\cosh ml - 1)}{m \sinh ml}\left(\Theta_o + \Theta_l\right)$$



See: *Fundamentals of Heat Exchanger Design.* Ramesh K. Shah, Dusan P. Sekulic. John Wiley & Sons, Hobeken, New Jersey. 2003

Θ is difference in temperatures between air stream and fin location.

The fin equations are necessary because large errors will result in the convective heat transfer calculations otherwise. It is impractical to mesh fins fine enough to accurately capture the fin temperature profile.

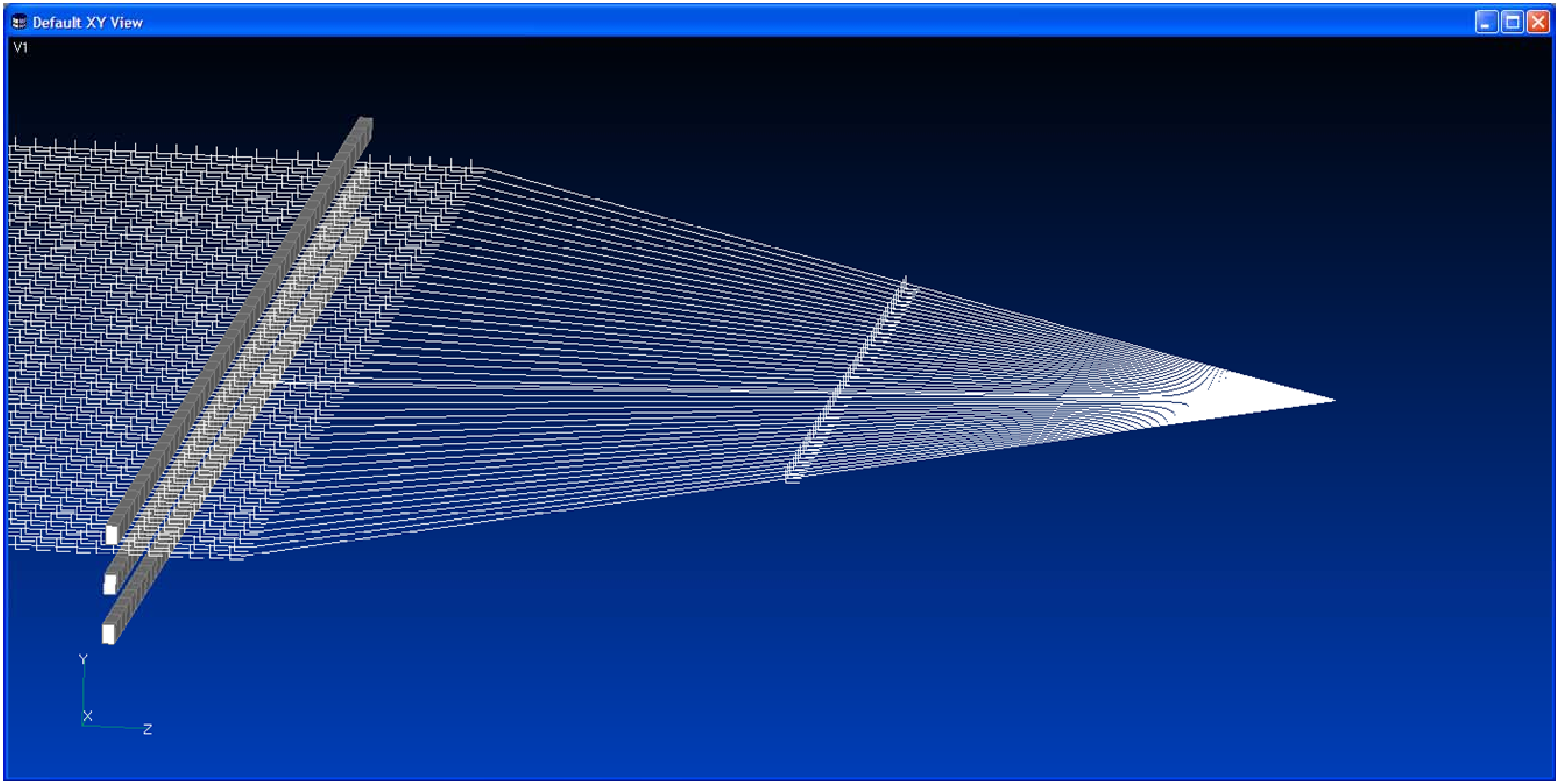


A fin temperature profile.

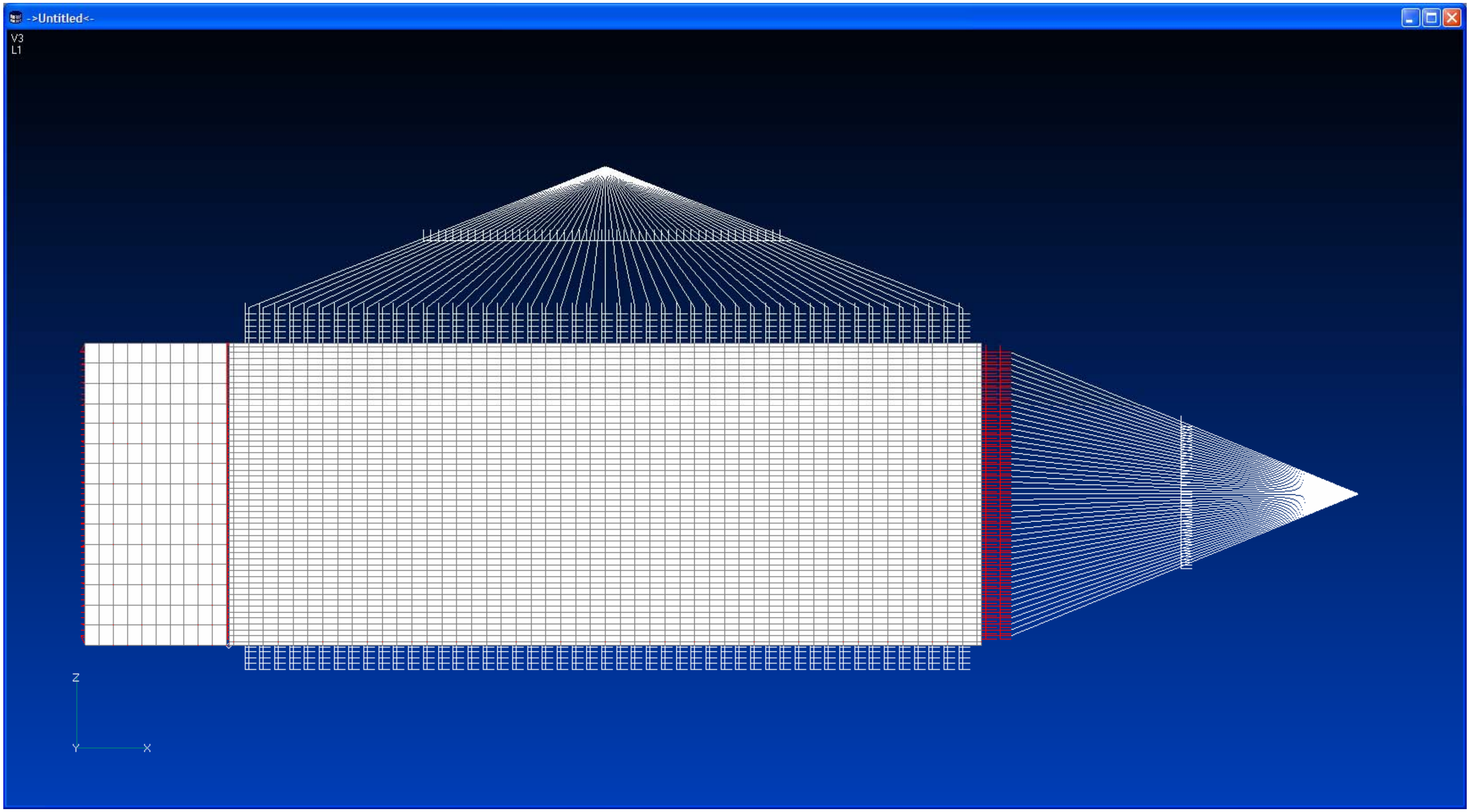
Custom Fortran code was written to find nodal relations, add heats, update convection conductors, simulate hot air pulse.

```
F      CALL ARRAYMAKER(FILENM(1) , HAALL123) !All Hot Air Nodes.LST
F      CALL ARRAYMAKER(FILENM(2) , HAL1    ) !Hot Air Nodes in HE in Layer 1.LST
…
c Construct the NGN arrays
F    hot=.true.
F    CALL MK(hot,HCL1,SHCL1,HP0L1,SHP0L1,HPLL1,SHPLL1,HP0L1NGN,
F   &SHP0L1NGN,HPLL1NGN,SHPLL1NGN,HC0L1NGN,SHC0L1NGN,HCLL1NGN,
F   &SHCLL1NGN)
…
c Construct Triplet arrays
F    CALL TRIPMAKR(HC0L1NGN,SHC0L1NGN,HCLL1NGN,SHCLL1NGN,HCL1T,SHCL1T)
F      PRINT*,"TRIPLET1"
…
F       hot=.true. !update conductors from partings to hot air
F       print*,"hot", hot
F       DO I=1,SHPL1T
F          DO J=2,4,2
F             CALL Gconv(hhotL1,hot,G(HPL1T(I,J)),G(HPL1T(I,J)))
F          ENDDO
F       ENDDO
…
F100    CONTINUE !Update hot layer heats
F     hot=.true.
F     CALL Qfin(HPL1T,SHPL1T,hhotL1,hot)
F     CALL Qfin(HCL1T,SHCL1T,hhotL1,hot)
…
F    IF( (TIMEO >  Timenot).AND.(TIMEO < Timenot+Tau)) THEN
F        DO J=1,SALLHOTG
F           G(ALLHOTGN(J))=0.0       !close all hot conductors
F        ENDDO
```

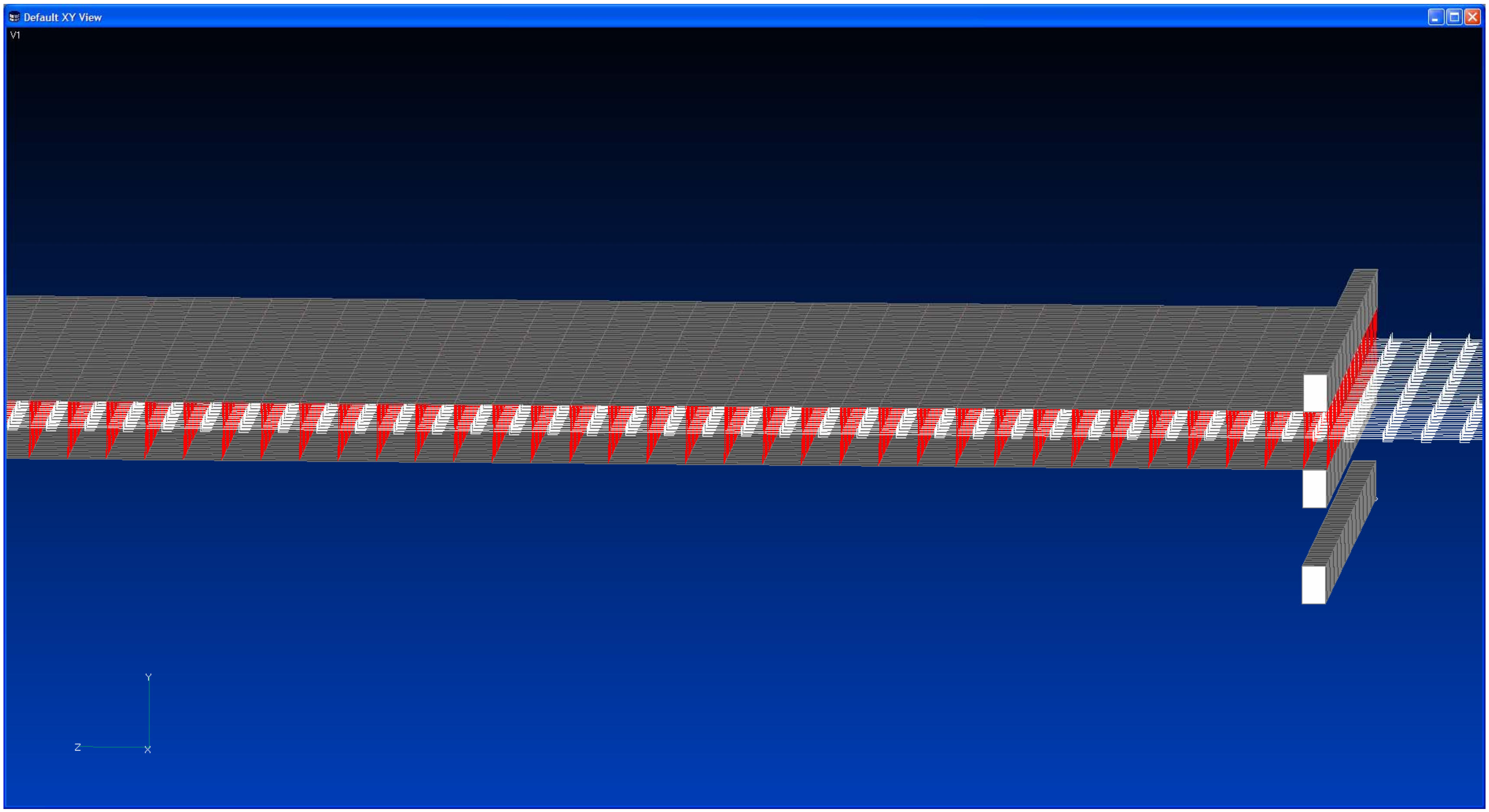
The average exit air temperature is computed by constructing one-way conductors from nodes at the exit to a single node, the Averaging Node. (Elements were constructed by using **Closest Link** under meshing menu).



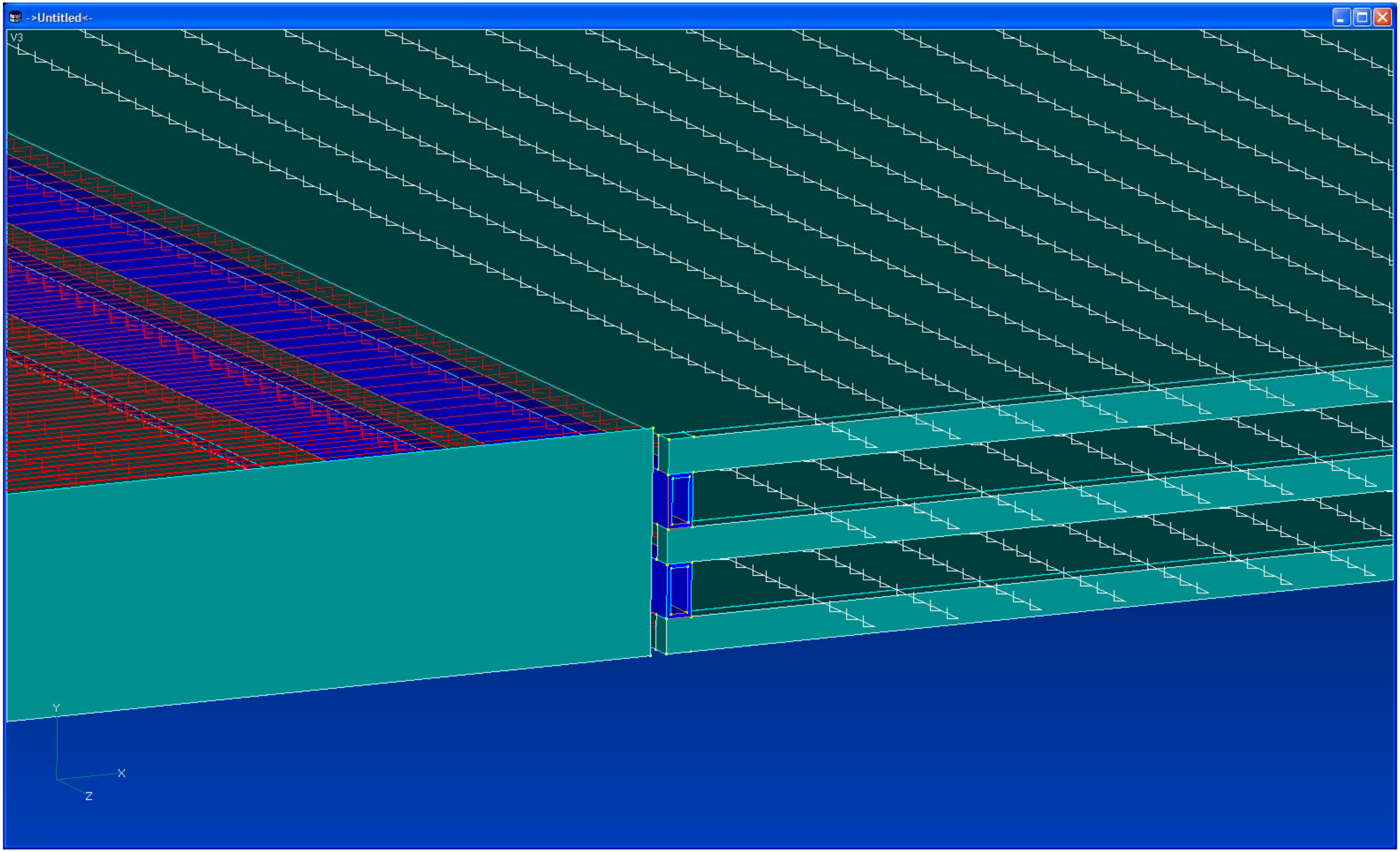
Heat Exchanger with One-Way Conductors to Averaging Nodes



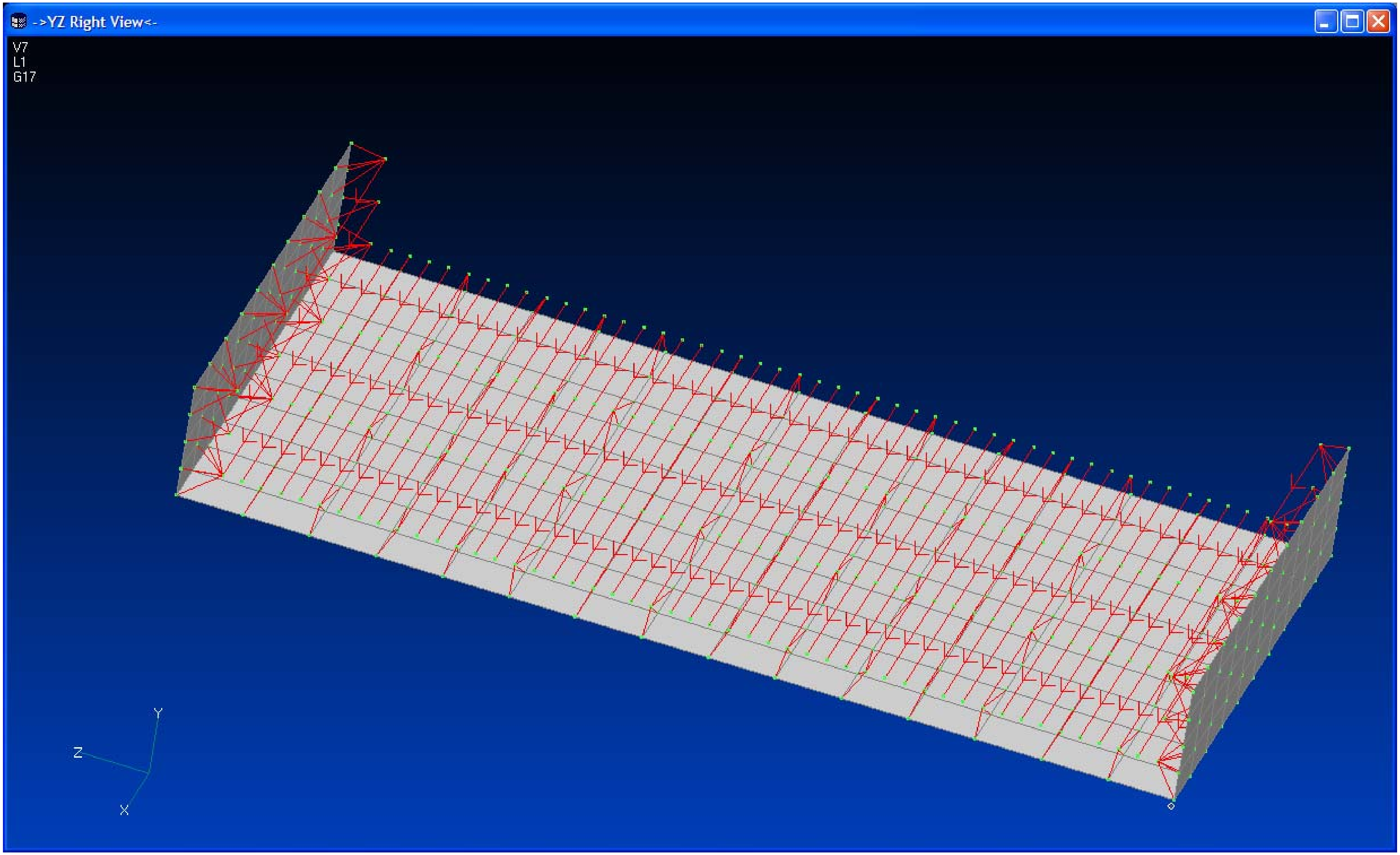
Convection conductors (shown in red) from air streams to parting plates were constructed by using the Contact Segments Algorithm.



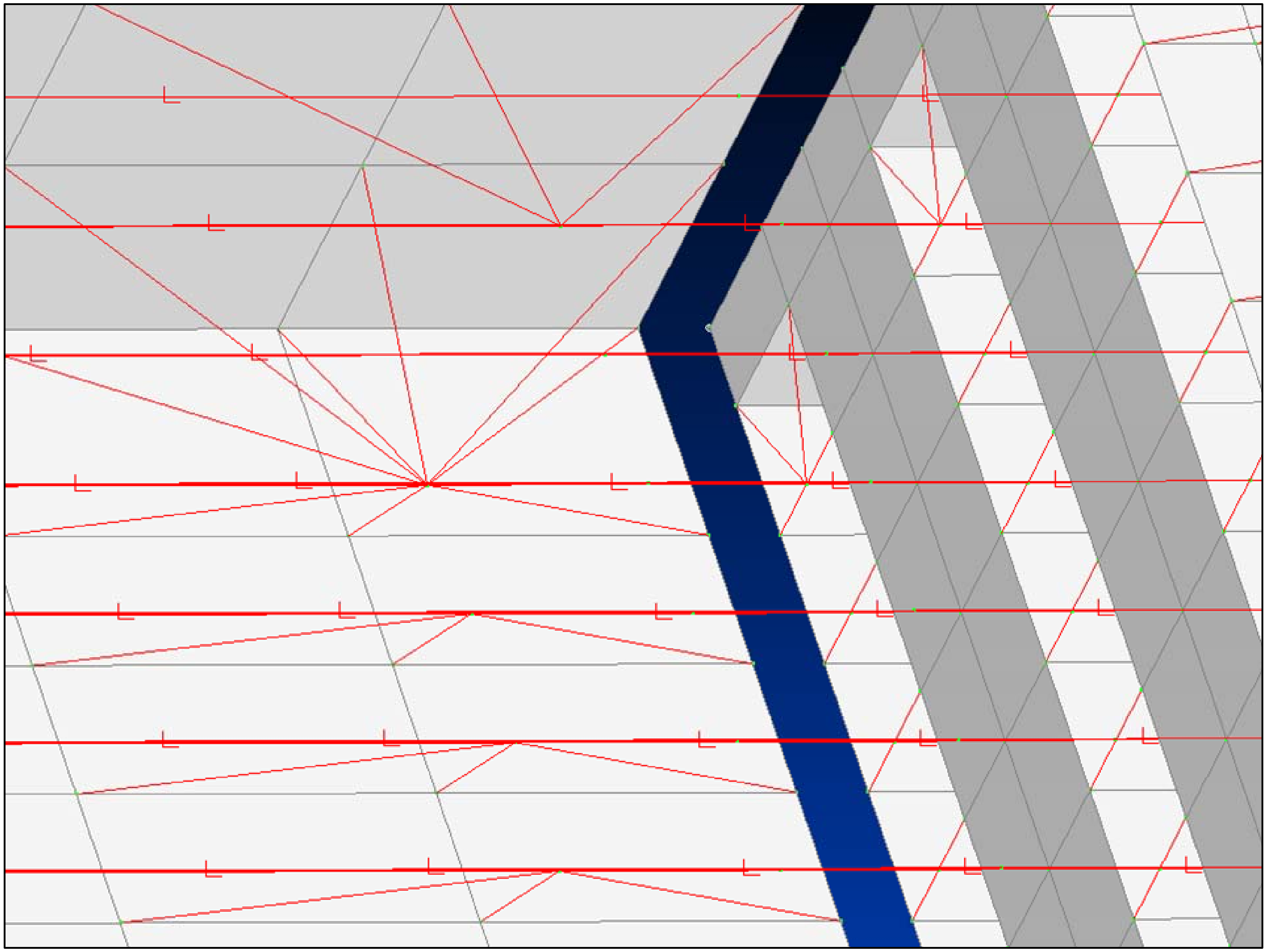
Hot and Cold Air Flow Through Ducts



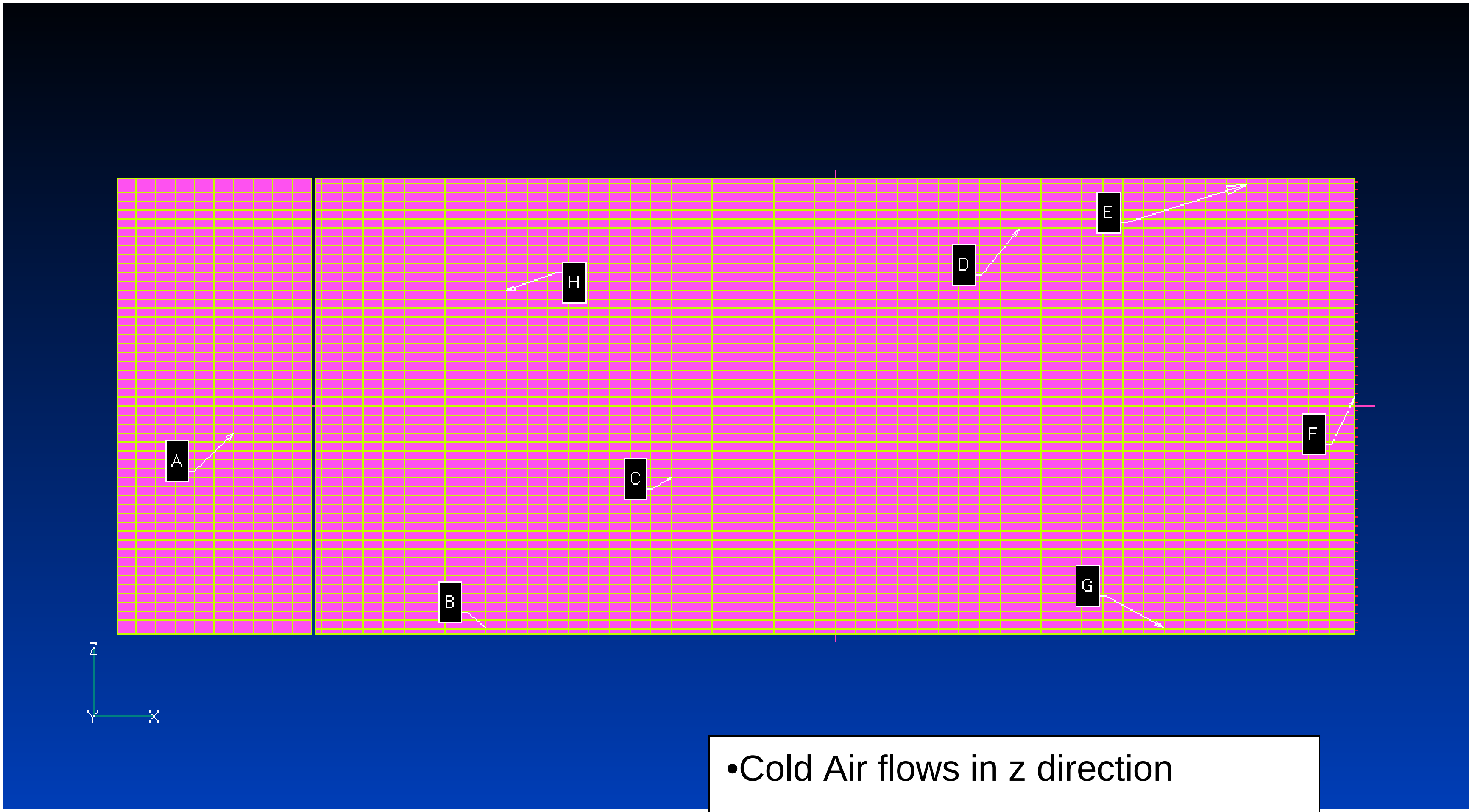
Header with Conductors to Air Streams



Corner of Header near hot air inlet showing contact conductors and one-way flow elements.



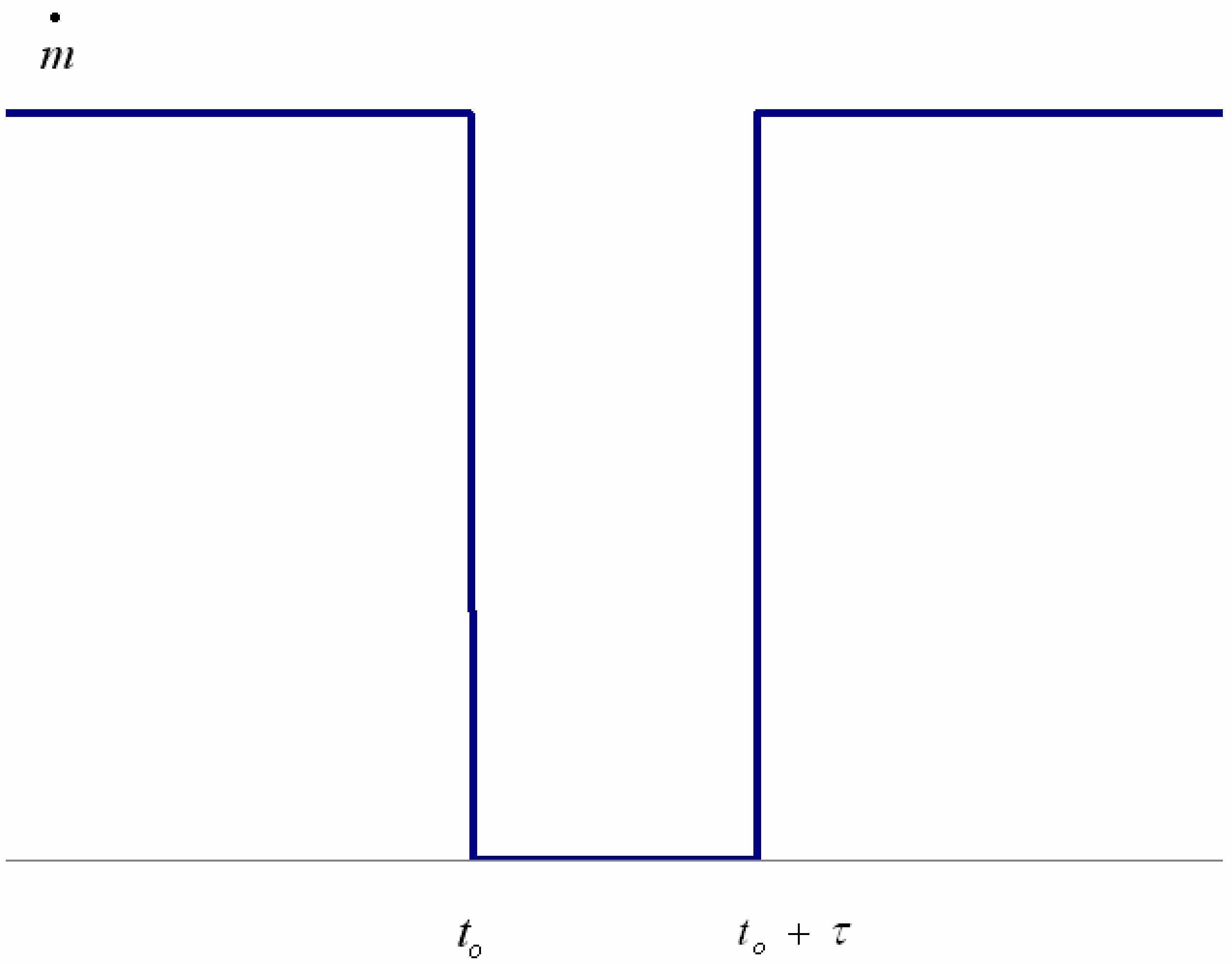
Some Plotting Locations

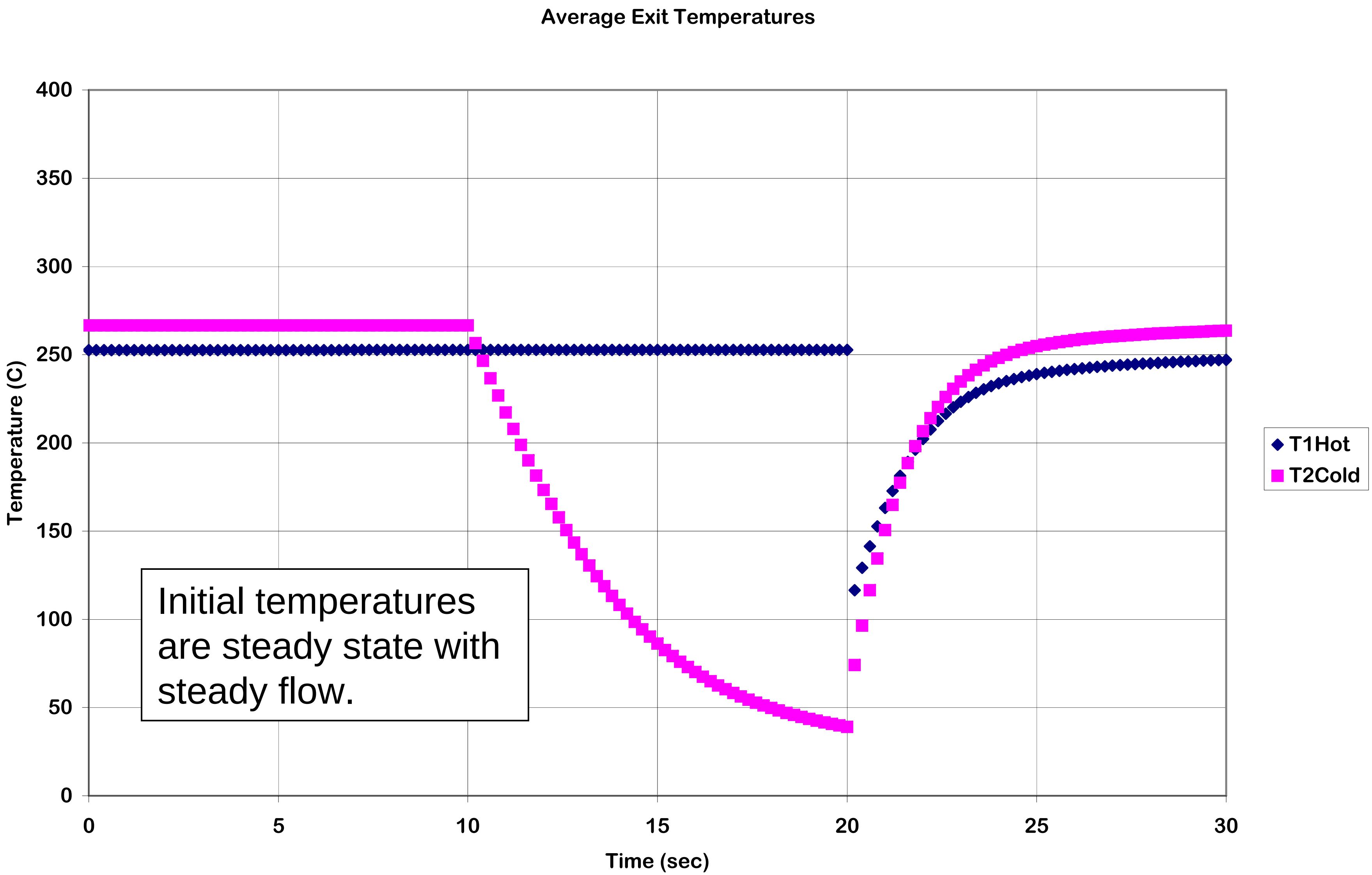


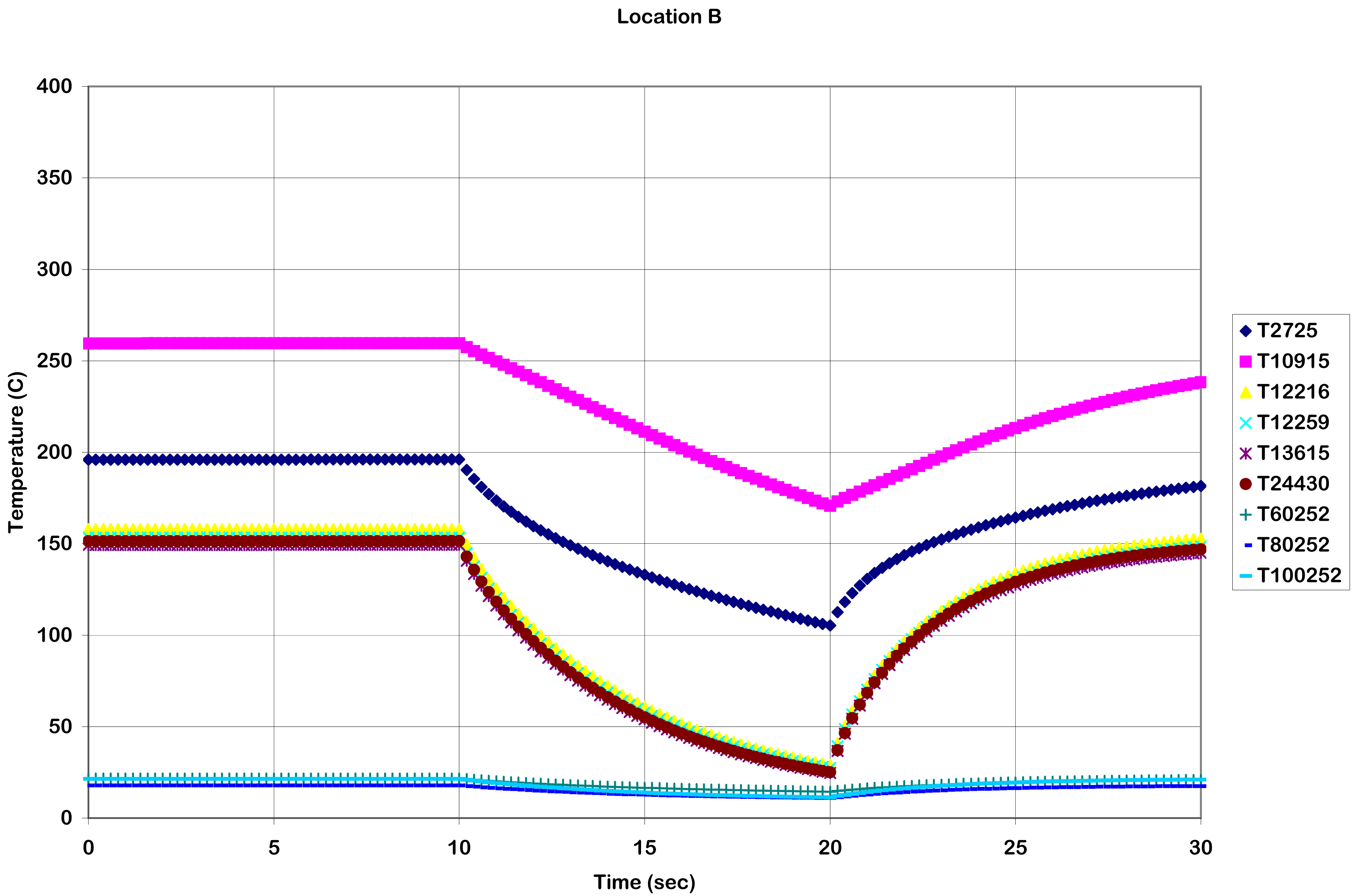
•Cold Air flows in z direction

•Hot Air flows in the x direction

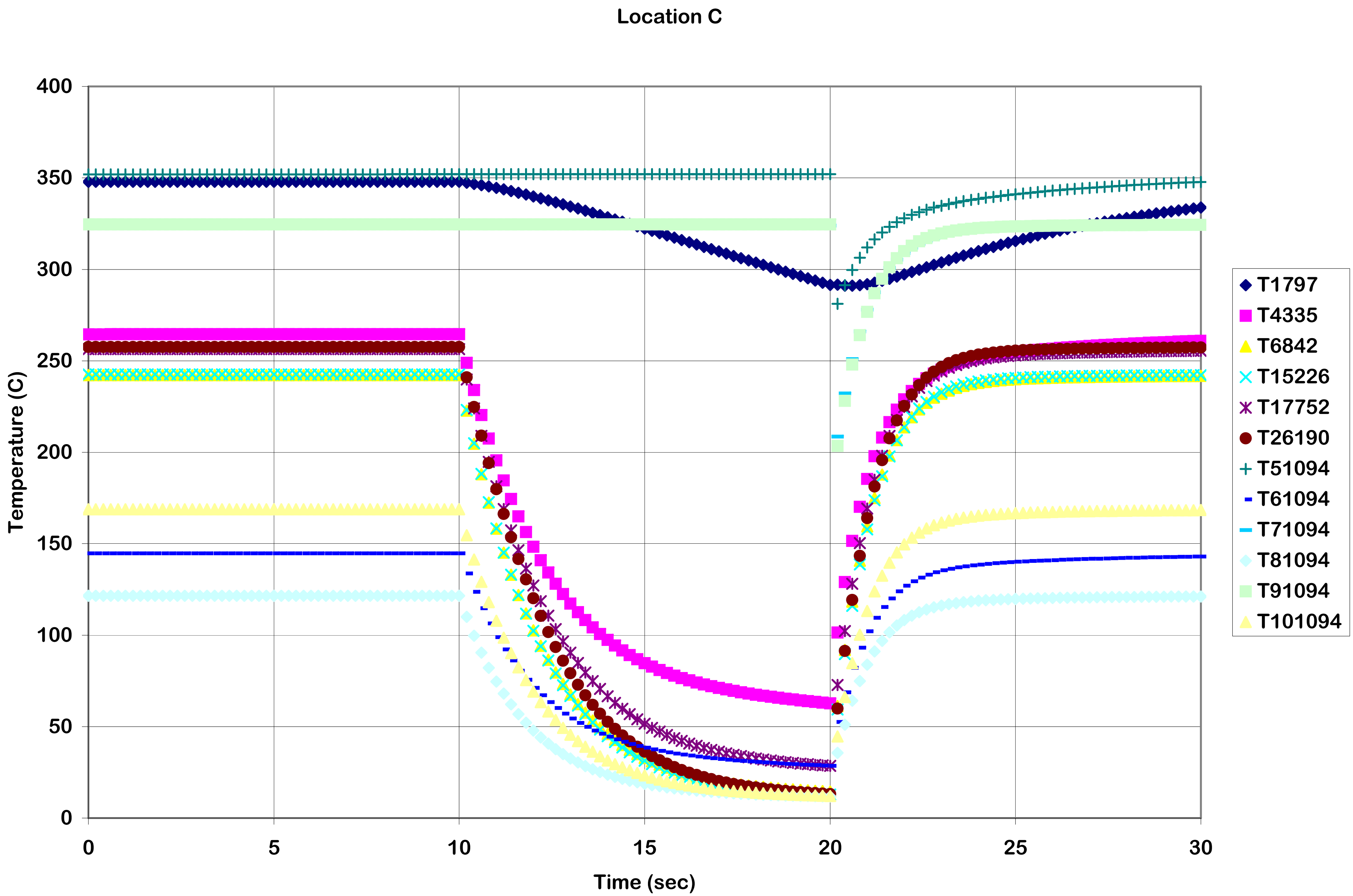
The Hot Air Stream is Pulsed



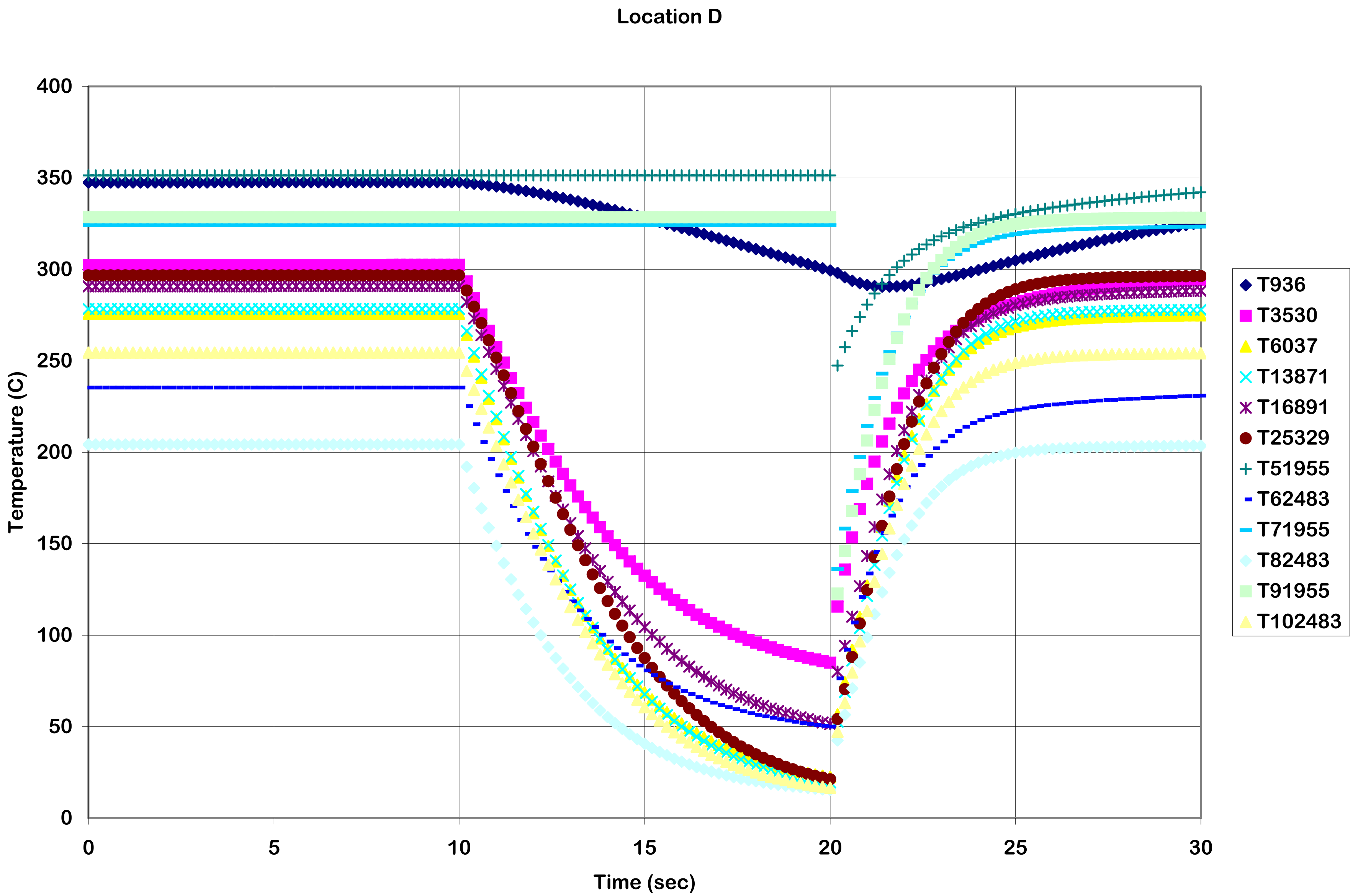

Average Exit Temperatures
400
350
300
250
200
150
100
50
0
Temperature (C)
0
5
10
15
20
25
30
Time (sec)
T1Hot
T2Cold
Initial temperatures are steady state with steady flow.

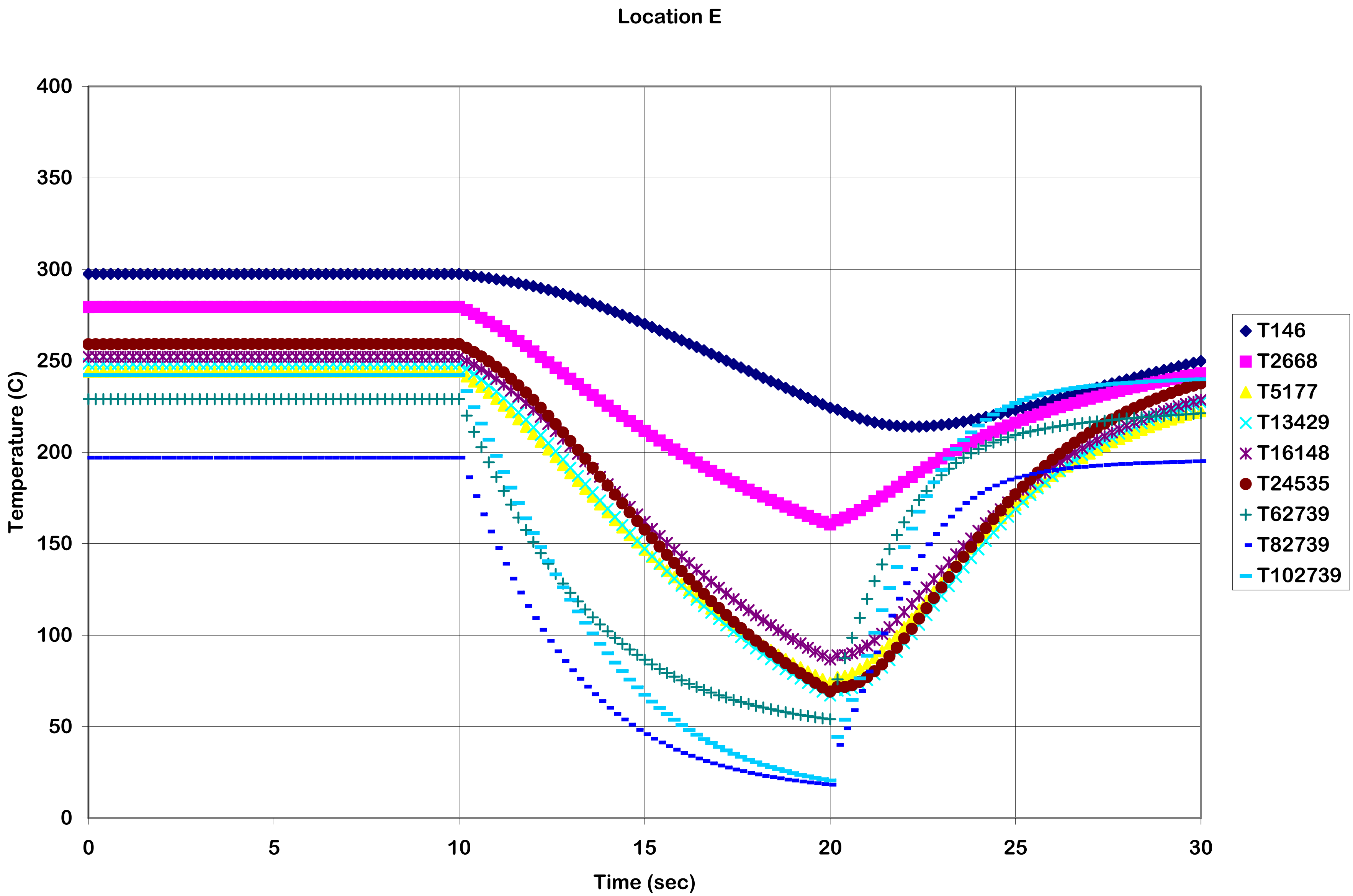


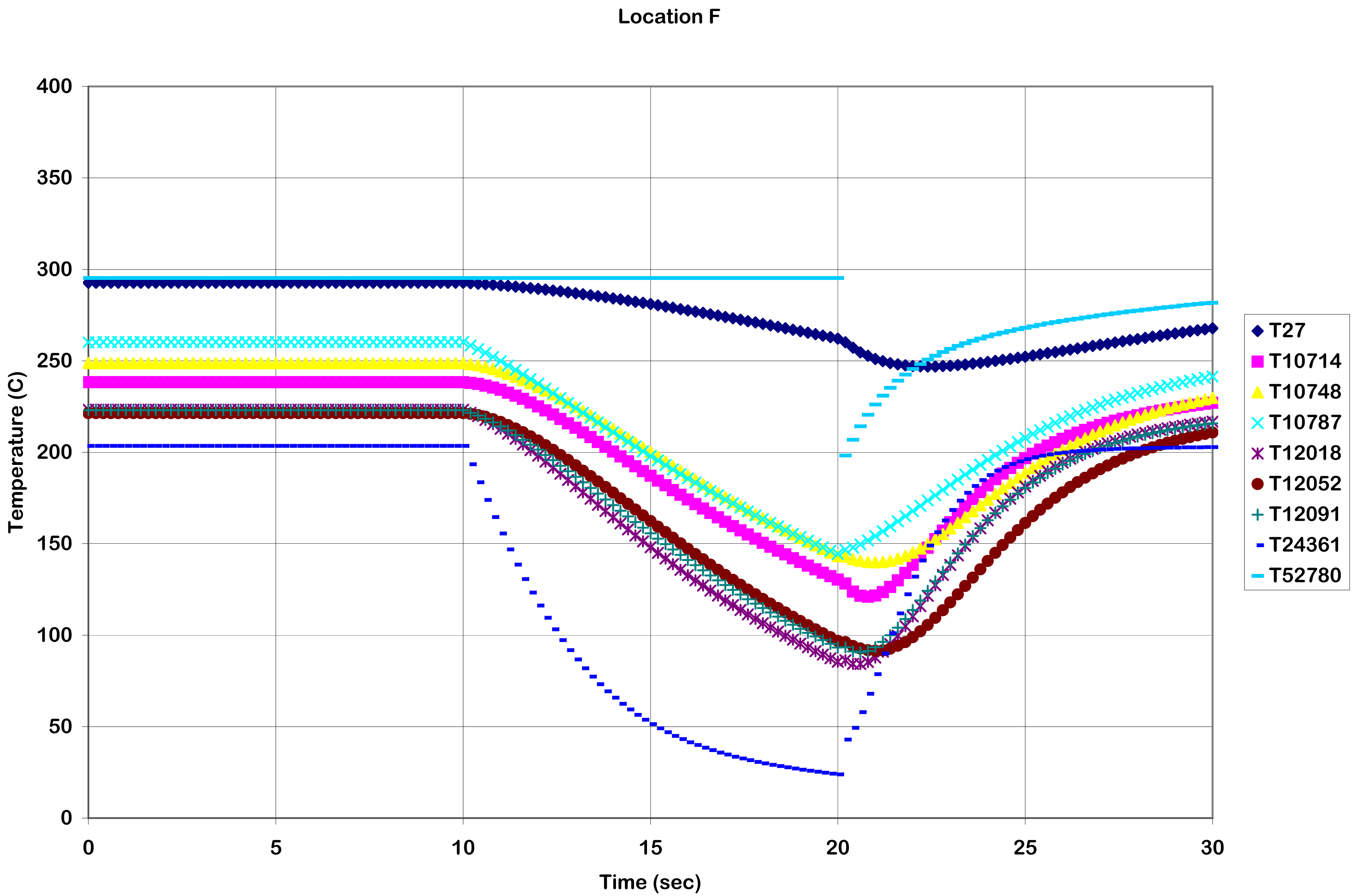
Location B
Temperature (C)
400
350
300
250
200
150
100
50
0
0
5
10
15
20
25
30
Time (sec)
T2725
T10915
T12216
T12259
T13615
T24430
T60252
T80252
T100252



Location C
400
350
300
250
200
150
100
50
0
Temperature (C)
0
5
10
15
20
25
30
Time (sec)
T1797
T4335
T6842
T15226
T17752
T26190
T51094
T61094
T71094
T81094
T91094
T101094

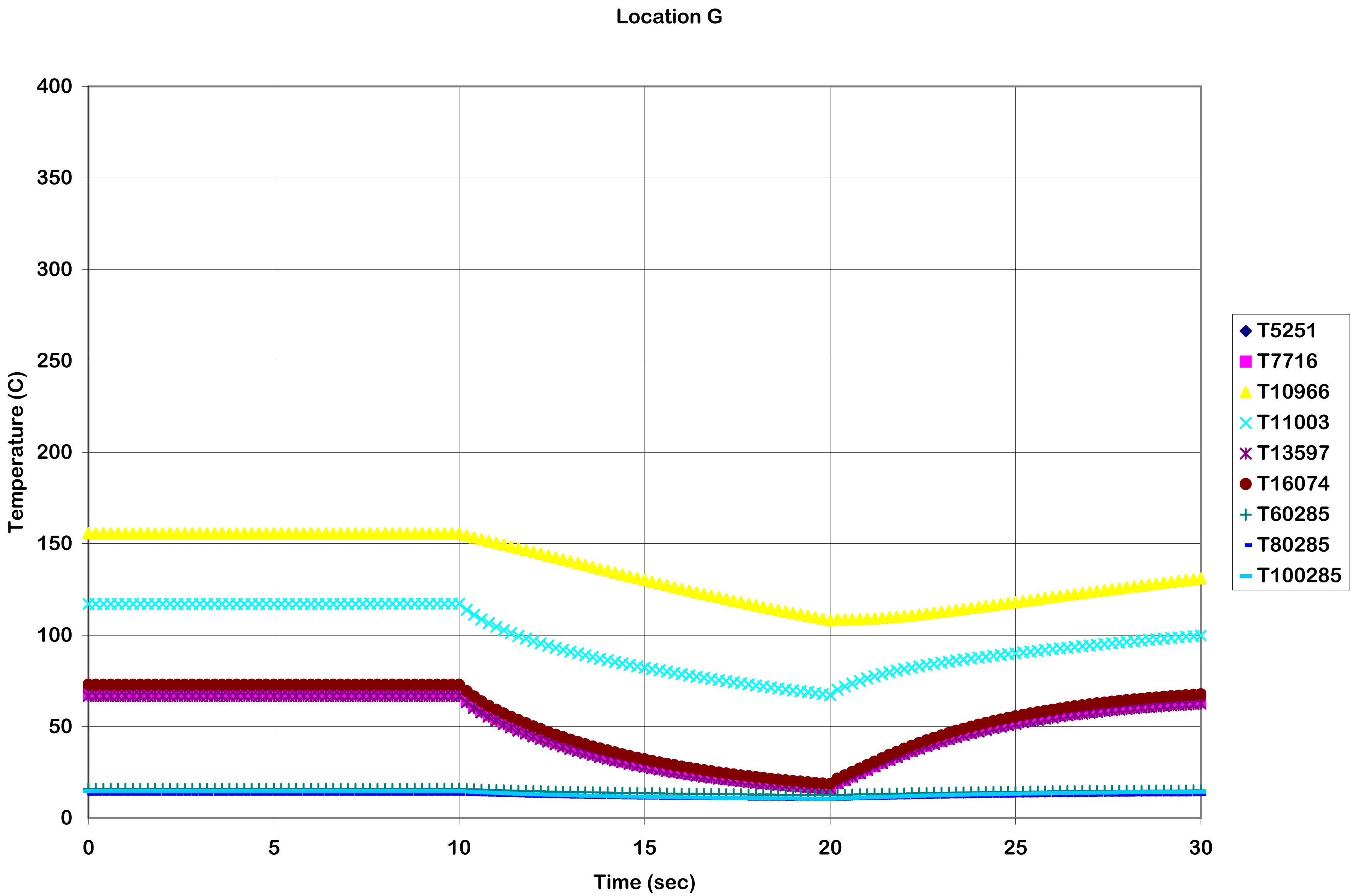

Location D
Temperature (C)
Time (sec)
400
350
300
250
200
150
100
50
0
0
5
10
15
20
25
30
T936
T3530
T6037
T13871
T16891
T25329
T51955
T62483
T71955
T82483
T91955
T102483

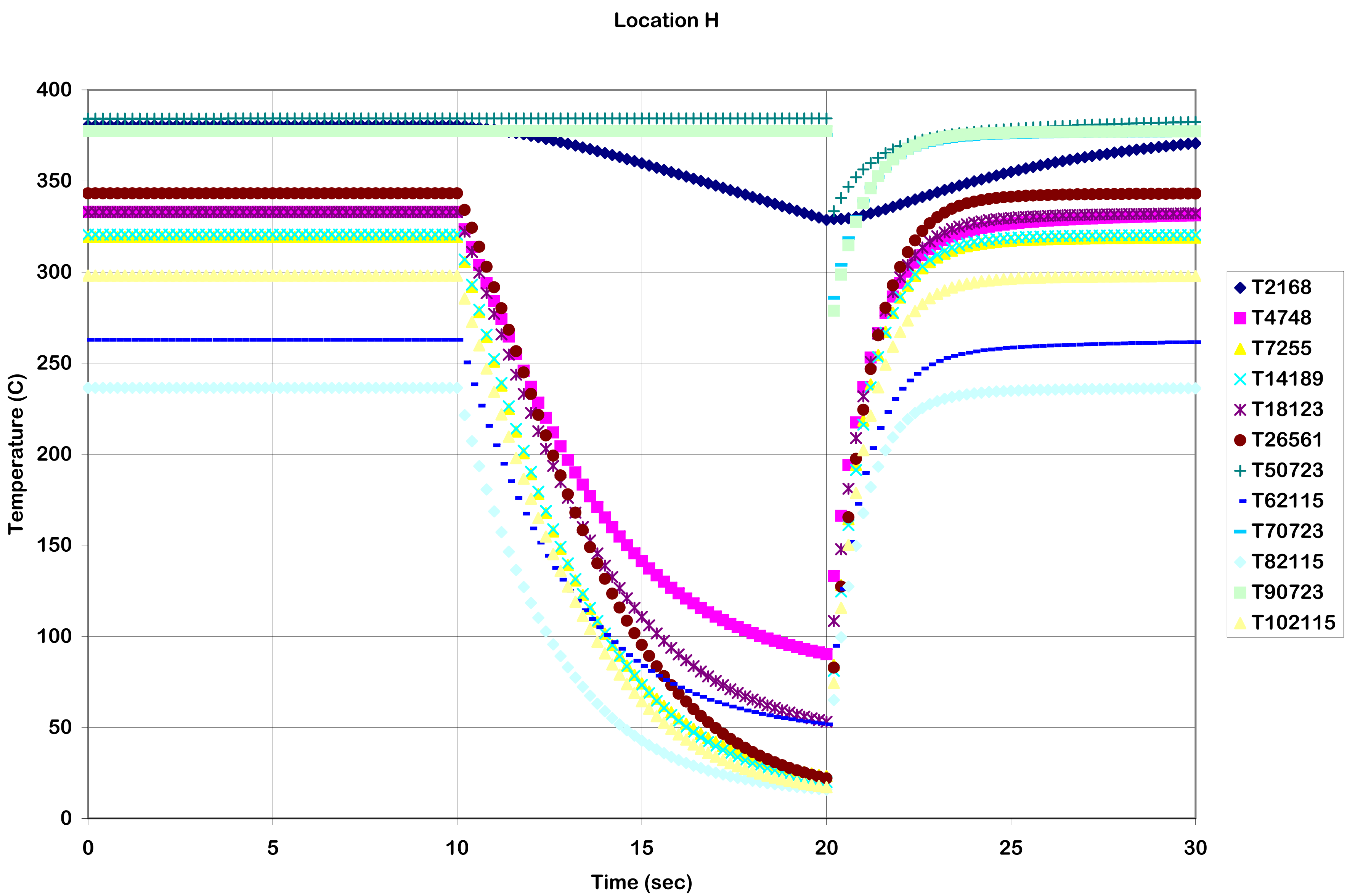

Location E
Temperature (C)
400
350
300
250
200
150
100
50
0
0
5
10
15
20
25
30
Time (sec)
T146
T2668
T5177
T13429
T16148
T24535
T62739
T82739
T102739



Location F
Temperature (C)
400
350
300
250
200
150
100
50
0
0
5
10
15
20
25
30
Time (sec)
T27
T10714
T10748
T10787

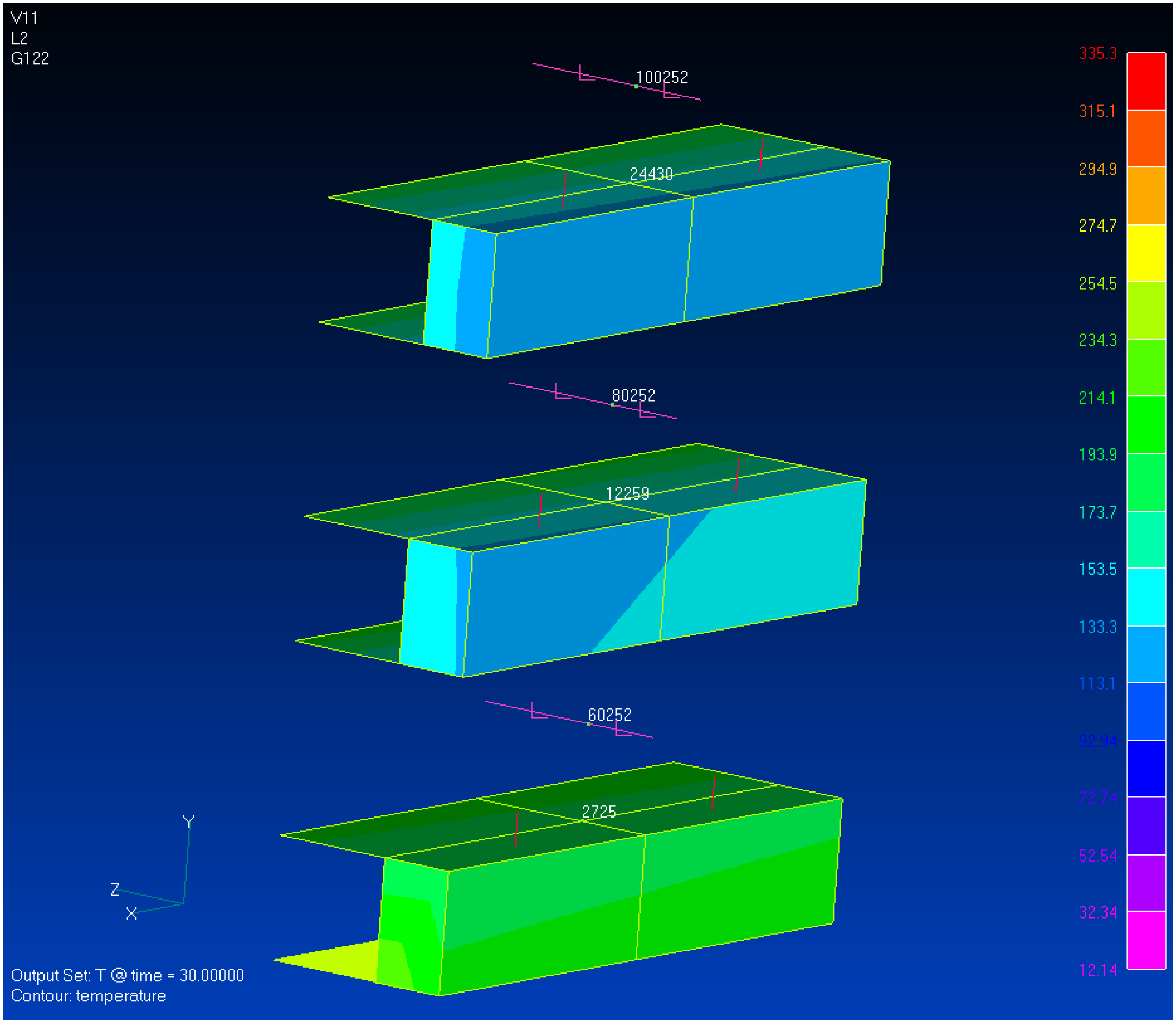

T12018
T12052
T12091
T24361
T52780

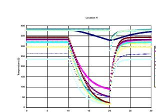

Location G
Temperature (C)
400
350
300
250
200
150
100
50
0
0
5
10
15
20
25
30
Time (sec)
T5251
T7716
T10966
T11003
T13597
T16074
T60285
T80285
T100285



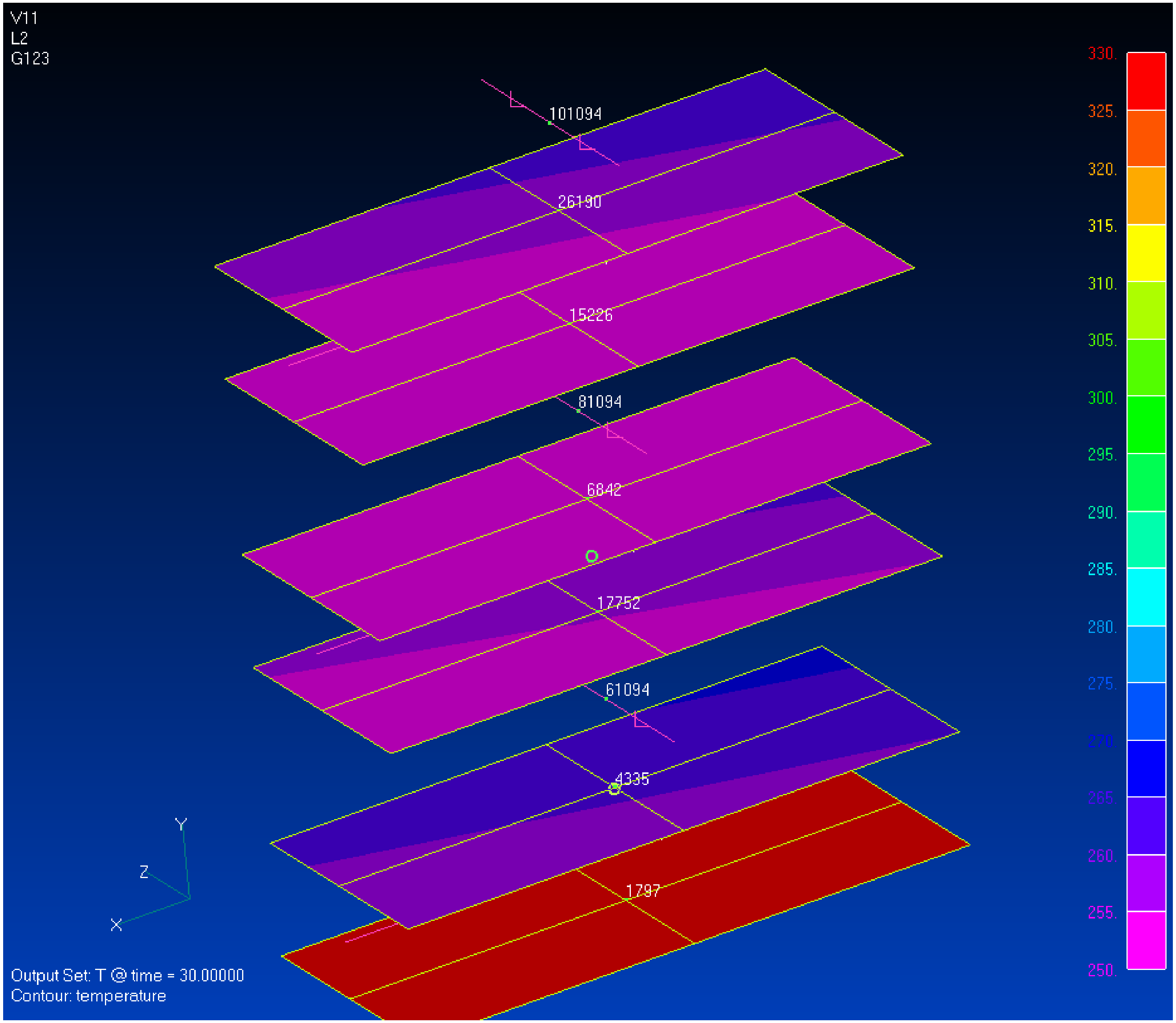
Location H
Temperature (C)
Time (sec)
400
350
300
250
200
150
100
50
0
0
5
10
15
20
25
30
T2168
T4748
T7255
T14189
T18123
T26561
T50723
T62115
T70723
T82115
T90723
T102115

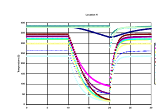
B


V11
L2
G122
100252
24430
80252
12259
60252
2725
335.3
315.1
294.9
274.7
254.5
234.3
214.1
193.9
173.7
153.5
133.3
113.1
92.94
72.74
52.54
32.34
12.14
Y
Z
X
Output Set: T @ time = 30.00000
Contour: temperature

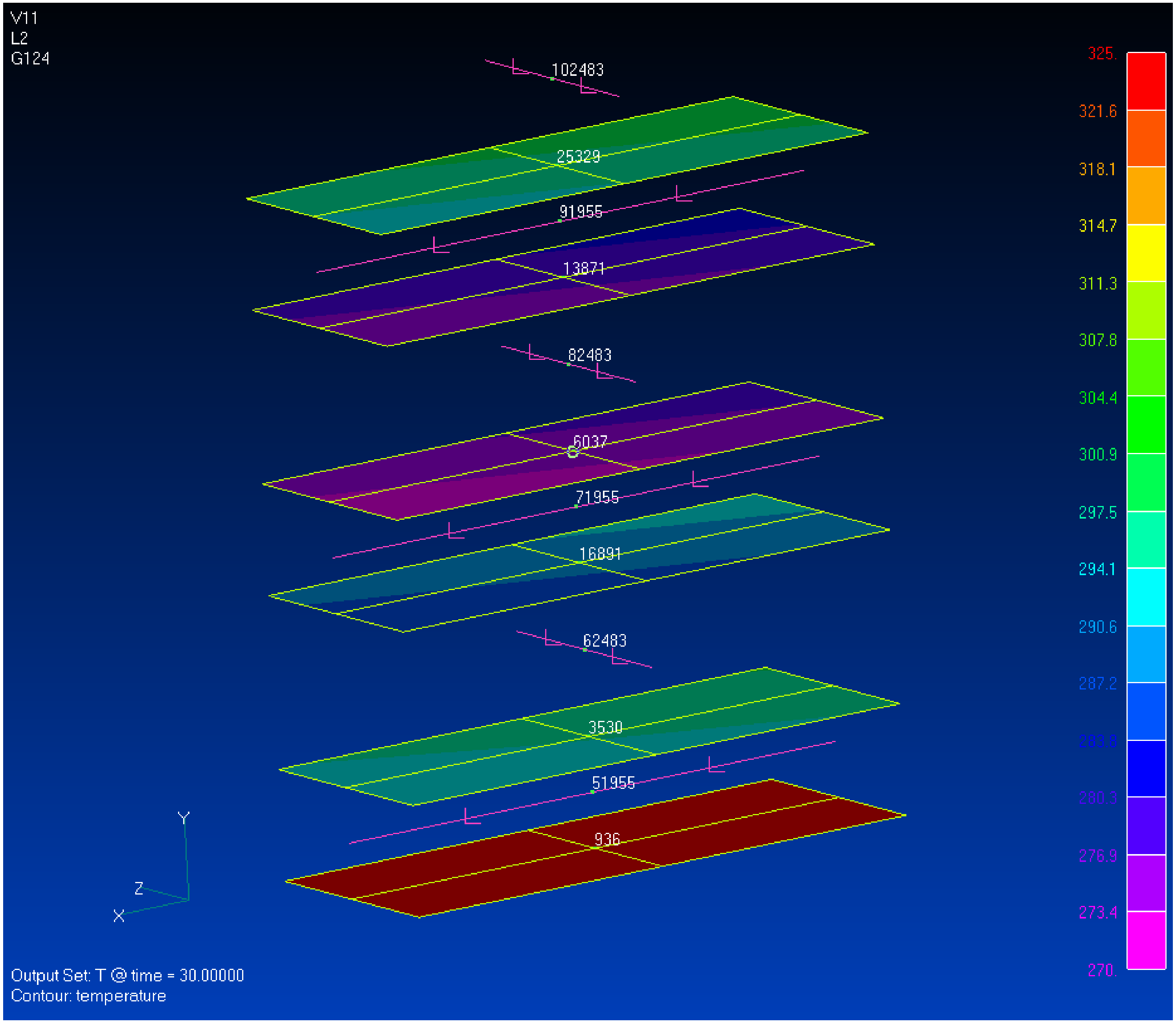


C

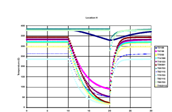

V11
L2
G123
101094
26190
15226
81094
6842
17752
61094
4335
1797
Y
Z
X
330.
325.
320.
315.
310.
305.
300.
295.
290.
285.
280.
275.
270.
265.
260.
255.
250.
Output Set: T @ time = 30.00000
Contour: temperature



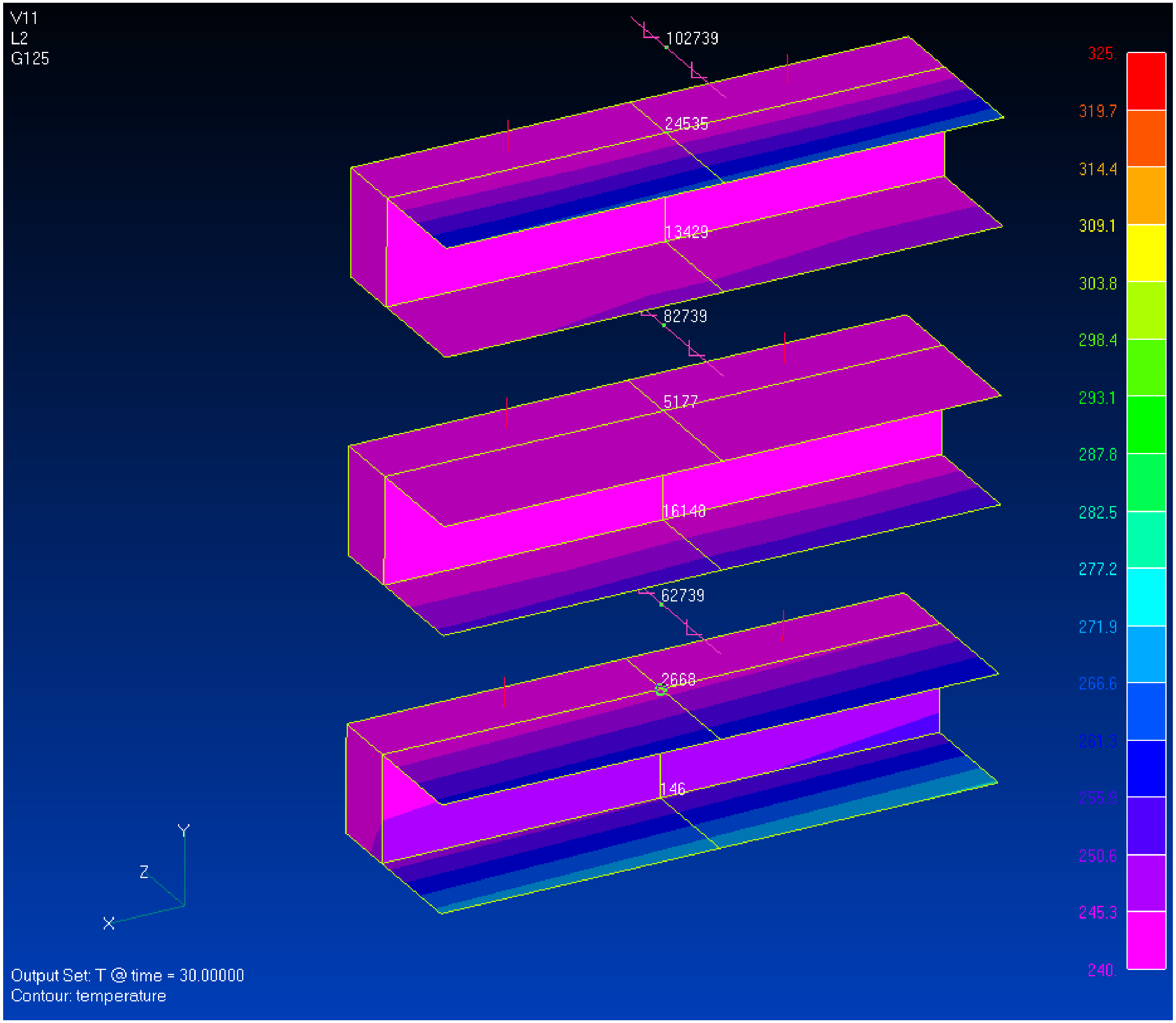
D

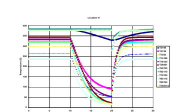


V11
L2
G124
102483
25329
91955
13871
82483
6037
71955
16891
62483
3530
51955
936
Y
Z
X
325.
321.6
318.1
314.7
311.3
307.8
304.4
300.9
297.5
294.1
290.6
287.2
283.8
280.3
276.9
273.4
270.
Output Set: T @ time = 30.00000
Contour: temperature

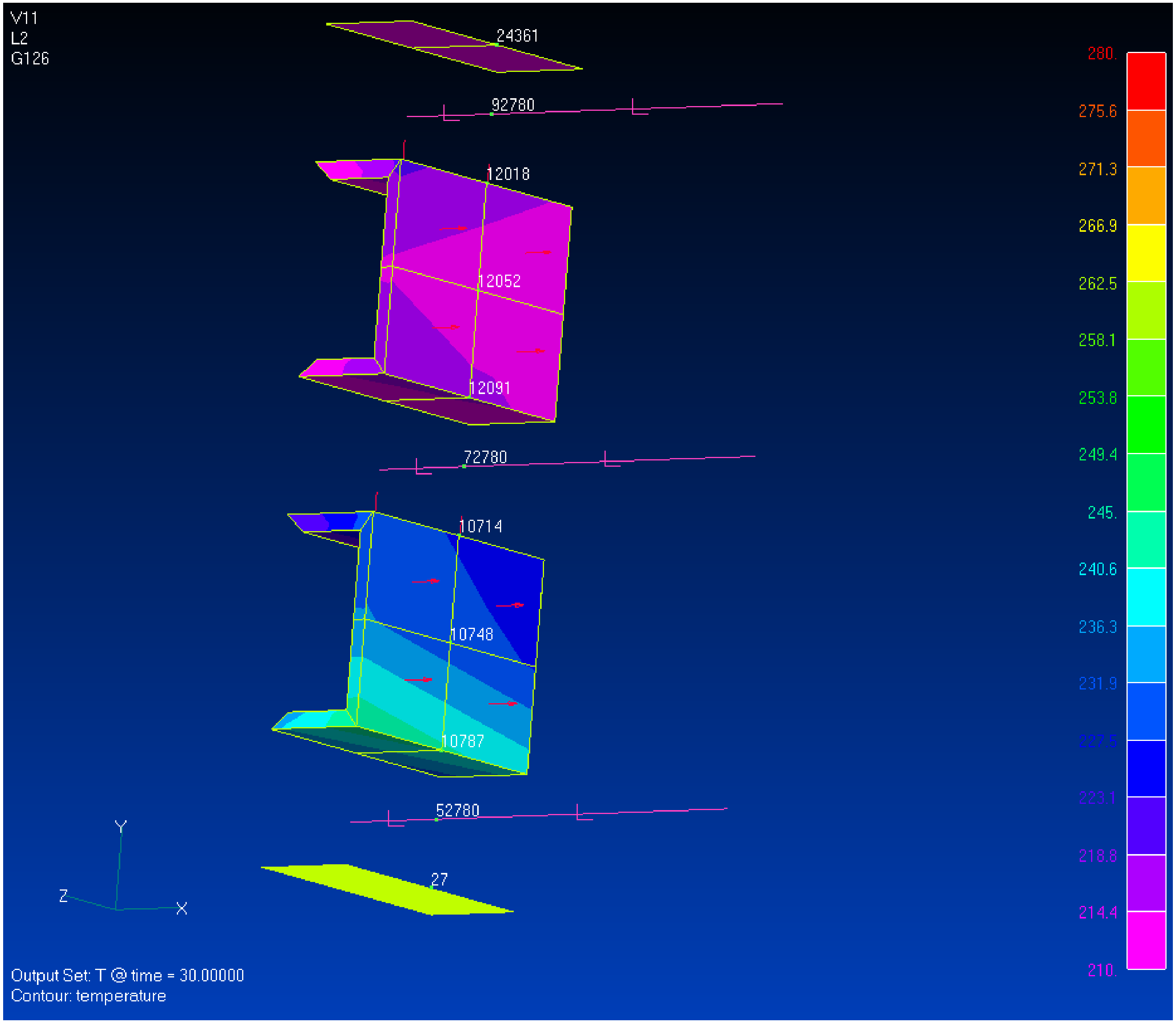


E

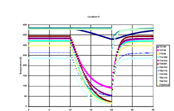

V11
L2
G125
102739
24535
13429
82739
5177
16148
62739
2668
146
325.
319.7
314.4
309.1
303.8
298.4
293.1
287.8
282.5
277.2
271.9
266.6
261.3
255.9
250.6
245.3
240.
Y
Z
X
Output Set: T @ time = 30.00000
Contour: temperature



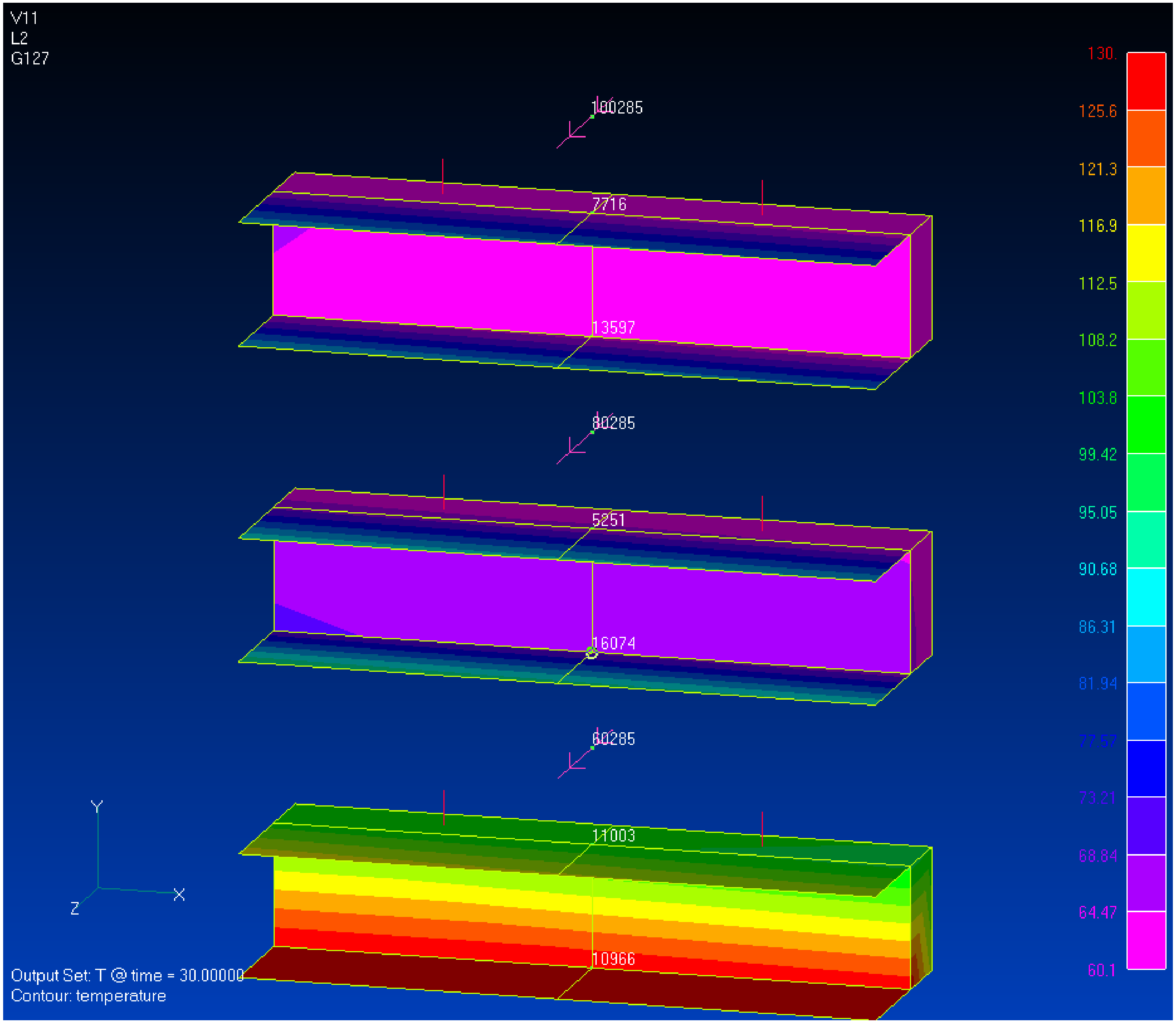
F

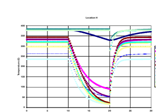


V11
L2
G126
24361
92780
12018
12052
12091
72780
10714
10748
10787
52780
27
Y
Z
X
280.
275.6
271.3
266.9
262.5
258.1
253.8
249.4
245.
240.6
236.3
231.9
227.5
223.1
218.8
214.4
210.
Output Set: T @ time = 30.00000
Contour: temperature

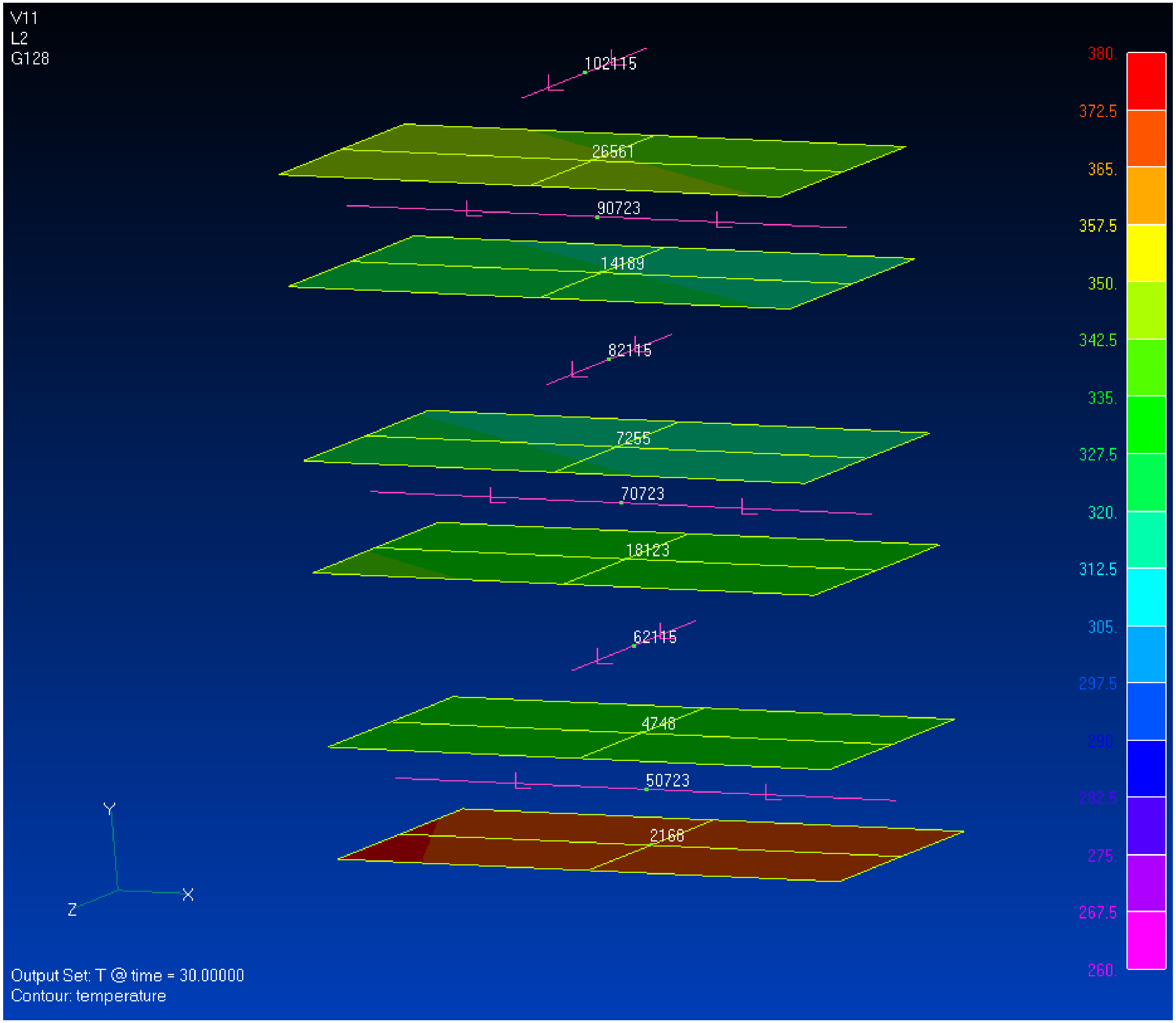


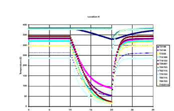
G


V11
L2
G127
100285
7716
13597
80285
5251
16074
60285
11003
10966
130.
125.6
121.3
116.9
112.5
108.2
103.8
99.42
95.05
90.68
86.31
81.94
77.57
73.21
68.84
64.47
60.1
Y
X
Z
Output Set: T @ time = 30.00000
Contour: temperature



H


V11
L2
G128
102115
26561
90723
14189
82115
7255
70723
18123
62115
4748
50723
2168
Y
X
Z
380.
372.5
365.
357.5
350.
342.5
335.
327.5
320.
312.5
305.
297.5
275.
267.5
260.
Output Set: T @ time = 30.00000
Contour: temperature



Letter of Appreciation for Phase 1

TAT Technologies Ltd.

To: Mr. Ron Behee,
President of NETWORK ANALYSIS INC.
Mr. John Pinckney
Technical Support Manager

April 04, 2005

Letter of Appreciation

We wish to express our heartfelt appreciation to Mr. John Pinckney for his assistance and support on the SINDA/FEMAP software we are using since 2002. We would like to mention the outstanding responsibility and professionalism of Mr. John Pinckney in carrying out the above activities.
TAT Technologies Ltd. is looking forward to closely cooperating with your company in the future.

Shlomo Ostersezer
TAT Chairmen, CEO

Mark Shmurak
Thermal Design Engineer