Second Sonic Boom Prediction Workshop: PCBoom Analysis

At the AIAA SciTech Conference

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Volpe The National Transportation Systems Center

Advancing transportation innovation for the public good

U.S. Department of Transportation
Office of the Secretary of Transportation
John A. Volpe National Transportation Systems Center

Outline

- Modeling Tools & Procedures
- Test Cases
  - LM1021
  - AxiBody
- Selected Results
- Propagation Evolution
- Observations & Suggestions
- Maneuvers & Focusing

PCBoom Suite of Programs

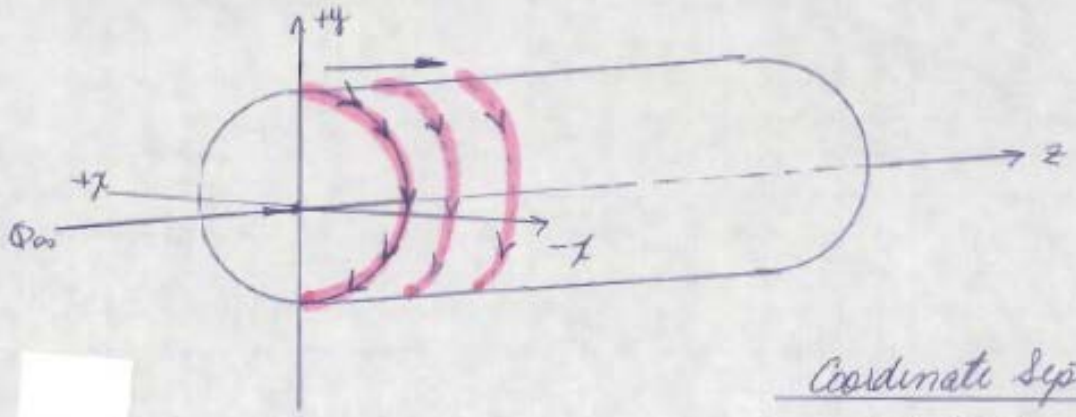
- FOBoom – "Focused Boom" propagation module
  - Considers vehicle operational state
  - Environmental Factors – Atmosphere & Terrain
  - Vehicle Source Characteristics
    - *Linear acoustic propagation* to large distances, accounts for atmospheric gradients via the method of geometrical acoustics. The amplitude of the acoustic disturbance is governed by the change in area of ray tubes (bundles of differentially separated rays) and local acoustic impedance (environmental parameters).
    - *Non-linear steepening* of the boom signature is based on the "advance" or "age" parameter (part of the geometrical acoustics solution) and non-linear distortion of the boom signature consists of an advance proportional to its original strength times the age parameter.
- PCBurg – Interactive graphical Burgers' solver that uses ray path info from FOBoom and computes the effect of molecular relaxation on shock structures on sonic boom signature evolution; computes loudness metrics
- PCBFoot – Organizes FoBoom output, applies "simple" Taylor shock structures to shocks and computes loudness metrics
- WCon6 – Interactive footprint and signature display module

Modeling Tools & Procedures

- Analysis utilized PCBoom Version 6
  - FOBoom V6.7a-VS15 (Volpe version)
  - Different allocatable array handling for cylinder inputs
  - Minor i/o formatting differences
- Cylinder Preparation
  - Axial stations matching at all azimuths
    - Linear Interpolation procedure
    - Use Azimuth = 40 deg as “template” for axial station distribution
  - PCBoom6 (X,Y,Z) data formats & sequencing
  - Units of Feet
  - For PCBFoot & WCon, limit of 203 points (ground boom signature)
    - Used all points in LM1021; Thinned out AxiBody points
  - No point limits in FOBoom or PCBurg solutions

10.14.91

MSBOOM Cylinder Input Definition:



Coordinate System:

+x: out right wing

-x: out left wing

+y: vertically up

+z: axially in freestream direction

Quikplot File Format:

```
> GEOM
> CNTLPTS
> SEC
    X
    Y
    Z
    :
< SEC
< CNTLPTS
< GEOM
> RESULTS
> SOLN
> SEC
    PRATR
    :
< SEC
< SOLN
< RESULTS
```

X, Y, Z are coordinate labels

PRATR is P/P_∞ label

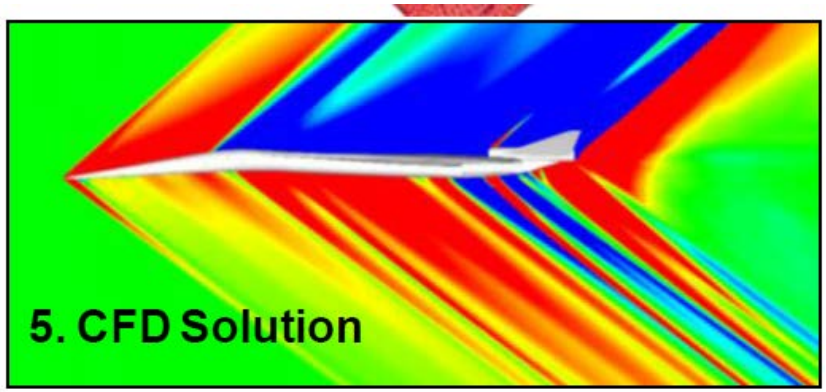
Notes:

- Circles are from top to bottom on -x side (left wing).
- Only 1/2 cylinder input (left wing, -x)
- Cylinder axis must be aligned with the freestream (not necessarily grid coords.)
- 2 stations must increase sequent.
- Must have 2-3 ambient condition stations @ start of cylinder ($P/P_\infty = 1.0$)

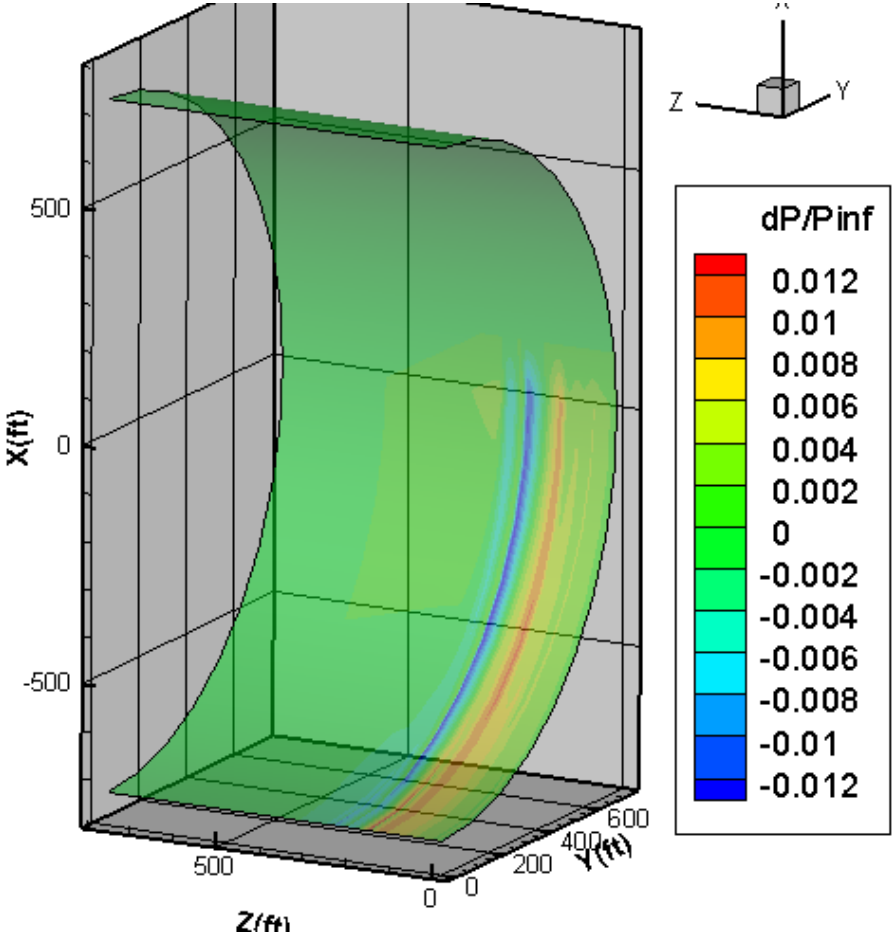
Test Cases

- LM2021 Configuration

  From AIAA 2013- Morgenstern et al.



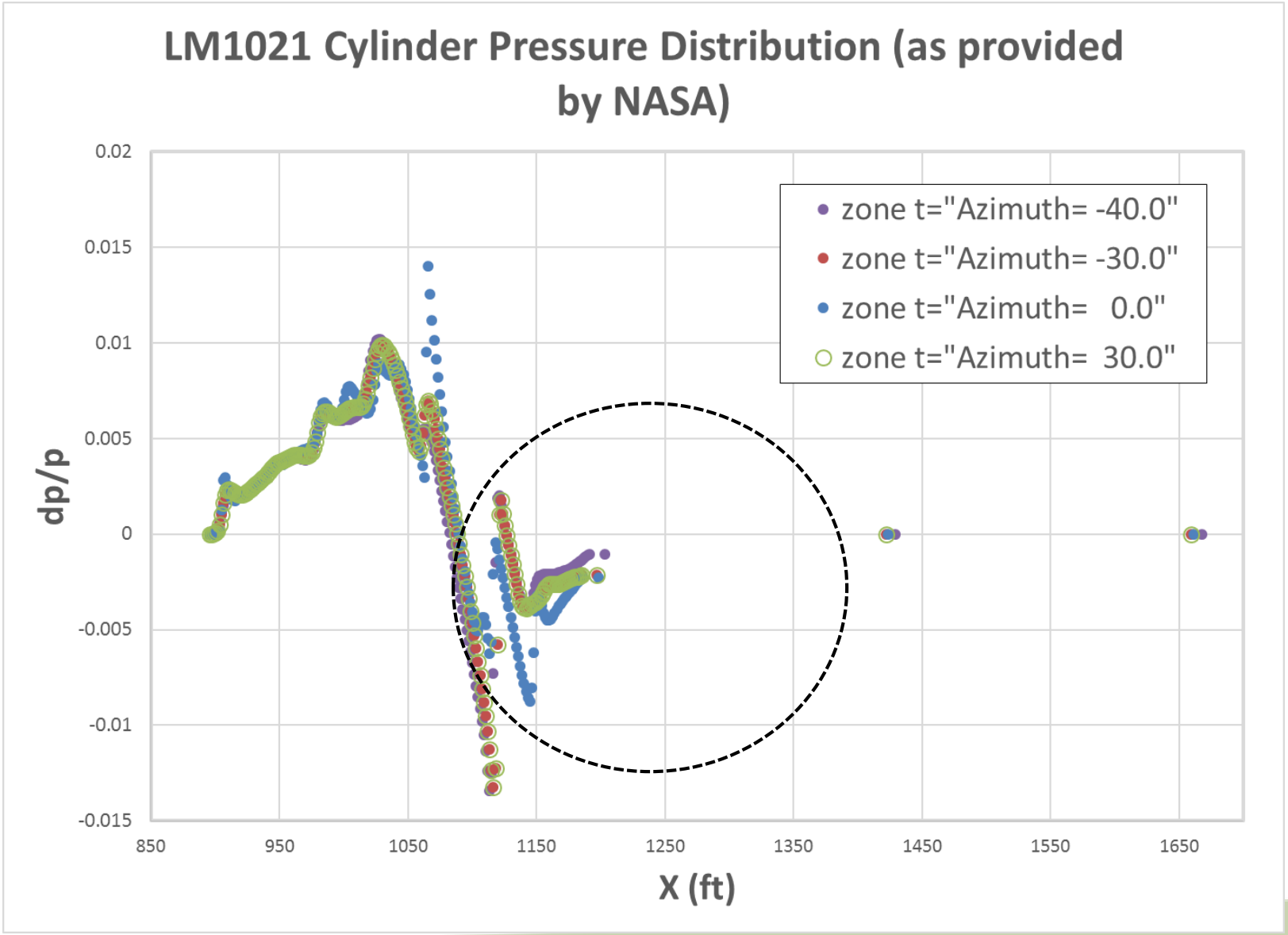
Lower Half of Solution Provided



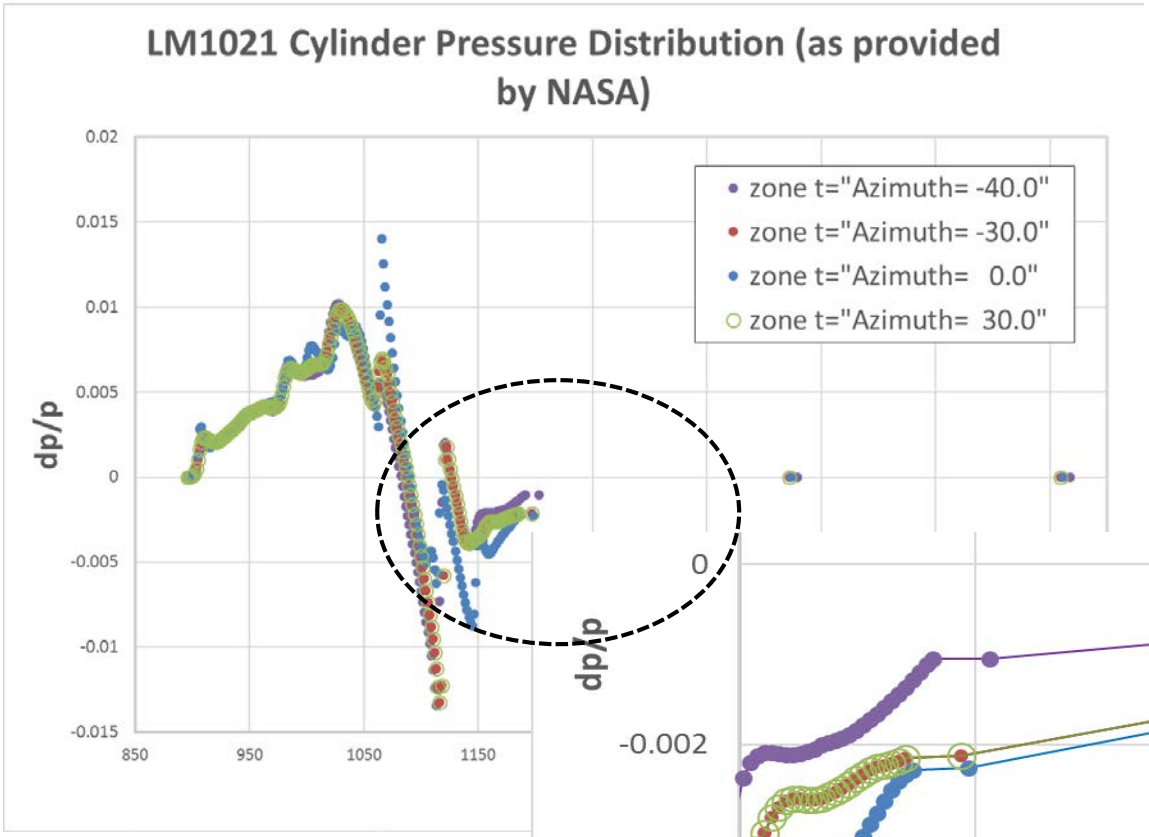
Mach = 1.6, Steady Flight
Alt = 55,000 Ft.
R/L start = 3.1299
Ground Refl = 1.9
Ground Alt Varies
Multiple Atmospheres
  Standard
  Atm 1
  Atm 2

} Plus Hydrostatic Pressure Variant

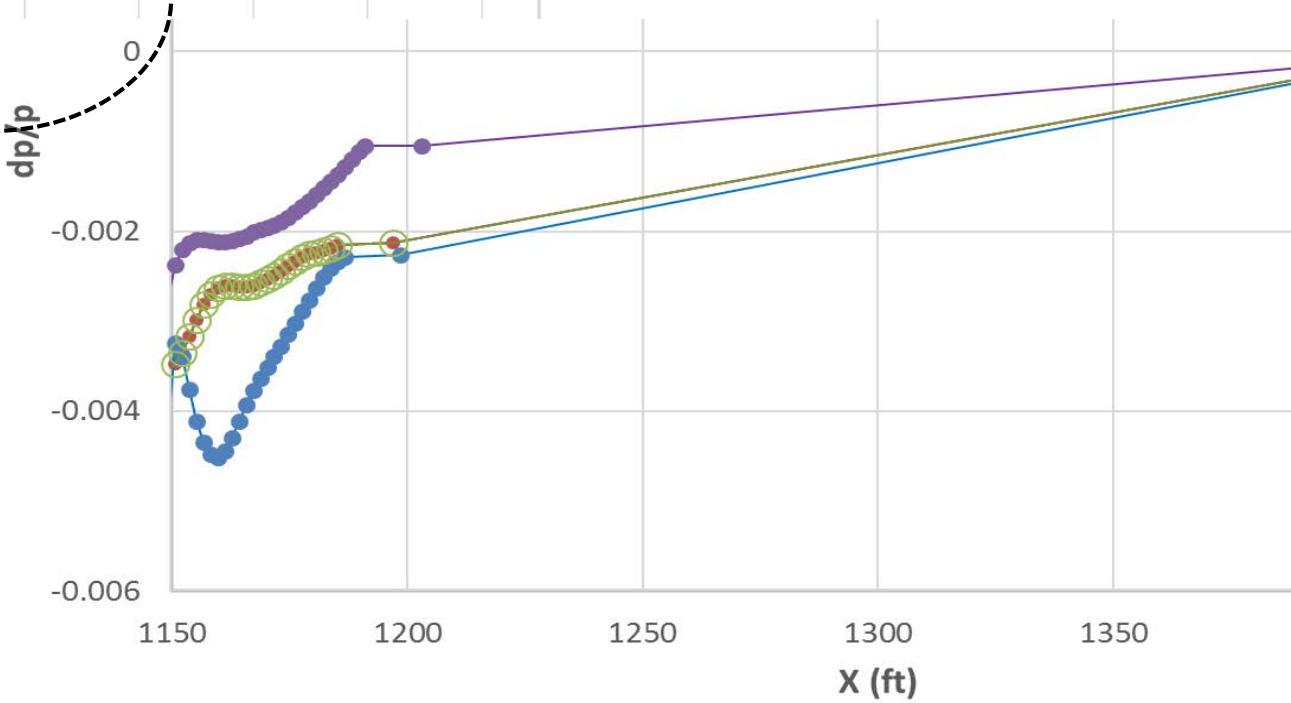
Cylinder Preparation – LM1021



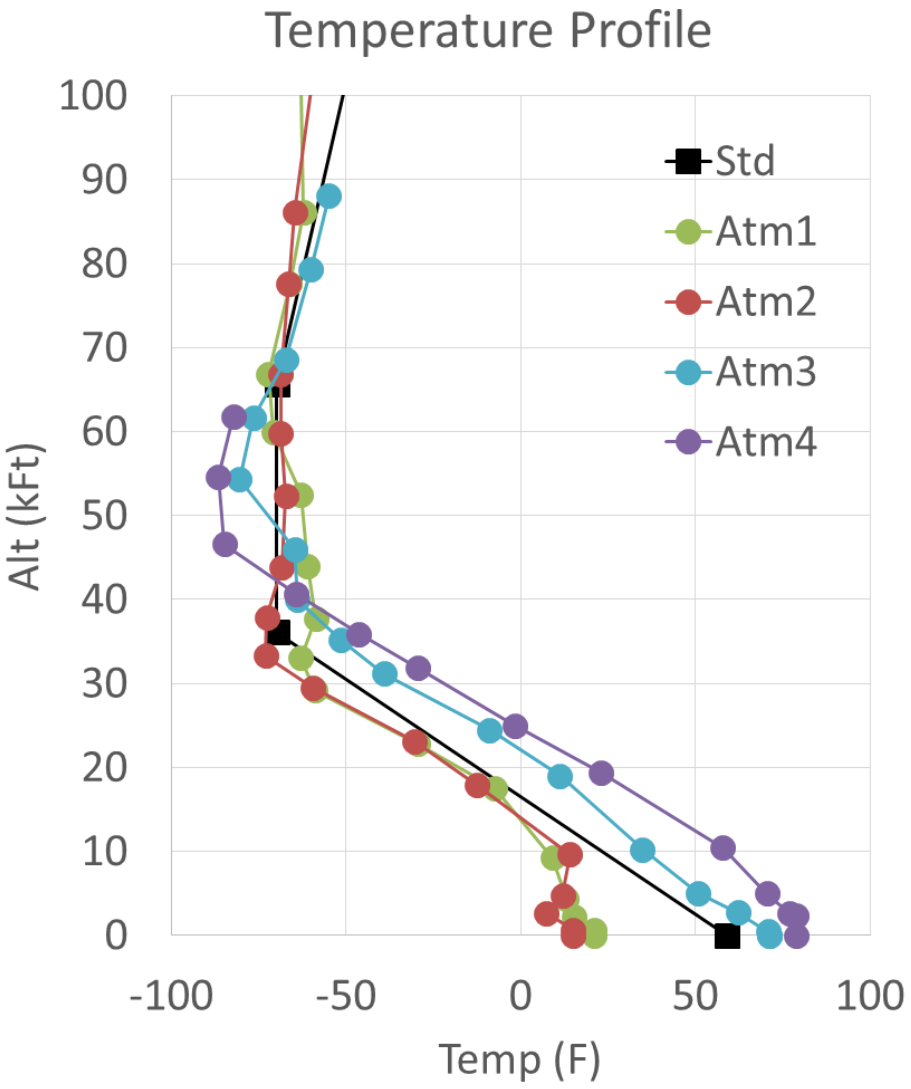
Cylinder Preparation – LM1021

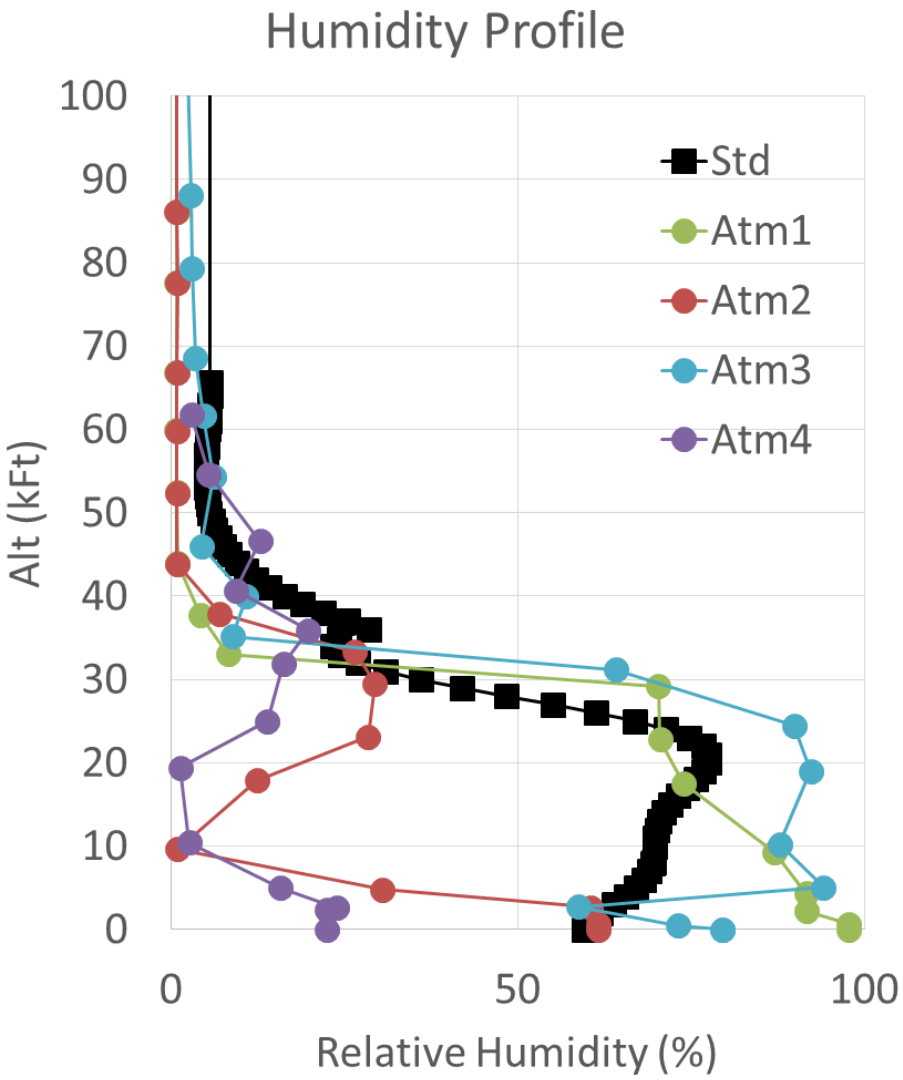


Zoom in on Aft End

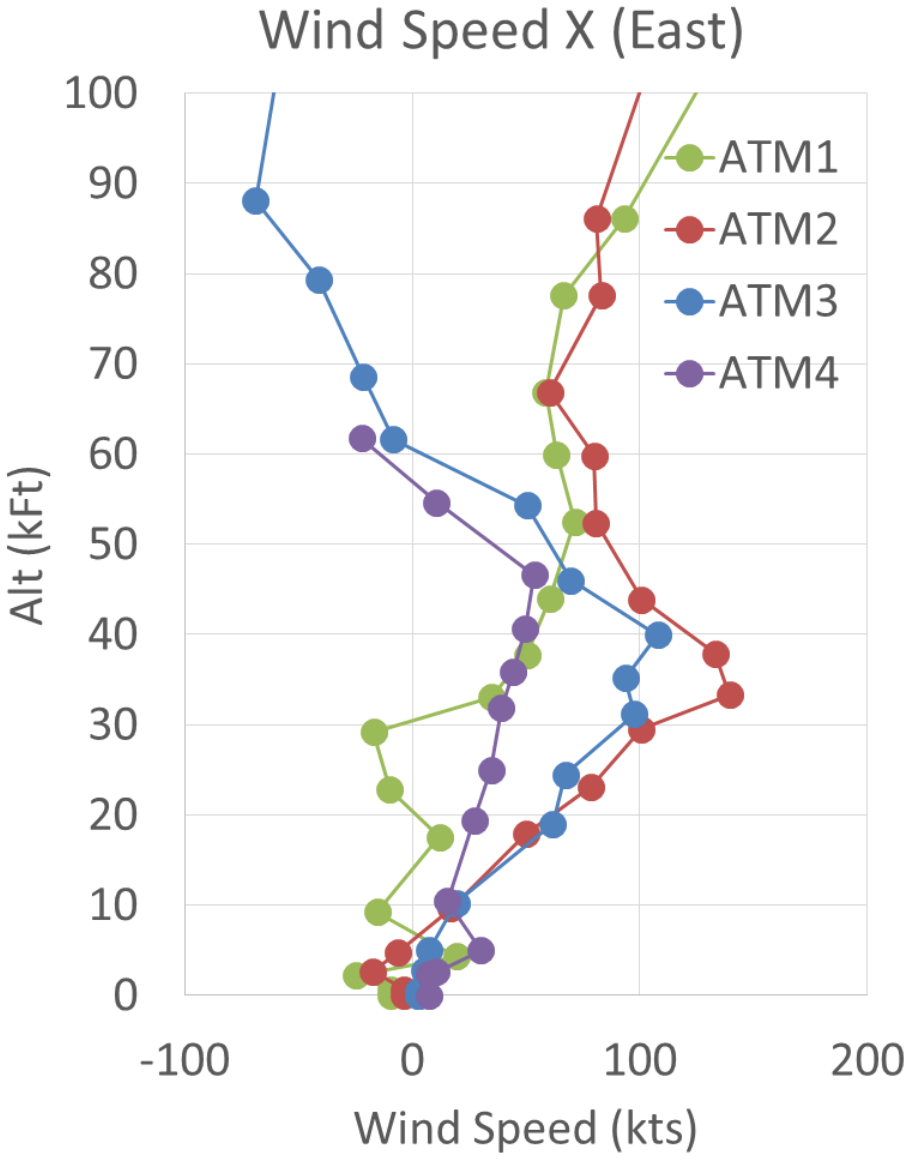


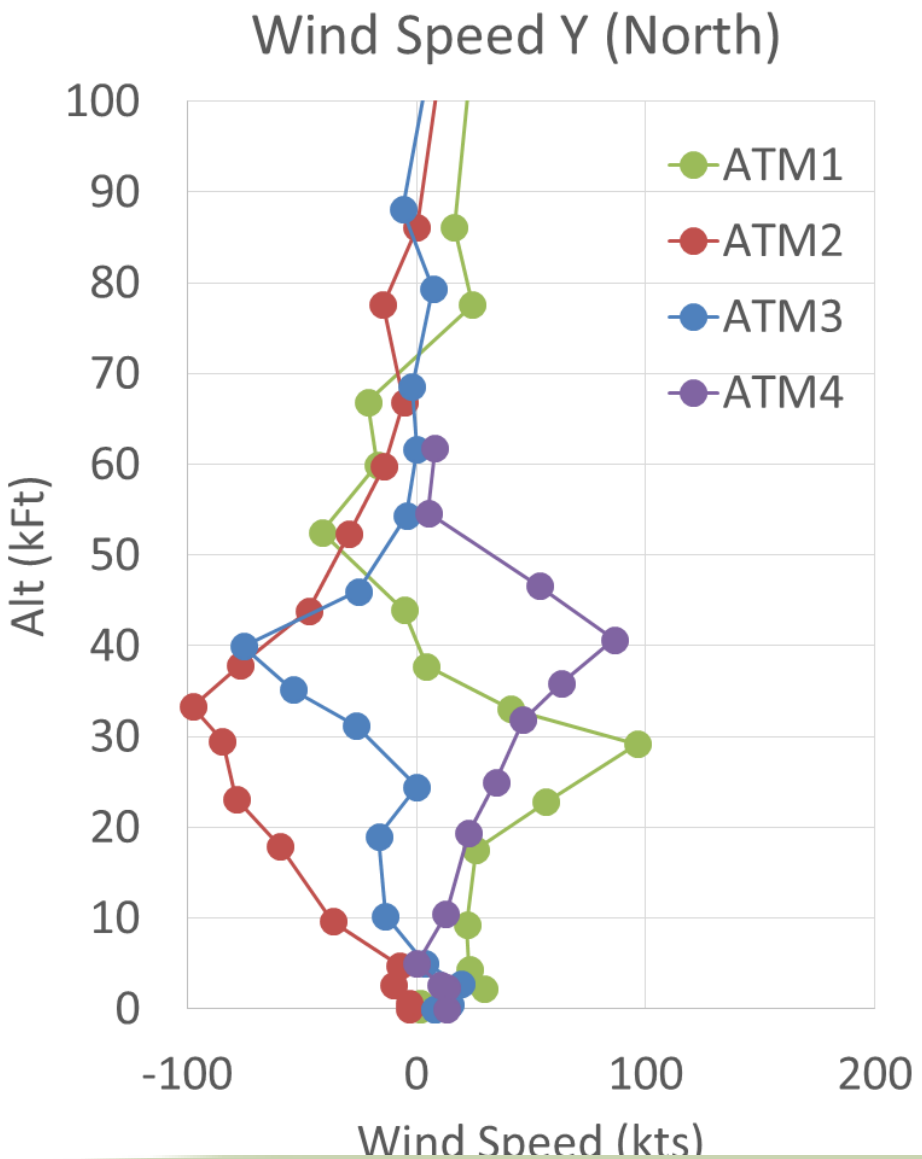
Atmospheres



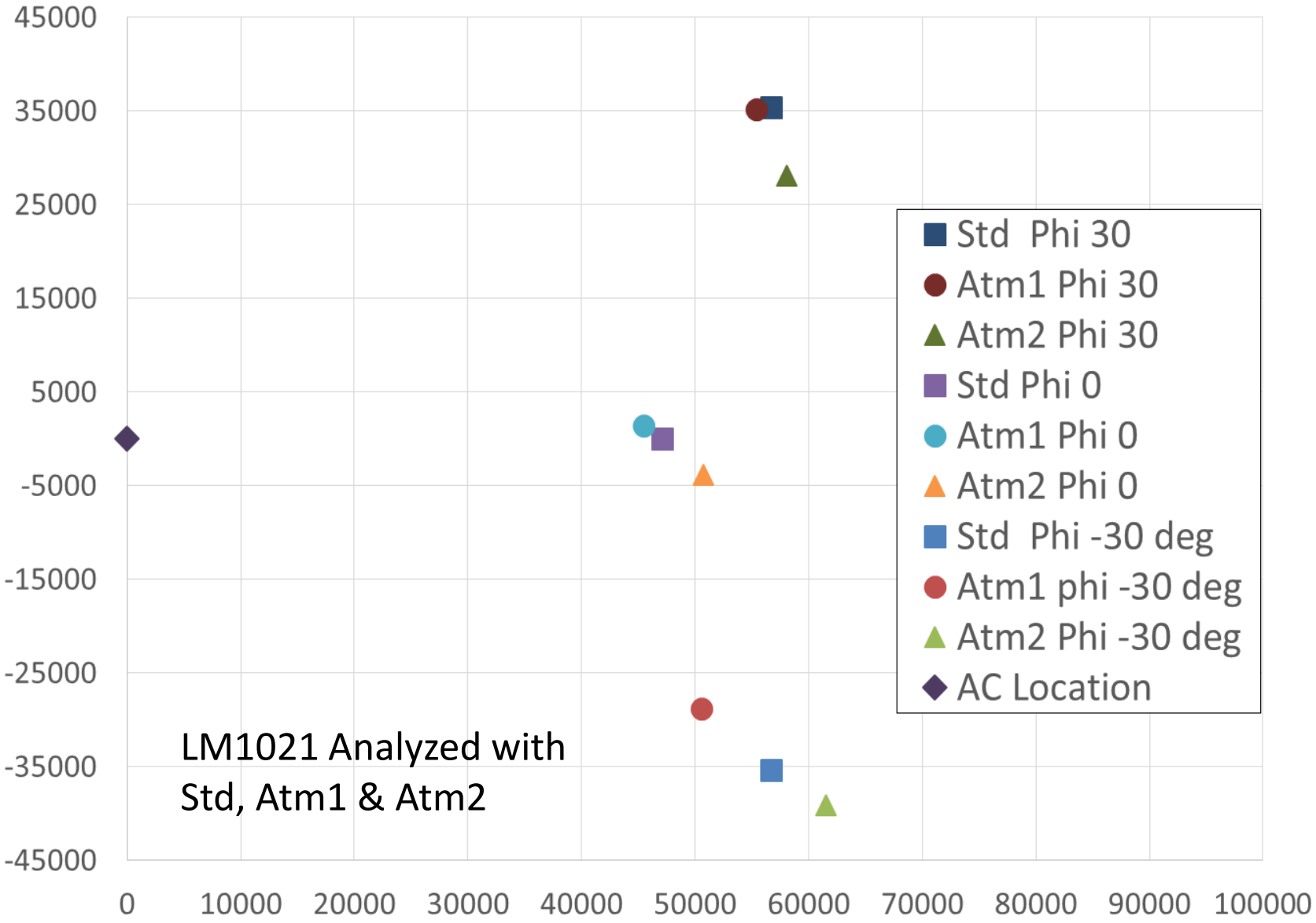


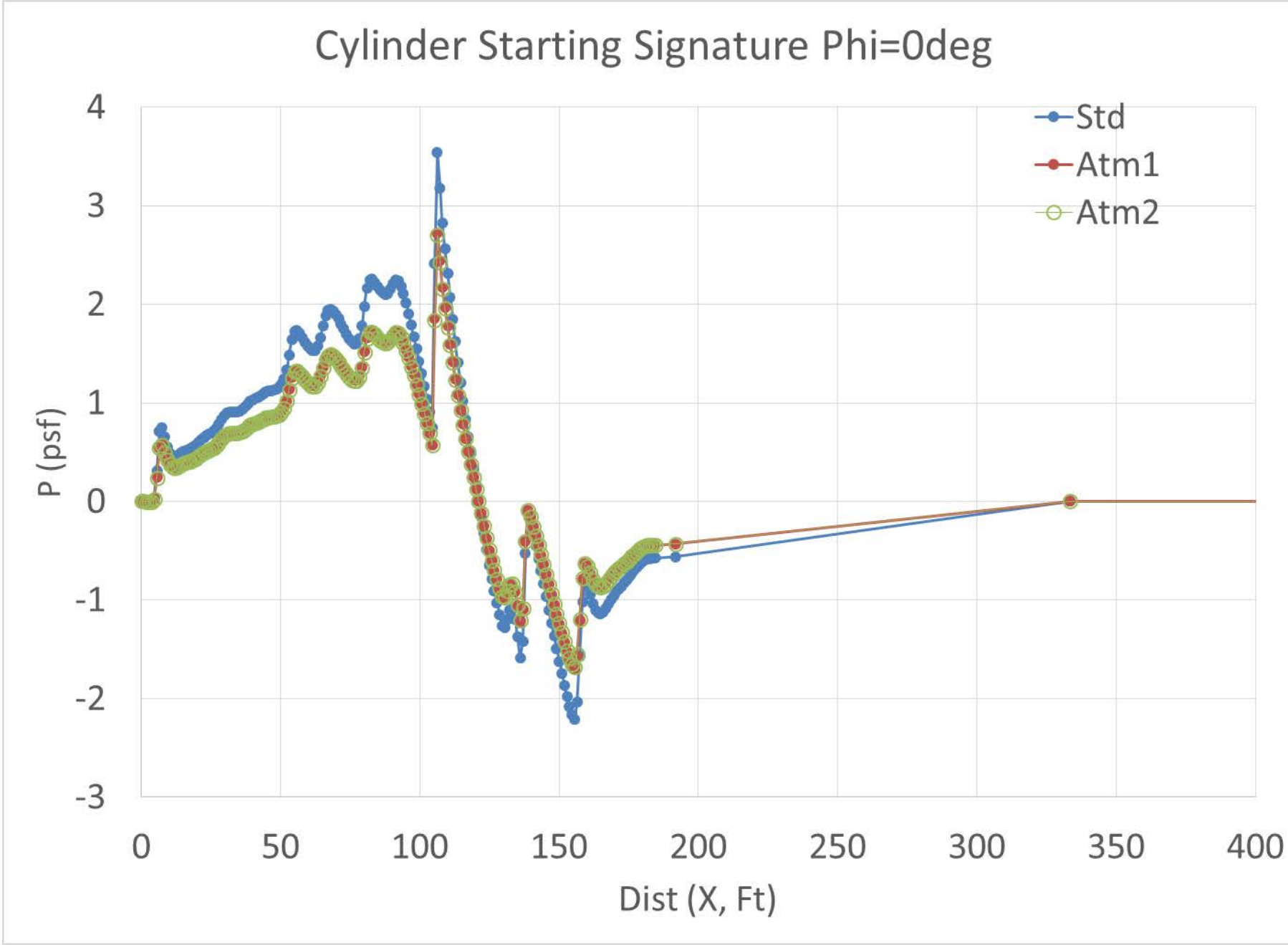
Atmospheres

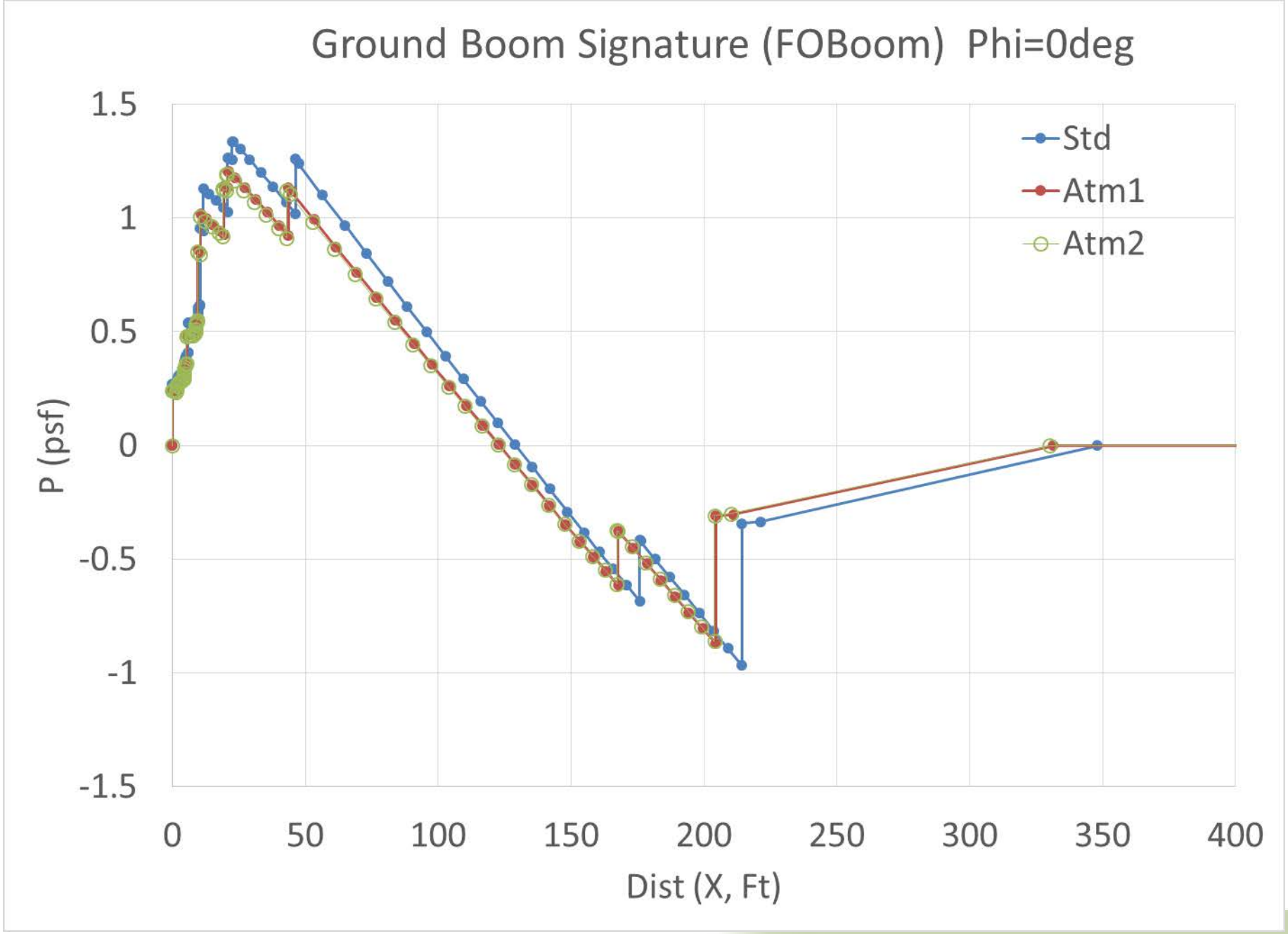




Ground Boom Intercept Location (x,y) Ft.




Cylinder Starting Signature Phi=0deg
Std
Atm1
Atm2
P (psf)
4
3
2
1
0
-1
-2
-3
0
50
100
150
200
250
300
350
400
Dist (X, Ft)


Ground Boom Signature (FOBoom) Phi=0deg
1.5
1
0.5
0
-0.5
-1
-1.5
P (psf)
0
50
100
150
200
250
300
350
400
Dist (X, Ft)
Std
Atm1
Atm2

LM1021 FOBoom Linear (no Relax.) Lateral Cutoff Angles plus Azi=0

Phi	Atmo	X-Gnd	Y-gnd	Pmax	Pmin	Csel	Asel	PLdB	Ray Ang	Elev Ang
-50.34	Std	105747	-101679	0.88	-0.64	100	80.8	97.7	313.9	4.9
50.34	Std	105747	101679	0.88	-0.64	100	80.8	97.7	226.1	4.9
-74.50	Atm1	131336	-149012	1.04	-0.79	102.2	81.5	99.2	320.3	6.1
56.91	Atm1	129038	136263	0.41	-0.3	93.3	69.8	87.9	223.7	13.3
-58.83	Atm2	184928	-191914	0.26	-0.18	88.5	61.3	80.2	316.9	19.9
65.25	Atm2	147801	144185	0.75	-0.54	99.1	79	95.9	221.4	4.1

PCBoom Algorithm to determine cutoff: Propagate primary ray – downward only - then other rays. See where one of the rays cuts off, then back off towards centerline.

Special Cases: Dive where there is no lateral cutoff (i.e. F-18 Dive Crescents)

Over the Top Booms where cutoff occurs later

LM1021 PCBurg Molecular Relaxation

- Utilized FOBoom to determine Ray Paths
- PCBurg is interactive Program
- Propagates Signatures along Prescribed Ray
- Utilizes Atmospheric Parameters as output by FOBoom
- Cases Analyzed (without and with hydrostatic pressure atmo)
  - Azi: -30, 0, +30 deg. Atmo: Std, Atm1, Atm2. SR:10kHz, 25.6kHz, 51.2kHz
  - Azi: Lateral Cutoff. Atmo: Std, Atm1, Atm2. Sampling Rate: 10kHz
  - Azi: -30, 0, +30 deg. Atmo HySP: Std, Atm1, Atm2. SR: 10 kHz, 25.6 kHz
  - Azi Lateral Cutoff. Atmo HySP: Std, Atm1, Atm2. SR: 10 kHz
- Burgers Propagation started at 54,000 Ft Altitude

LM1021 Std (No HySP)

Phi	Atmo	Sampling Rate	Pmax	Esel	Csel	Asel	PLdB	Rise Time	Thickness
-30	Std	10000.0	1.16	116.54	99.55	75.85	90.32	0.00295	0.00690
-30	Std	25600.0	1.17	116.57	99.55	77.03	91.41	0.00193	0.00703
-30	Std	51200.0	1.17	116.65	99.48	77.55	92.02	0.00149	0.00734
0	Std	10000.0	1.12	117.09	98.87	76.28	90.31	0.00484	0.01470
0	Std	25600.0	1.26	118.25	99.55	77.58	92.18	0.00481	0.01652
0	Std	51200.0	1.26	118.27	99.49	78.22	92.79	0.00452	0.01713
30	Std	10000.0	1.16	116.54	99.55	75.85	90.32	0.00295	0.00690
30	Std	25600.0	1.17	116.57	99.55	77.03	91.41	0.00193	0.00703
30	Std	51200.0	1.17	116.65	99.48	77.55	92.02	0.00149	0.00734

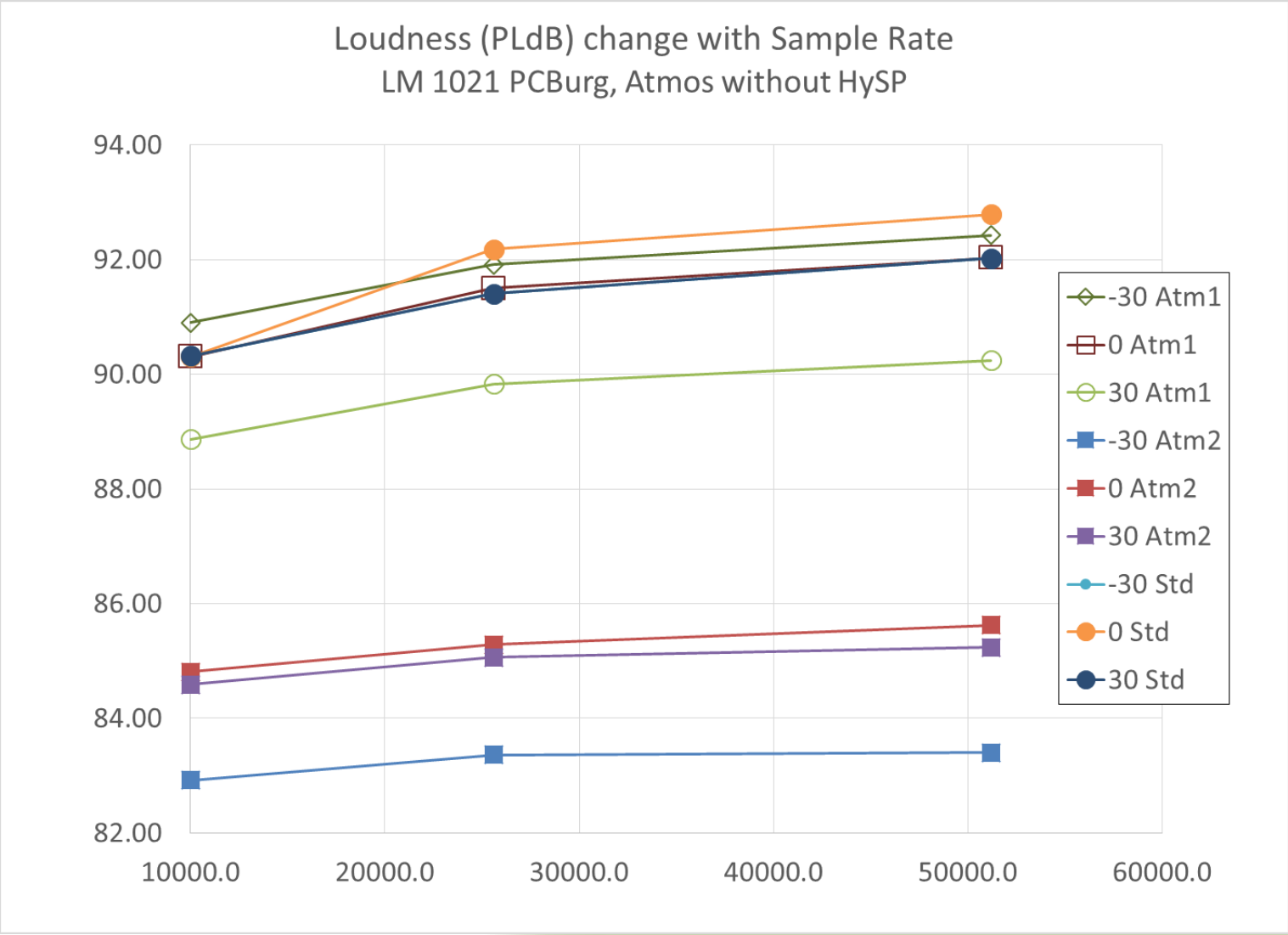
LM1021 Atm1 (No HySP)

Phi	Atmo	Sampling Rate	Pmax	Esel	Csel	Asel	PLdB	Rise Time	Thickness
-30	Atm1	10000.0	1.11	115.99	99.32	76.92	90.90	0.00262	0.00660
-30	Atm1	25600.0	1.12	116.06	99.32	78.07	91.91	0.00173	0.00672
-30	Atm1	51200.0	1.12	116.15	99.24	78.54	92.43	0.00141	0.00705
0	Atm1	10000.0	1.12	117.09	98.87	76.28	90.31	0.00484	0.01470
0	Atm1	25600.0	1.13	117.11	98.88	77.61	91.50	0.00406	0.01535
0	Atm1	51200.0	1.13	117.13	98.82	78.15	92.03	0.00385	0.01596
30	Atm1	10000.0	0.97	114.85	98.00	74.80	88.87	0.00297	0.00700
30	Atm1	25600.0	0.98	114.92	98.00	75.82	89.83	0.00210	0.00715
30	Atm1	51200.0	0.98	115.01	97.91	76.23	90.24	0.00178	0.00750

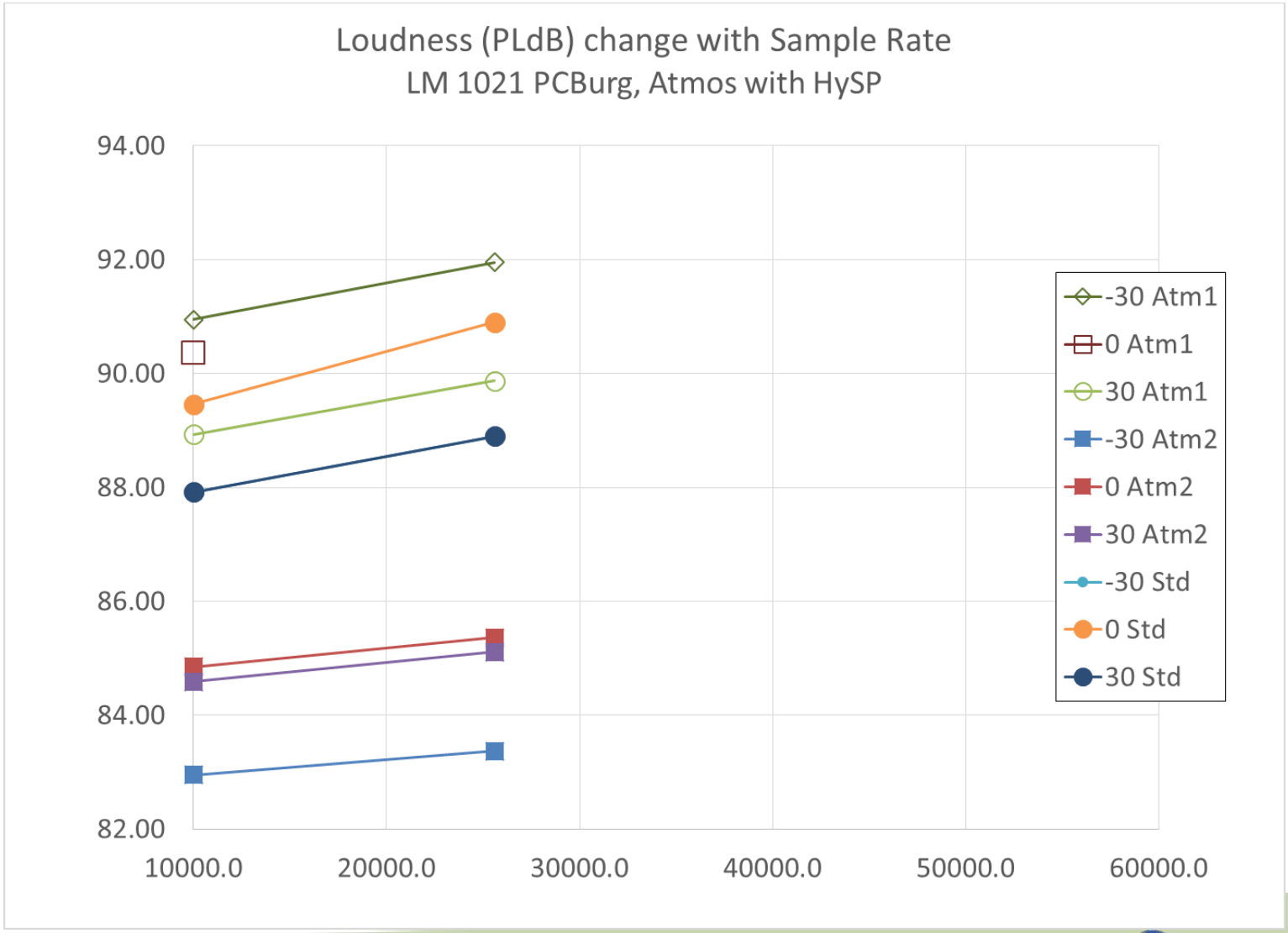
LM1021 Atm2 (No HySP)

Phi	Atmo	Sampling Rate	Pmax	Esel	Csel	Asel	PLdB	Rise Time	Thickness
-30	Atm2	10000.0	0.91	114.63	96.54	68.40	82.92	0.00516	0.00910
-30	Atm2	25600.0	0.91	114.70	96.48	68.83	83.36	0.00468	0.00934
-30	Atm2	51200.0	0.91	114.79	96.36	68.84	83.40	0.00455	0.00963
0	Atm2	10000.0	1.06	116.88	97.46	69.86	84.81	0.00724	0.01440
0	Atm2	25600.0	1.08	116.90	97.40	70.51	85.28	0.00683	0.01492
0	Atm2	51200.0	1.07	116.92	97.31	70.66	85.62	0.00678	0.01551
30	Atm2	10000.0	0.99	115.39	97.61	69.99	84.59	0.00460	0.00820
30	Atm2	25600.0	0.99	115.46	97.55	70.51	85.06	0.00414	0.00848
30	Atm2	51200.0	0.99	115.55	97.43	70.53	85.24	0.00402	0.00875

LM1021: Sampling Rates

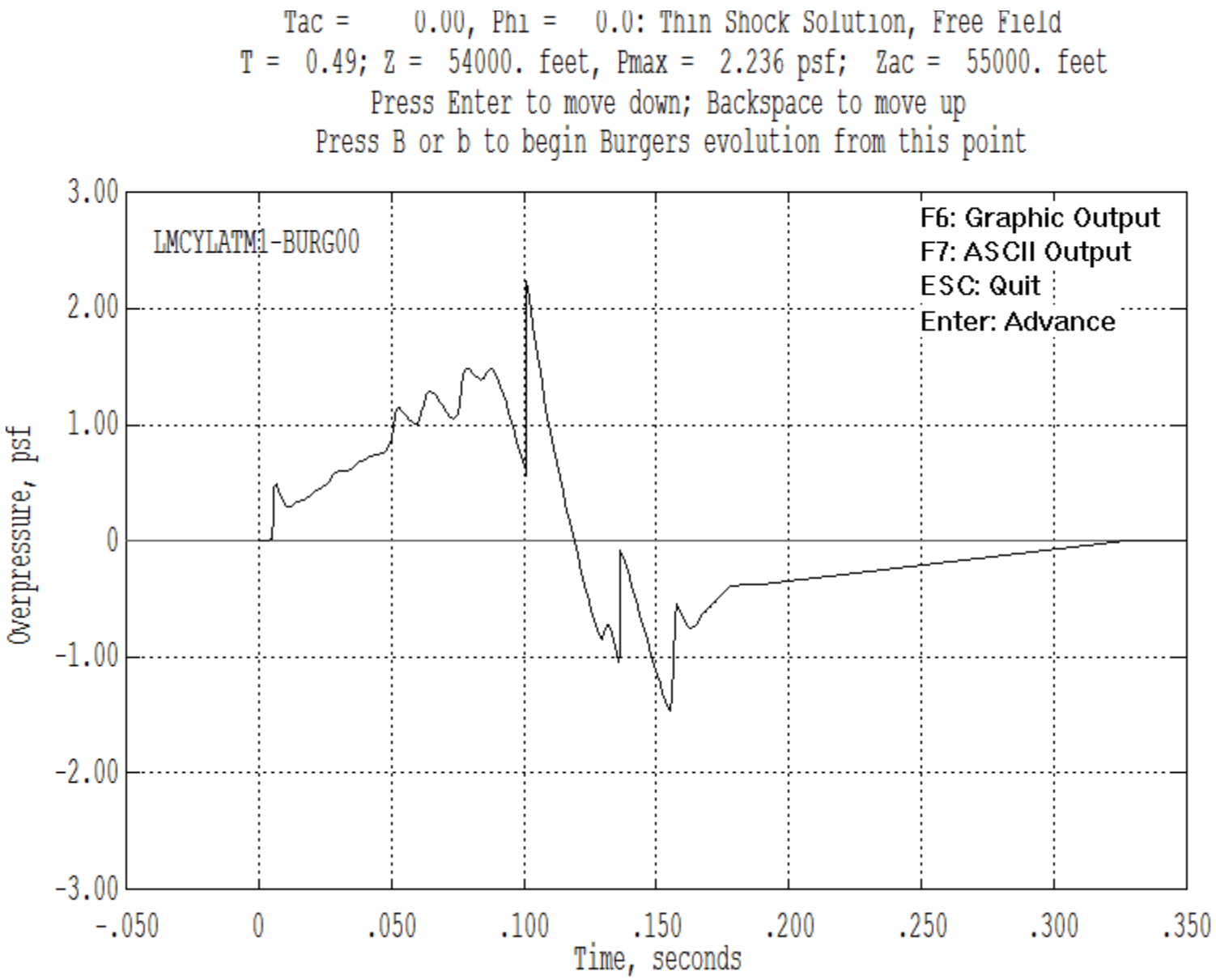


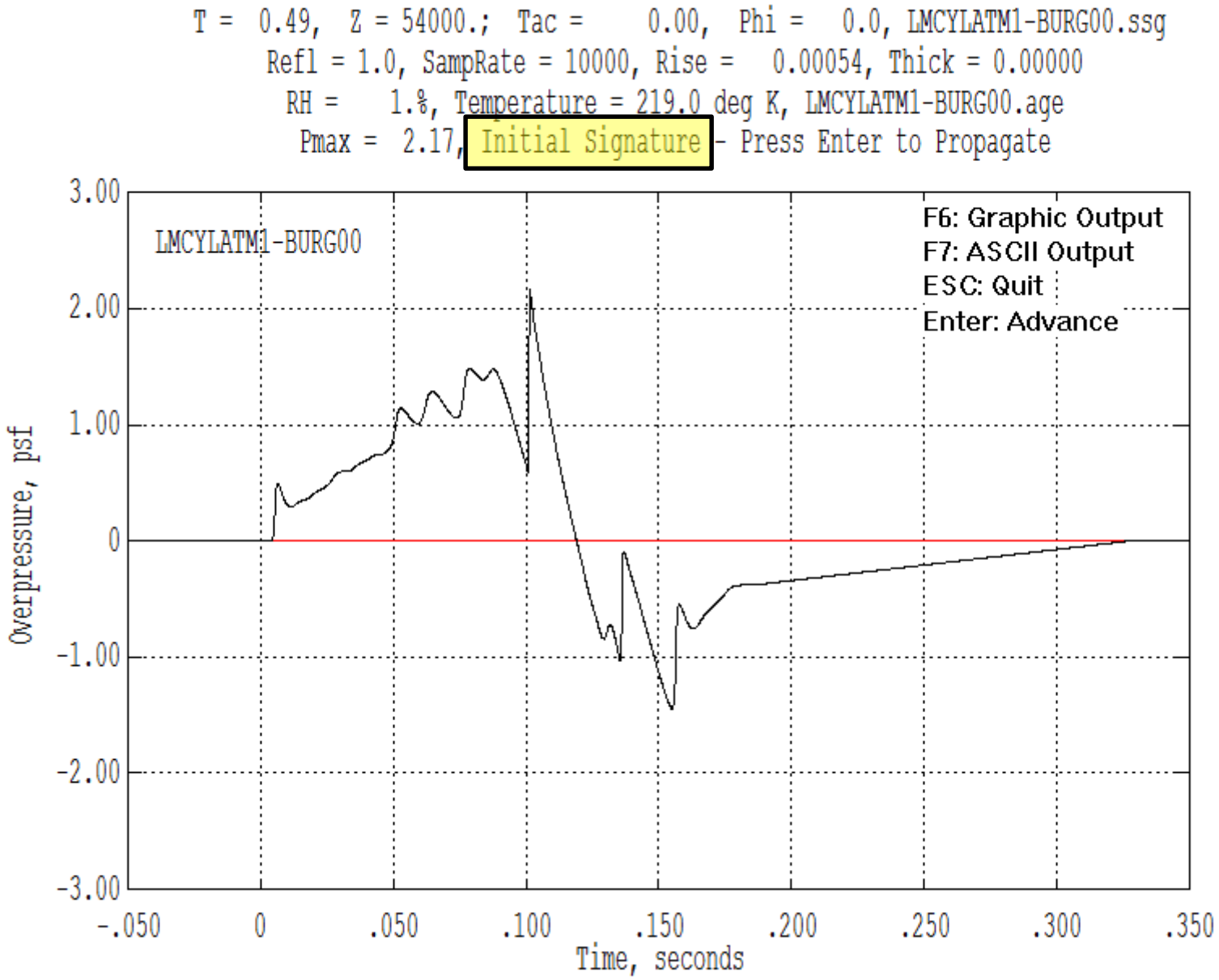
LM1021: Sampling Rates No HySP

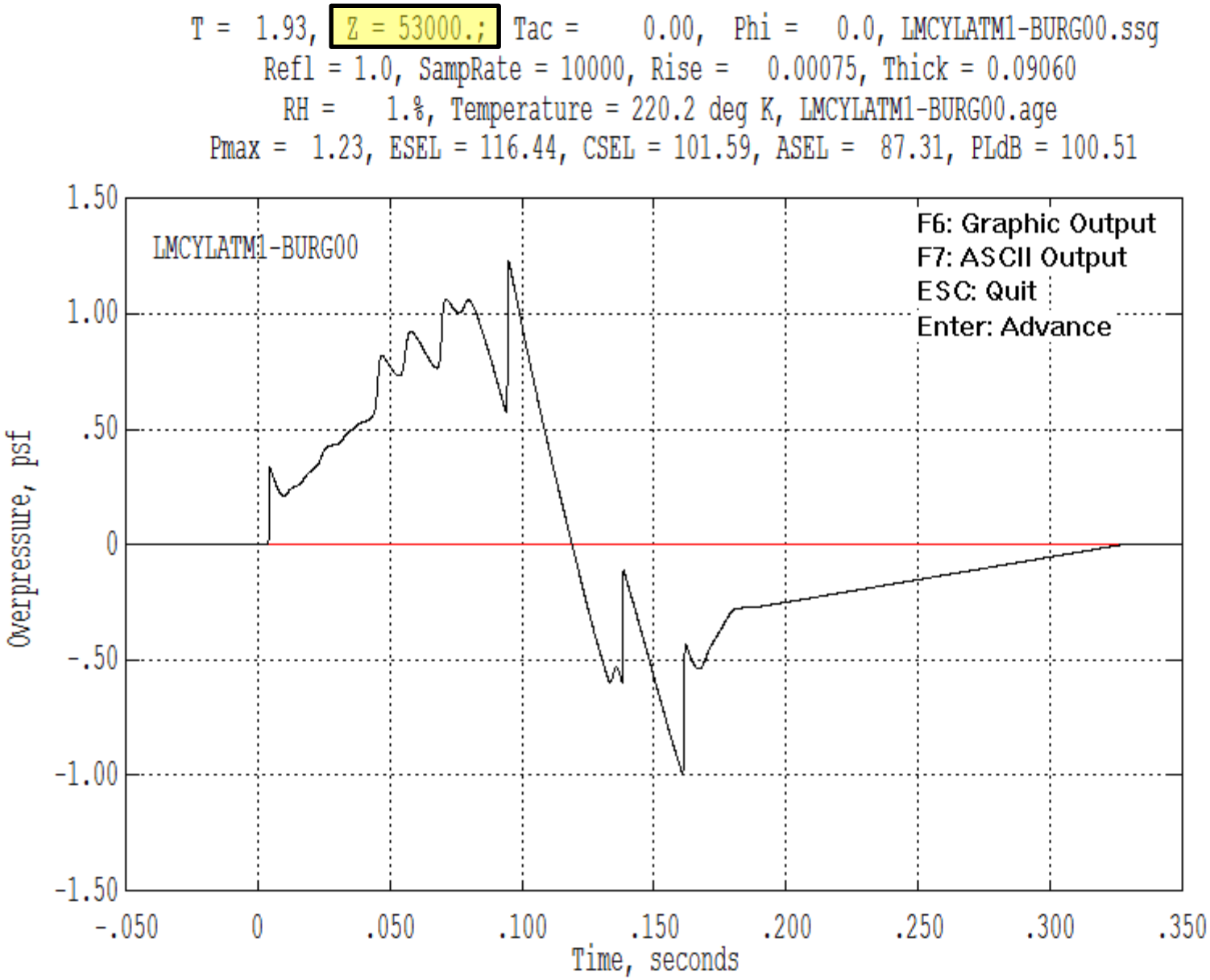


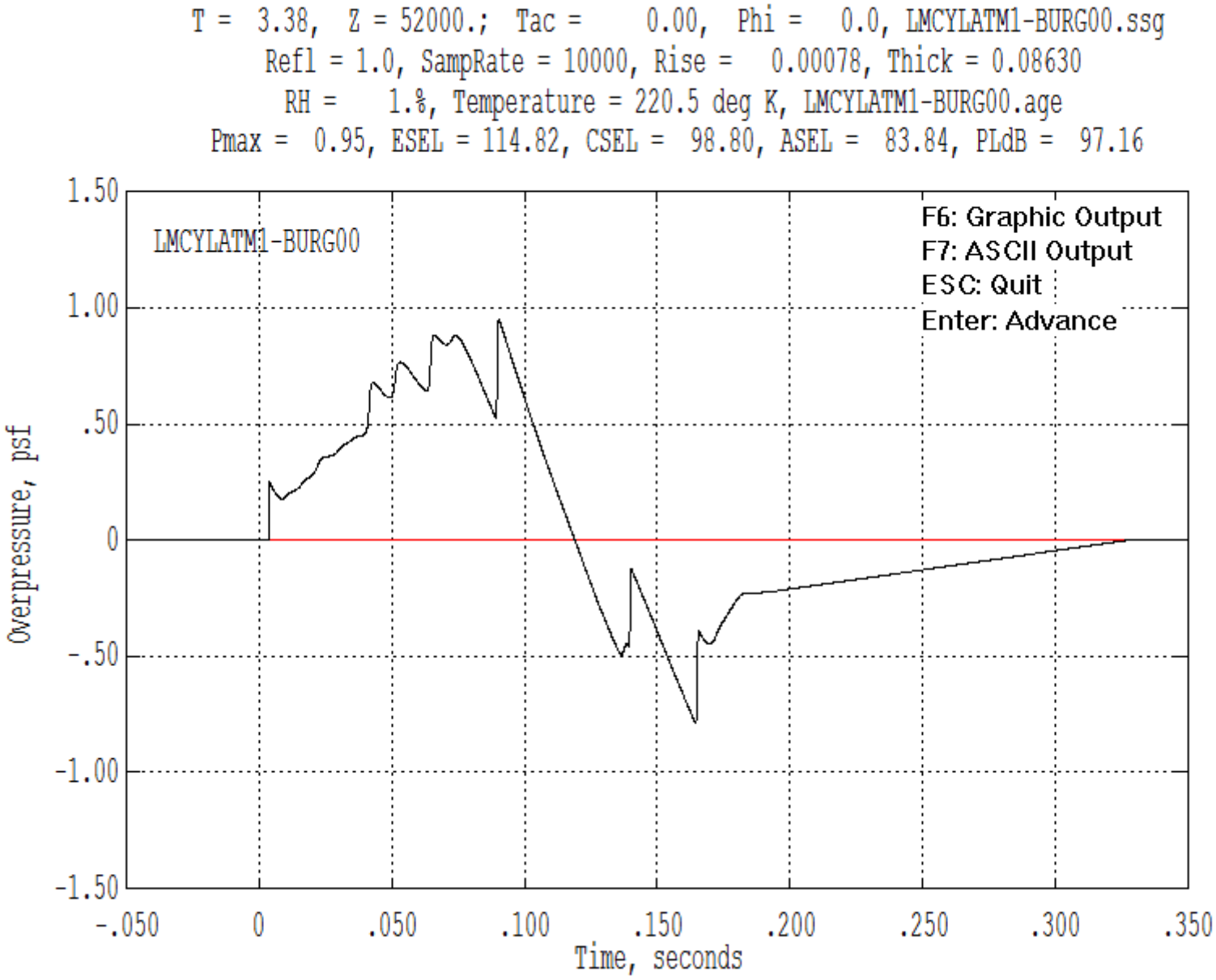
Propagation Evolution

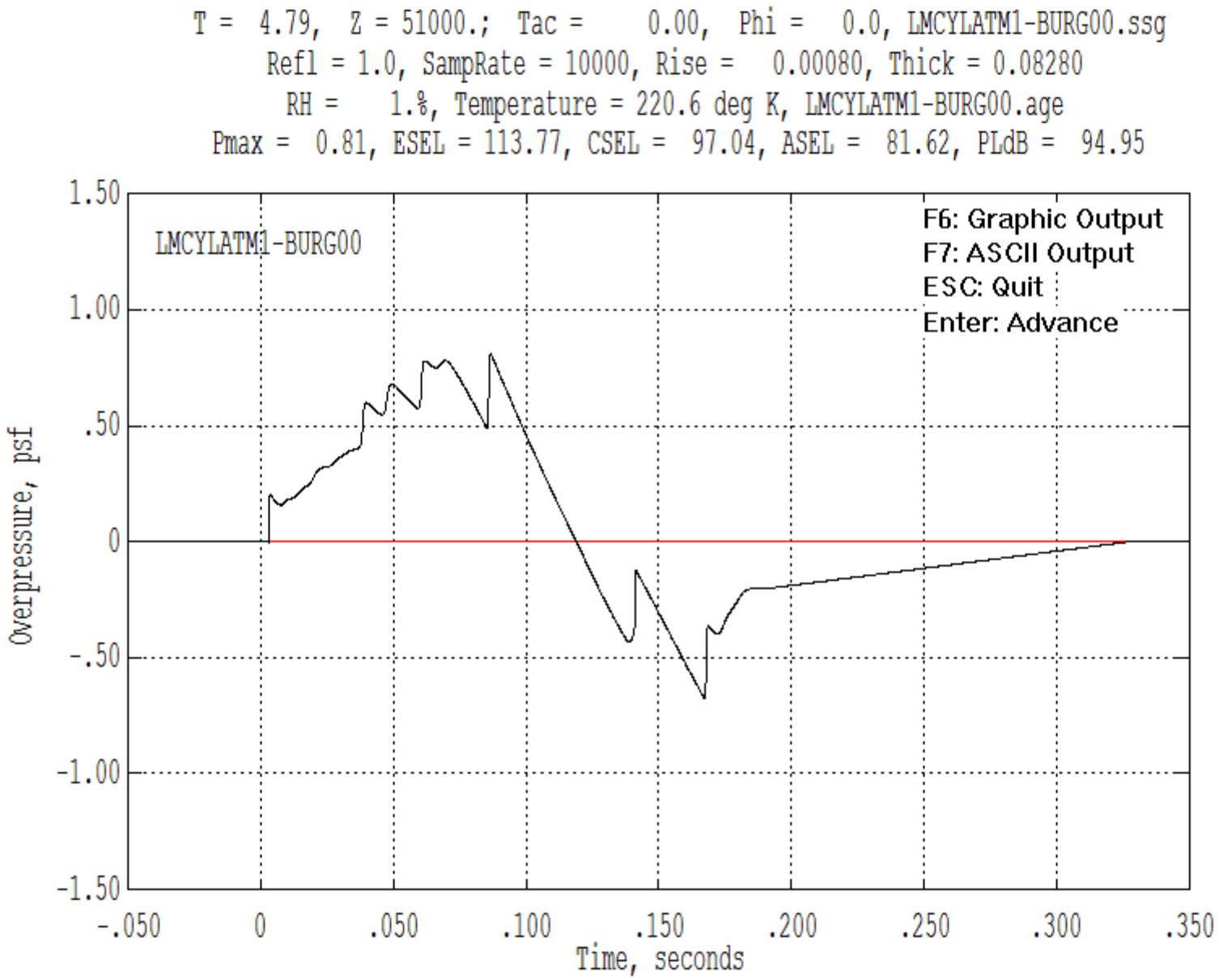
- PCBurg
- LM1021
- Sample Rate 10kHz
- Flight Altitude 55,000 Ft
- Burgers Propagation starts at 54,000 Ft
- Standard Atmo, Linear Pressure


Tac = 0.00, Phi = 0.0: Thin Shock Solution, Free Field
T = 0.49; Z = 54000. feet, Pmax = 2.236 psf; Zac = 55000. feet
Press Enter to move down; Backspace to move up
Press B or b to begin Burgers evolution from this point
LMCYLATM1-BURG00
F6: Graphic Output
F7: ASCII Output
ESC: Quit
Enter: Advance
Overpressure, psf
3.00
2.00
1.00
0
-1.00
-2.00
-3.00
-.050
0
.050
.100
.150
.200
.250
.300
.350
Time, seconds

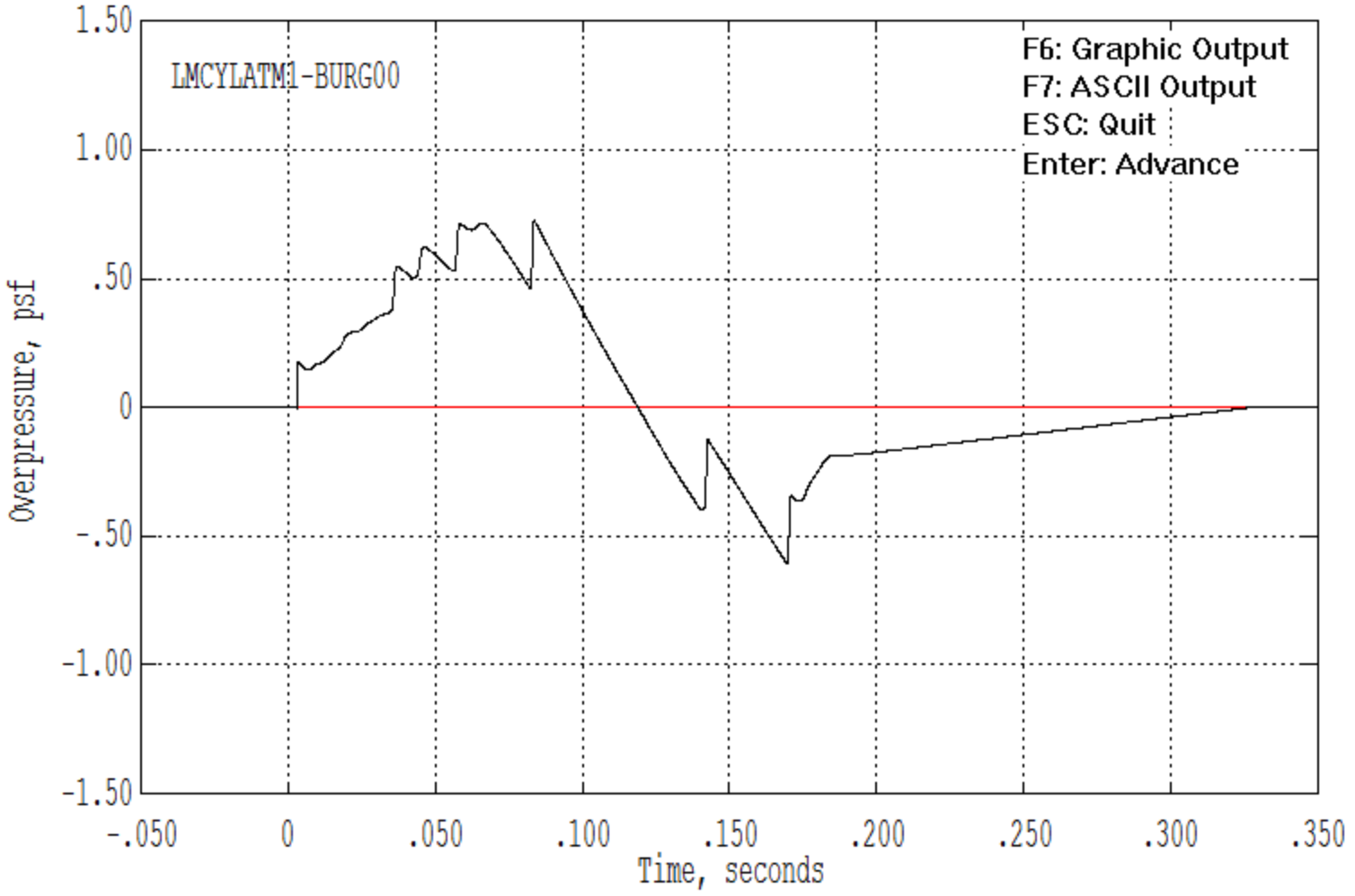

T = 0.49, Z = 54000.; Tac = 0.00, Phi = 0.0, LMCYLATM1-BURG00.ssg
Refl = 1.0, SampRate = 10000, Rise = 0.00054, Thick = 0.00000
RH = 1.%, Temperature = 219.0 deg K, LMCYLATM1-BURG00.age
Pmax = 2.17, Initial Signature - Press Enter to Propagate
LMCYLATM1-BURG00
F6: Graphic Output
F7: ASCII Output
ESC: Quit
Enter: Advance
Overpressure, psf
3.00
2.00
1.00
0
-1.00
-2.00
-3.00
-.050
0
.050
.100
.150
.200
.250
.300
.350
Time, seconds

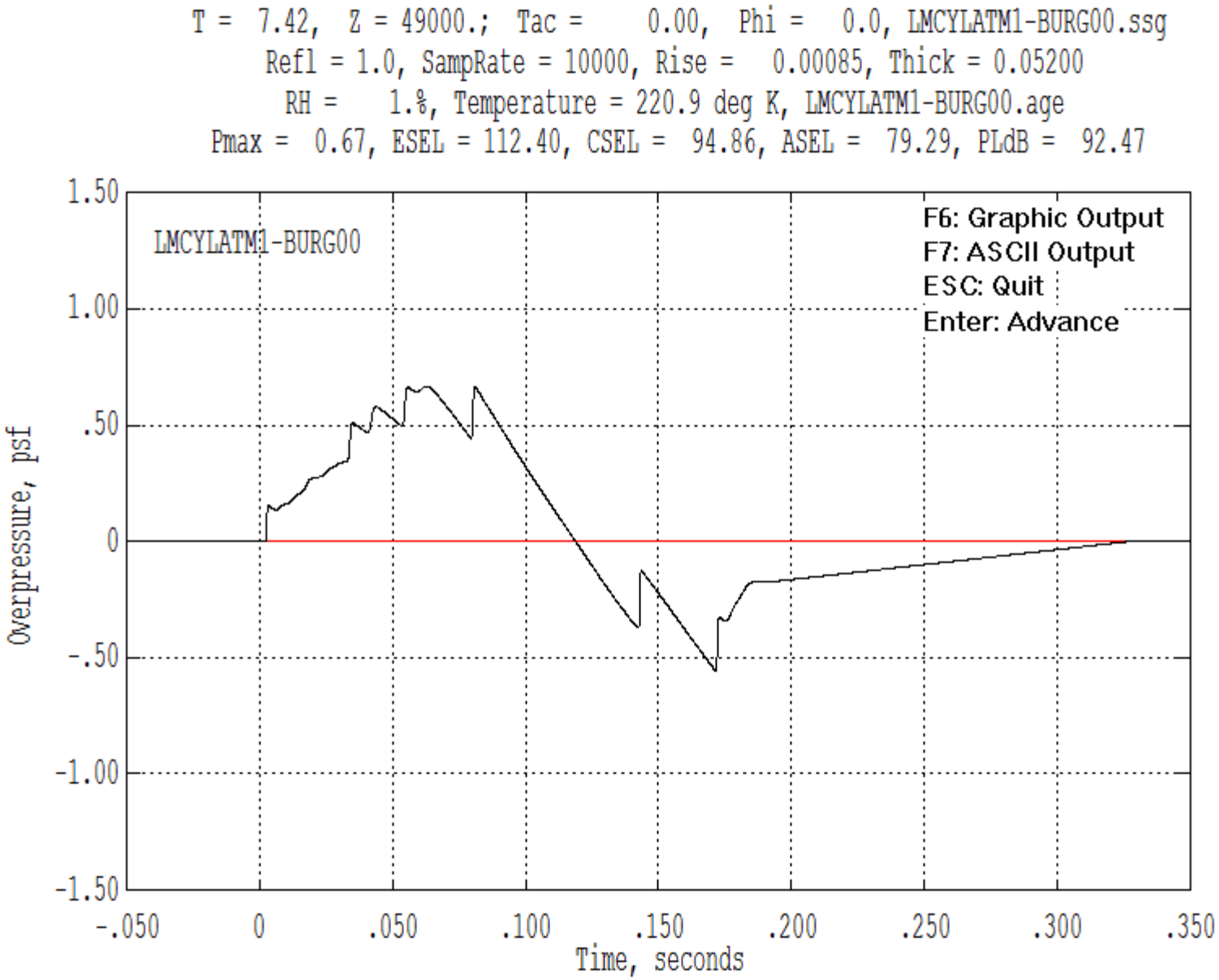

T = 1.93, Z = 53000.; Tac = 0.00, Phi = 0.0, LMCYLATM1-BURG00.ssg
Refl = 1.0, SampRate = 10000, Rise = 0.00075, Thick = 0.09060
RH = 1.%, Temperature = 220.2 deg K, LMCYLATM1-BURG00.age
Pmax = 1.23, ESEL = 116.44, CSEL = 101.59, ASEL = 87.31, PLdB = 100.51
LMCYLATM1-BURG00
F6: Graphic Output
F7: ASCII Output
ESC: Quit
Enter: Advance
Overpressure, psf
1.50
1.00
.50
0
-.50
-1.00
-1.50
-.050
0
.050
.100
.150
.200
.250
.300
.350
Time, seconds

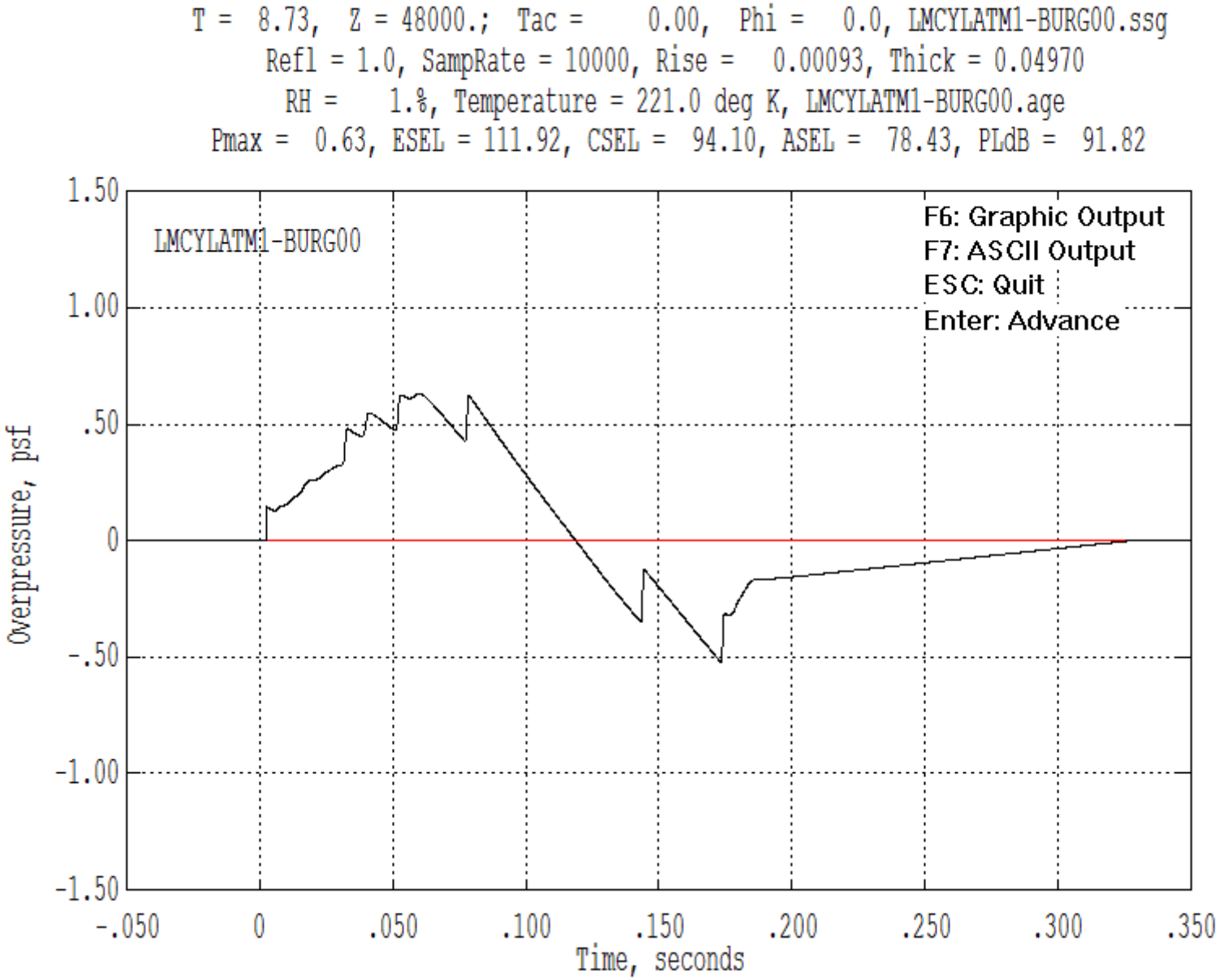

T = 3.38, Z = 52000.; Tac = 0.00, Phi = 0.0, LMCYLATM1-BURG00.ssg
Refl = 1.0, SampRate = 10000, Rise = 0.00078, Thick = 0.08630
RH = 1.%, Temperature = 220.5 deg K, LMCYLATM1-BURG00.age
Pmax = 0.95, ESEL = 114.82, CSEL = 98.80, ASEL = 83.84, PLdB = 97.16
LMCYLATM1-BURG00
F6: Graphic Output
F7: ASCII Output
ESC: Quit
Enter: Advance
Overpressure, psf
1.50
1.00
.50
0
-.50
-1.00
-1.50
-.050
0
.050
.100
.150
.200
.250
.300
.350
Time, seconds

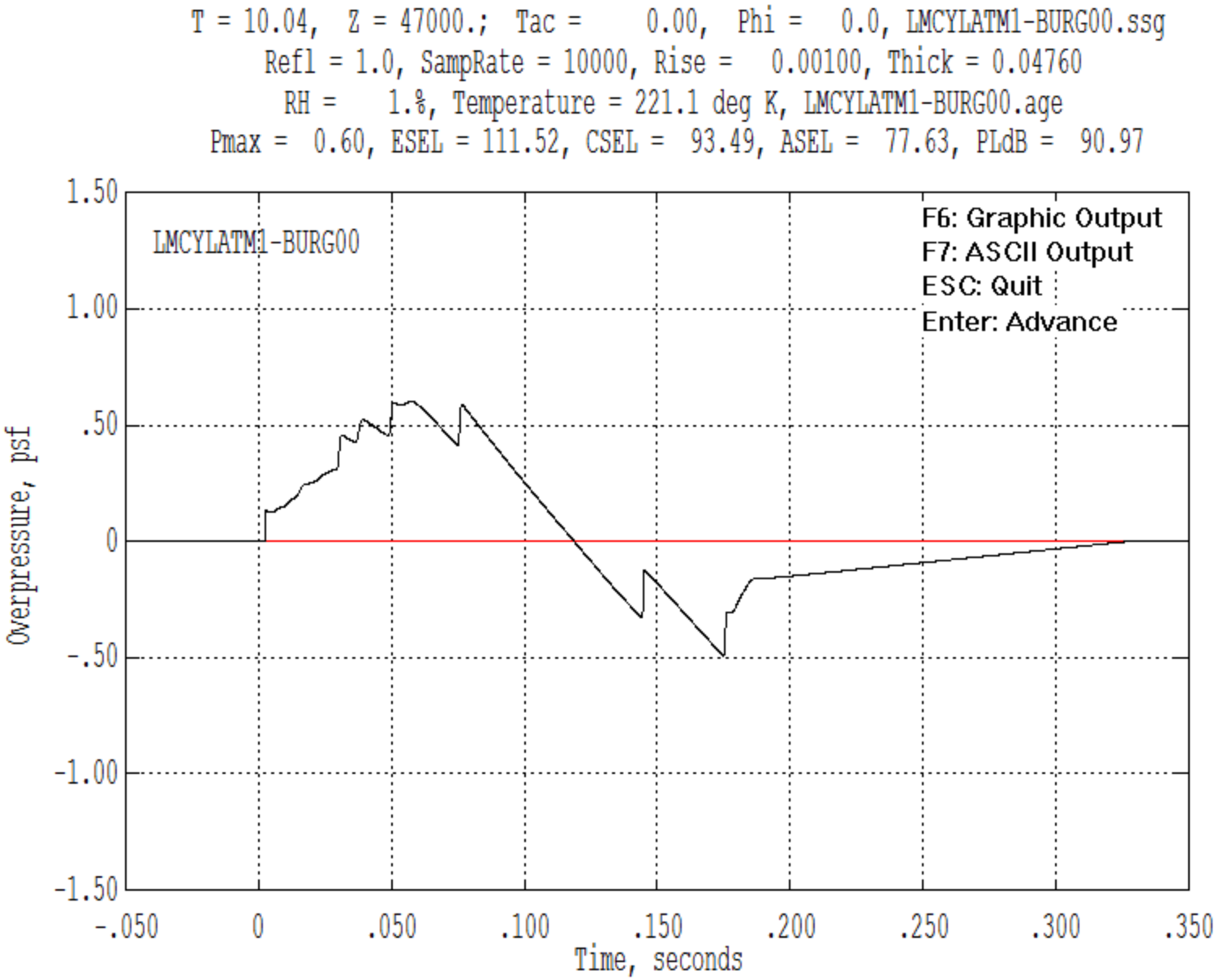

T = 4.79, Z = 51000.; Tac = 0.00, Phi = 0.0, LMCYLATM1-BURG00.ssg
Refl = 1.0, SampRate = 10000, Rise = 0.00080, Thick = 0.08280
RH = 1.%, Temperature = 220.6 deg K, LMCYLATM1-BURG00.age
Pmax = 0.81, ESEL = 113.77, CSEL = 97.04, ASEL = 81.62, PLdB = 94.95
LMCYLATM1-BURG00
F6: Graphic Output
F7: ASCII Output
ESC: Quit
Enter: Advance
Overpressure, psf
1.50
1.00
.50
0
-.50
-1.00
-1.50
-.050
0
.050
.100
.150
.200
.250
.300
.350
Time, seconds

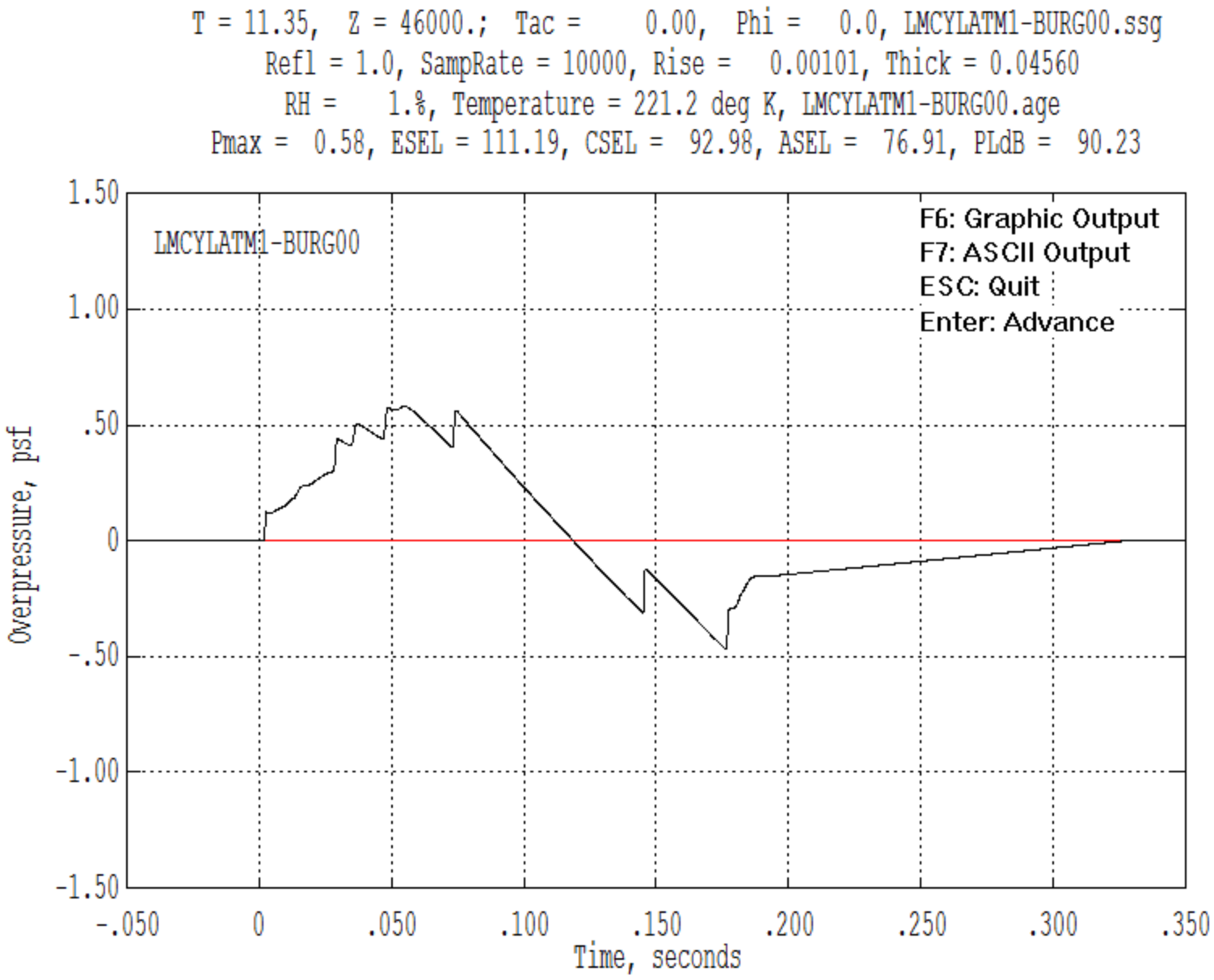
T = 6.11, Z = 50000.; Tac = 0.00, Phi = 0.0, LMCYLATM1-BURG00.ssg
Refl = 1.0, SampRate = 10000, Rise = 0.00087, Thick = 0.05450
RH = 1.%, Temperature = 220.7 deg K, LMCYLATM1-BURG00.age
Pmax = 0.72, ESEL = 113.00, CSEL = 95.81, ASEL = 80.33, PLdB = 93.66

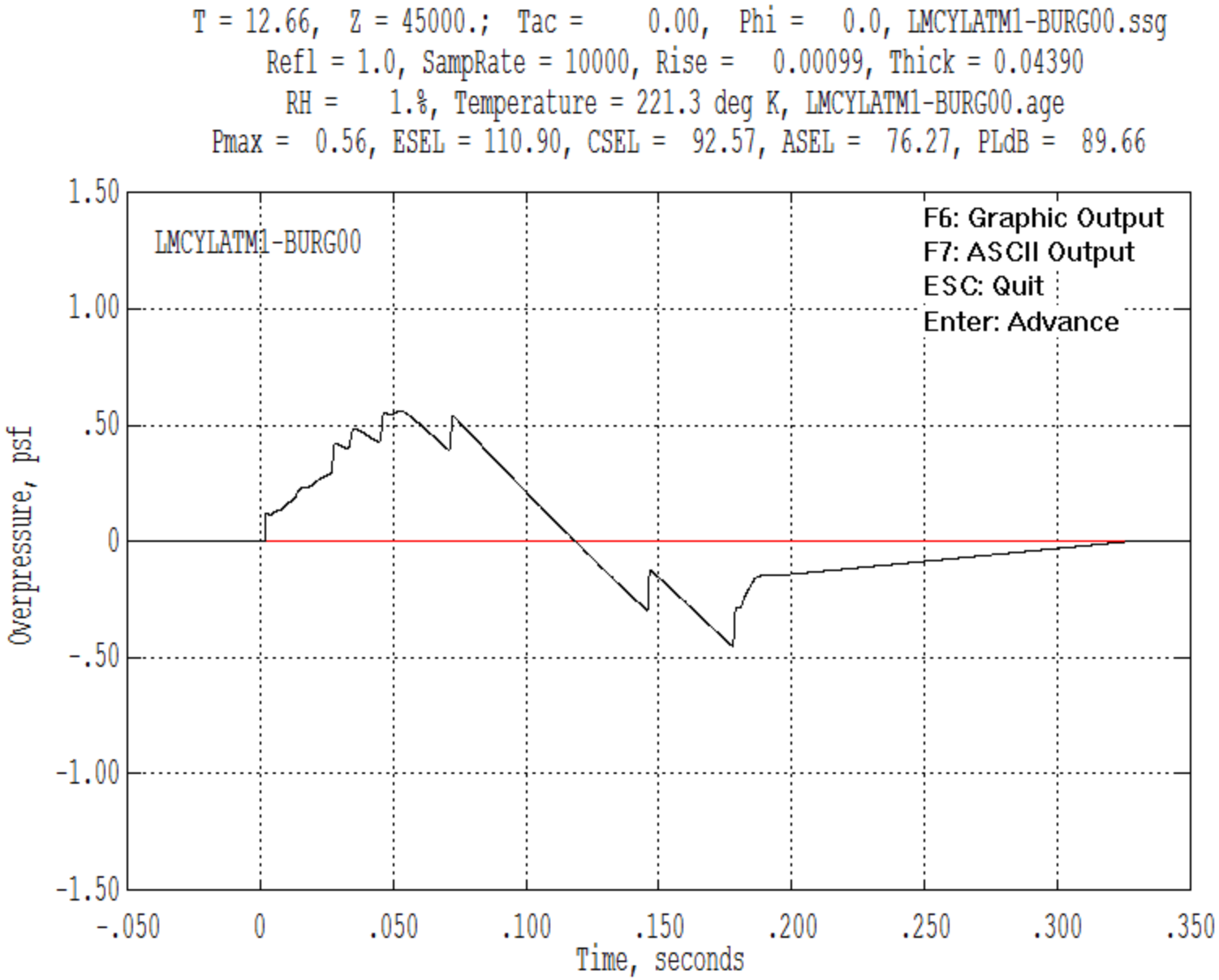


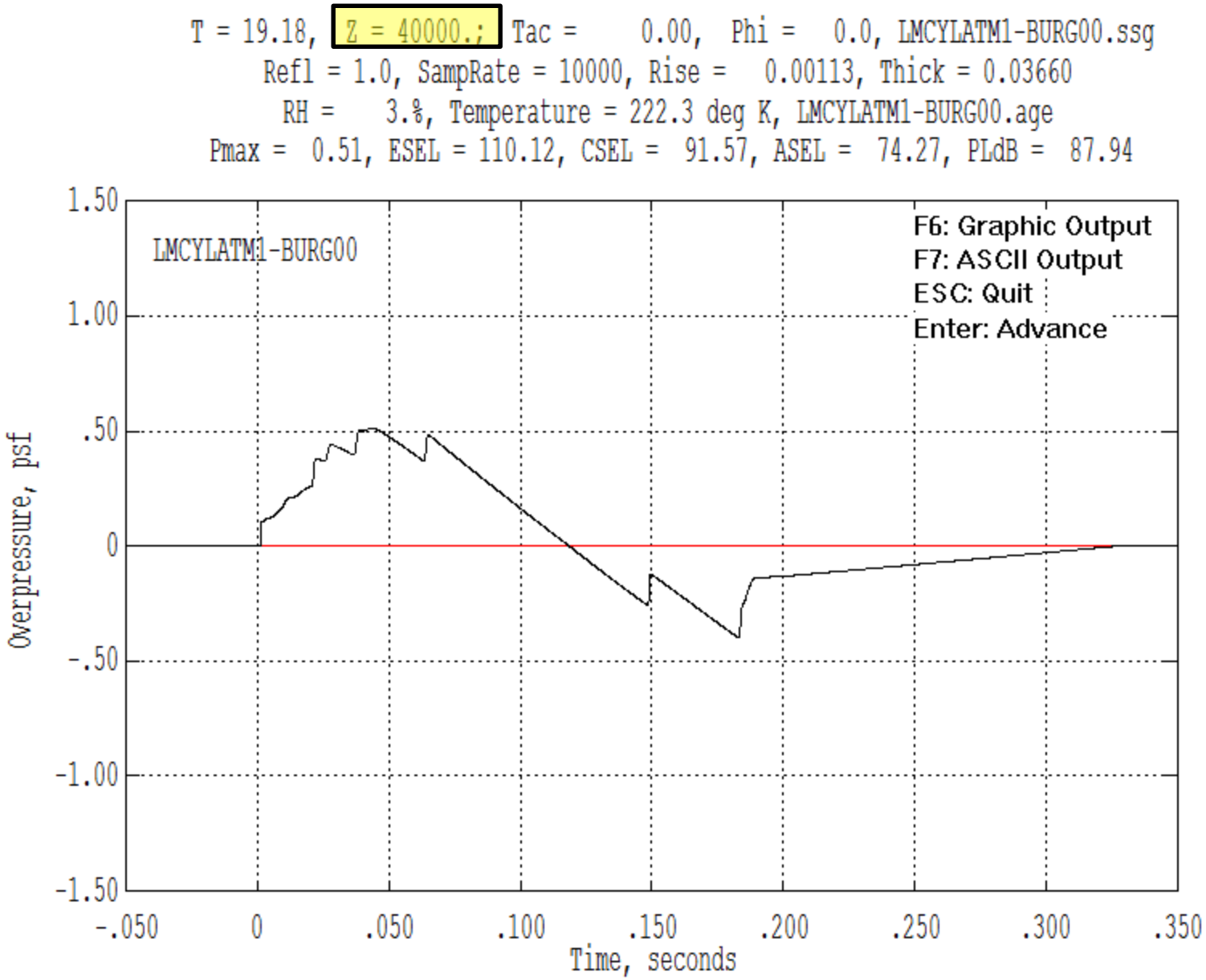

T = 7.42, Z = 49000.; Tac = 0.00, Phi = 0.0, LMCYLATM1-BURG00.ssg
Refl = 1.0, SampRate = 10000, Rise = 0.00085, Thick = 0.05200
RH = 1.%, Temperature = 220.9 deg K, LMCYLATM1-BURG00.age
Pmax = 0.67, ESEL = 112.40, CSEL = 94.86, ASEL = 79.29, PLdB = 92.47
LMCYLATM1-BURG00
F6: Graphic Output
F7: ASCII Output
ESC: Quit
Enter: Advance
Overpressure, psf
1.50
1.00
.50
0
-.50
-1.00
-1.50
-.050
0
.050
.100
.150
.200
.250
.300
.350
Time, seconds

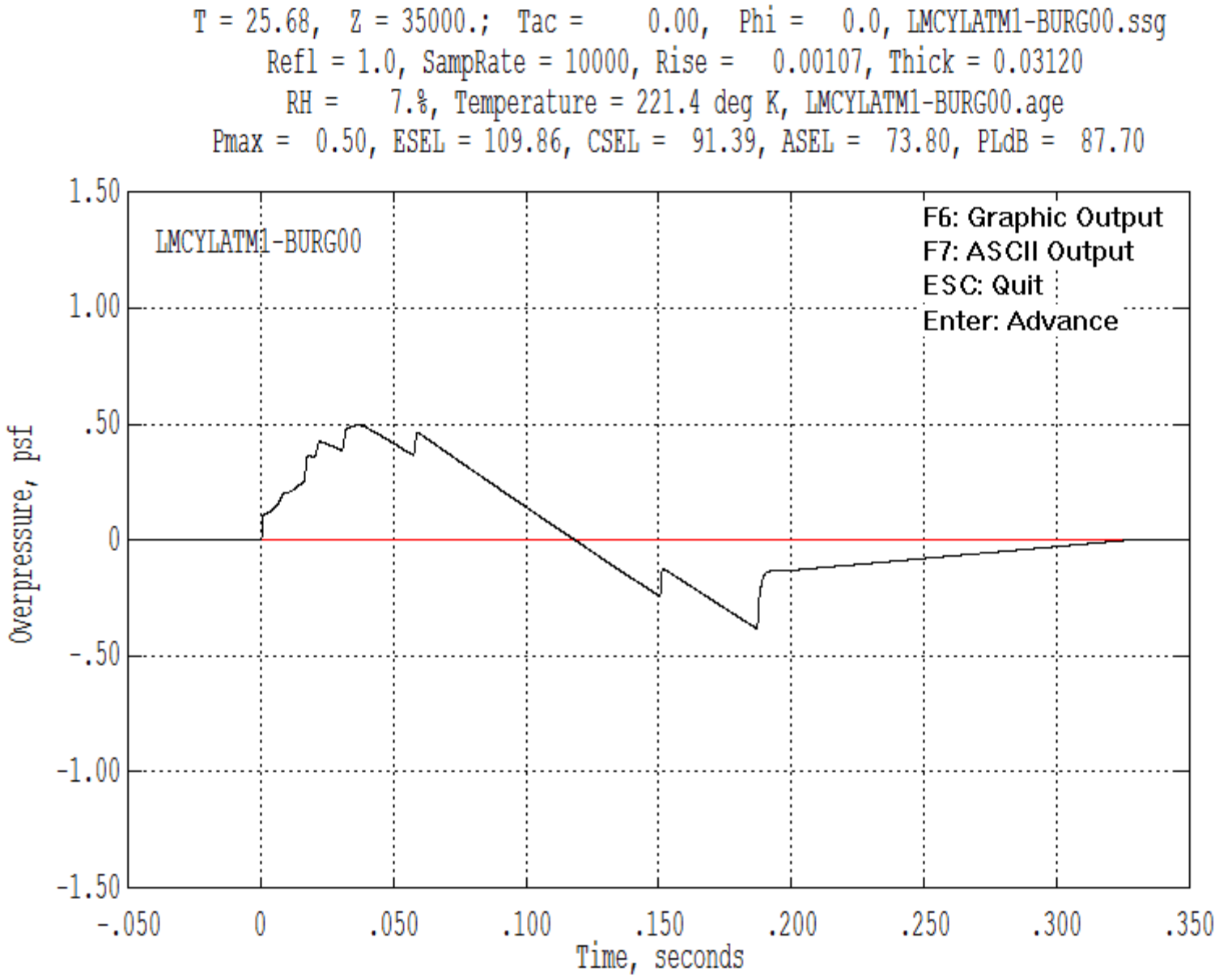

T = 8.73, Z = 48000.; Tac = 0.00, Phi = 0.0, LMCYLATM1-BURG00.ssg
Refl = 1.0, SampRate = 10000, Rise = 0.00093, Thick = 0.04970
RH = 1.%, Temperature = 221.0 deg K, LMCYLATM1-BURG00.age
Pmax = 0.63, ESEL = 111.92, CSEL = 94.10, ASEL = 78.43, PLdB = 91.82
LMCYLATM1-BURG00
F6: Graphic Output
F7: ASCII Output
ESC: Quit
Enter: Advance
Overpressure, psf
1.50
1.00
.50
0
-.50
-1.00
-1.50
-.050
0
.050
.100
.150
.200
.250
.300
.350
Time, seconds

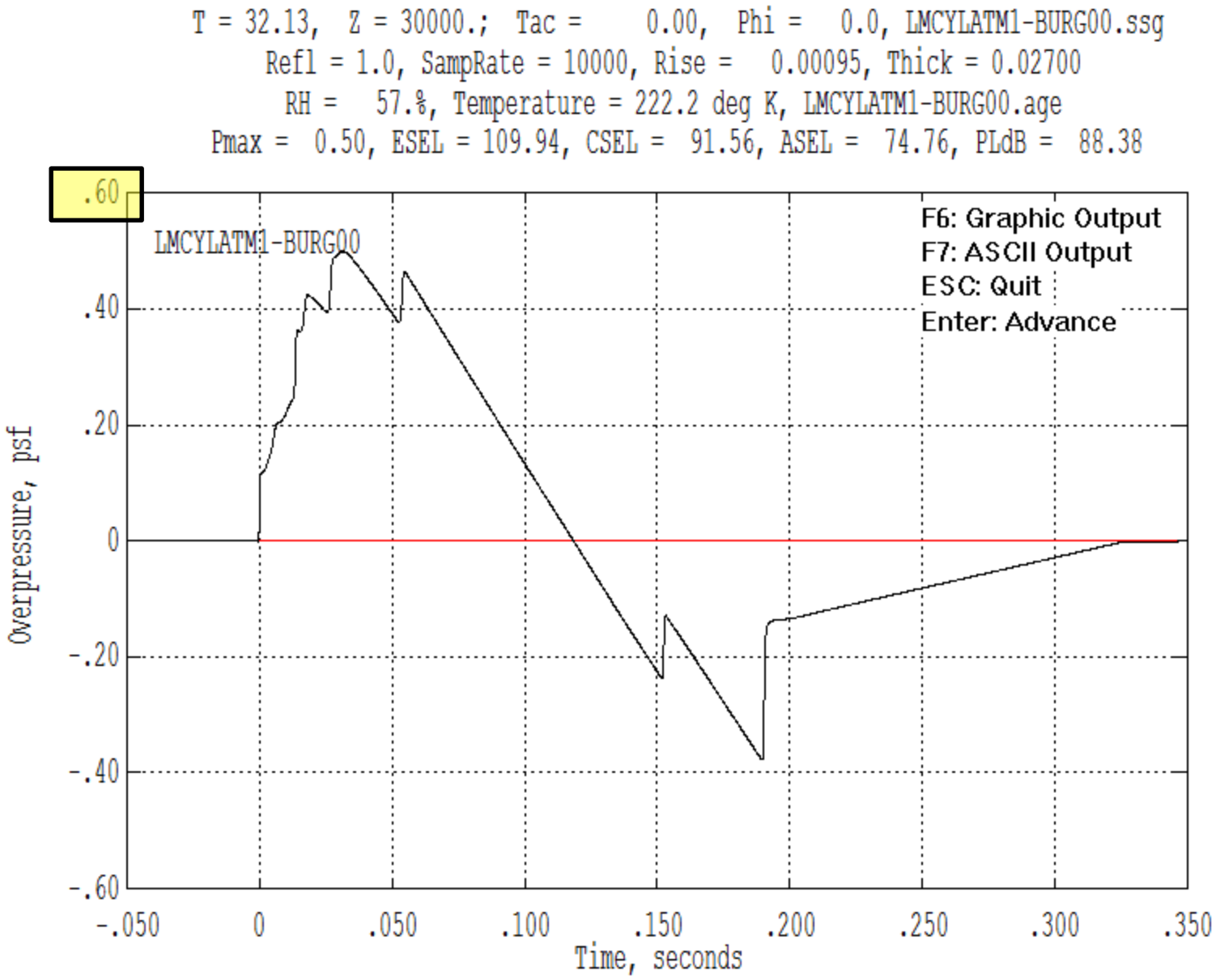

T = 10.04, Z = 47000.; Tac = 0.00, Phi = 0.0, LMCYLATM1-BURG00.ssg
Refl = 1.0, SampRate = 10000, Rise = 0.00100, Thick = 0.04760
RH = 1.%, Temperature = 221.1 deg K, LMCYLATM1-BURG00.age
Pmax = 0.60, ESEL = 111.52, CSEL = 93.49, ASEL = 77.63, PLdB = 90.97
LMCYLATM1-BURG00
F6: Graphic Output
F7: ASCII Output
ESC: Quit
Enter: Advance
Overpressure, psf
1.50
1.00
.50
0
-.50
-1.00
-1.50
-.050
0
.050
.100
.150
.200
.250
.300
.350
Time, seconds

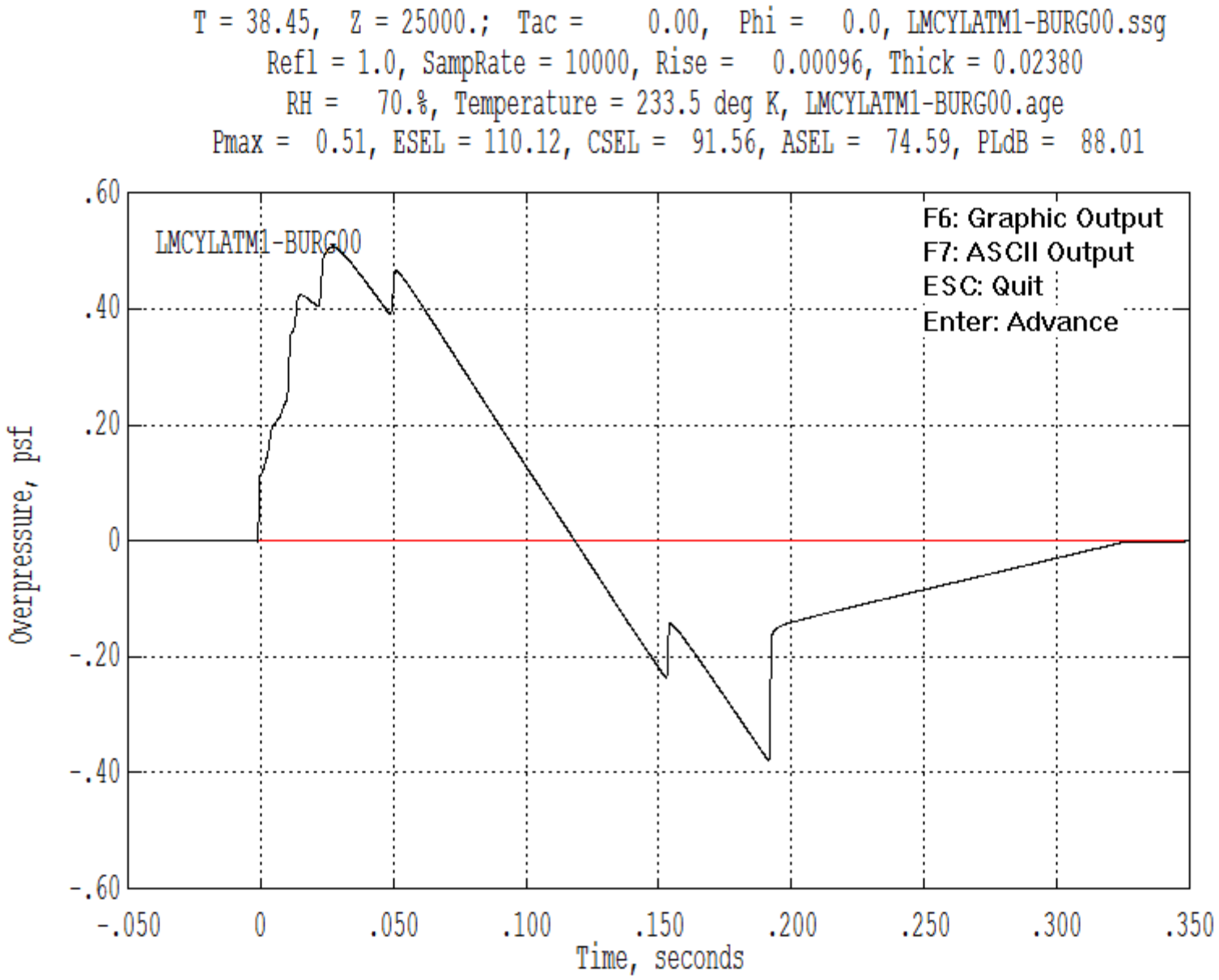

T = 11.35, Z = 46000.; Tac = 0.00, Phi = 0.0, LMCYLATM1-BURG00.ssg
Refl = 1.0, SampRate = 10000, Rise = 0.00101, Thick = 0.04560
RH = 1.%, Temperature = 221.2 deg K, LMCYLATM1-BURG00.age
Pmax = 0.58, ESEL = 111.19, CSEL = 92.98, ASEL = 76.91, PLdB = 90.23
LMCYLATM1-BURG00
F6: Graphic Output
F7: ASCII Output
ESC: Quit
Enter: Advance
Overpressure, psf
1.50
1.00
.50
0
-.50
-1.00
-1.50
-.050
0
.050
.100
.150
.200
.250
.300
.350
Time, seconds

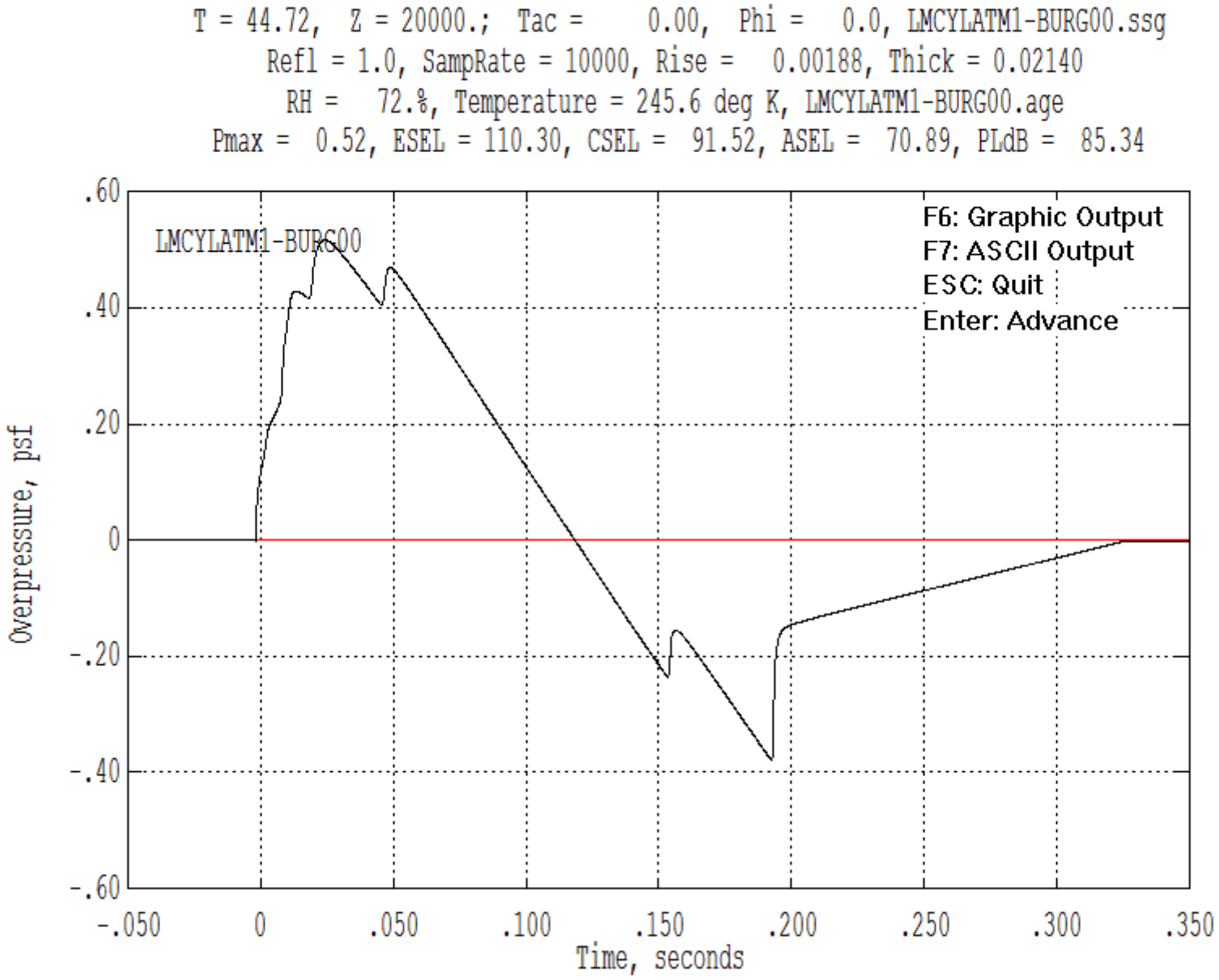

T = 12.66, Z = 45000.; Tac = 0.00, Phi = 0.0, LMCYLATM1-BURG00.ssg
Refl = 1.0, SampRate = 10000, Rise = 0.00099, Thick = 0.04390
RH = 1.%, Temperature = 221.3 deg K, LMCYLATM1-BURG00.age
Pmax = 0.56, ESEL = 110.90, CSEL = 92.57, ASEL = 76.27, PLdB = 89.66
LMCYLATM1-BURG00
F6: Graphic Output
F7: ASCII Output
ESC: Quit
Enter: Advance
Overpressure, psf
1.50
1.00
.50
0
-.50
-1.00
-1.50
-.050
0
.050
.100
.150
.200
.250
.300
.350
Time, seconds

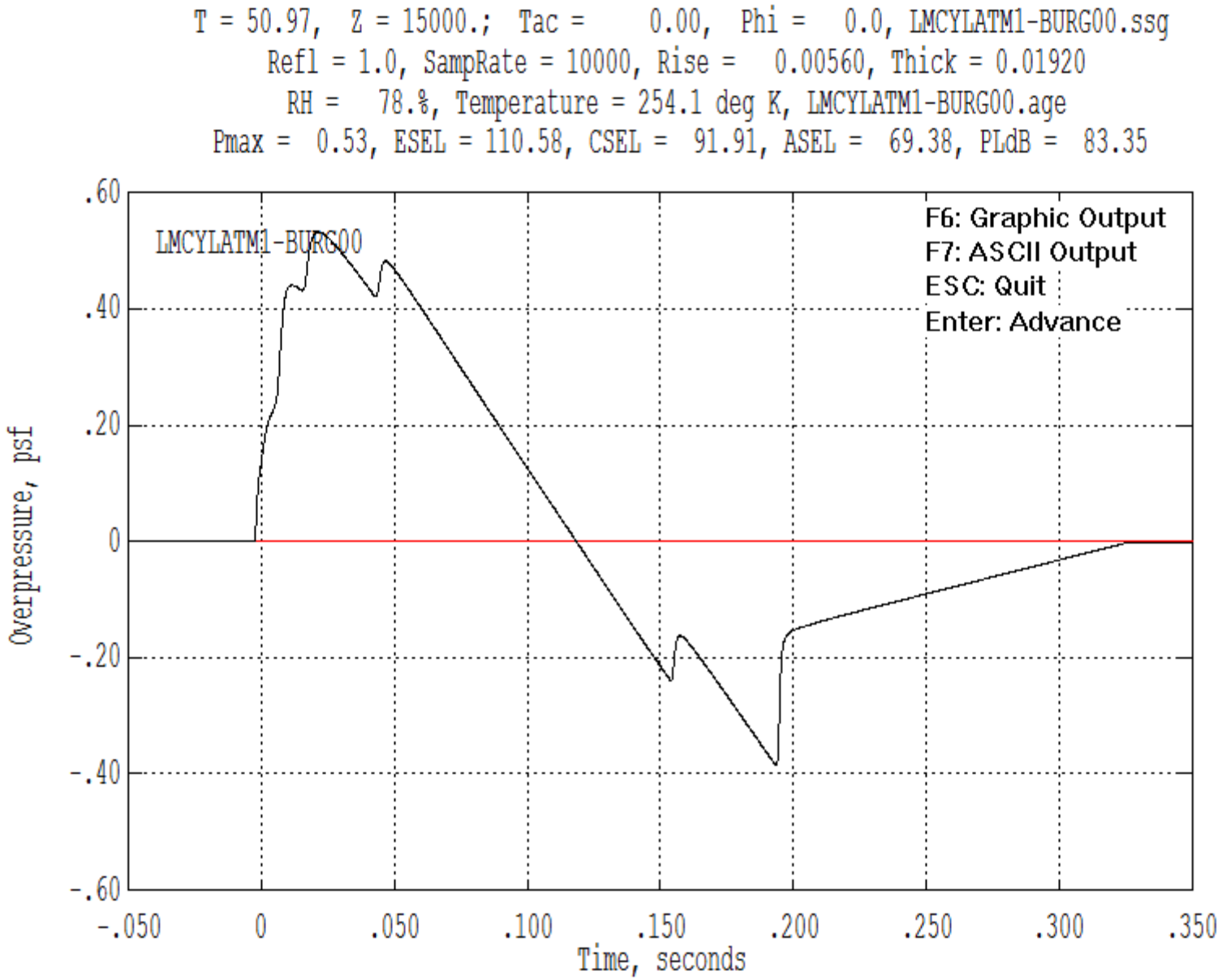

T = 19.18, Z = 40000.; Tac = 0.00, Phi = 0.0, LMCYLATM1-BURG00.ssg
Refl = 1.0, SampRate = 10000, Rise = 0.00113, Thick = 0.03660
RH = 3.%, Temperature = 222.3 deg K, LMCYLATM1-BURG00.age
Pmax = 0.51, ESEL = 110.12, CSEL = 91.57, ASEL = 74.27, PLdB = 87.94
LMCYLATM1-BURG00
F6: Graphic Output
F7: ASCII Output
ESC: Quit
Enter: Advance
Overpressure, psf
1.50
1.00
.50
0
-.50
-1.00
-1.50
-.050
0
.050
.100
.150
.200
.250
.300
.350
Time, seconds


T = 25.68, Z = 35000.; Tac = 0.00, Phi = 0.0, LMCYLATM1-BURG00.ssg
Refl = 1.0, SampRate = 10000, Rise = 0.00107, Thick = 0.03120
RH = 7.%, Temperature = 221.4 deg K, LMCYLATM1-BURG00.age
Pmax = 0.50, ESEL = 109.86, CSEL = 91.39, ASEL = 73.80, PLdB = 87.70
LMCYLATM1-BURG00
F6: Graphic Output
F7: ASCII Output
ESC: Quit
Enter: Advance
Overpressure, psf
1.50
1.00
.50
0
-.50
-1.00
-1.50
-.050
0
.050
.100
.150
.200
.250
.300
.350
Time, seconds

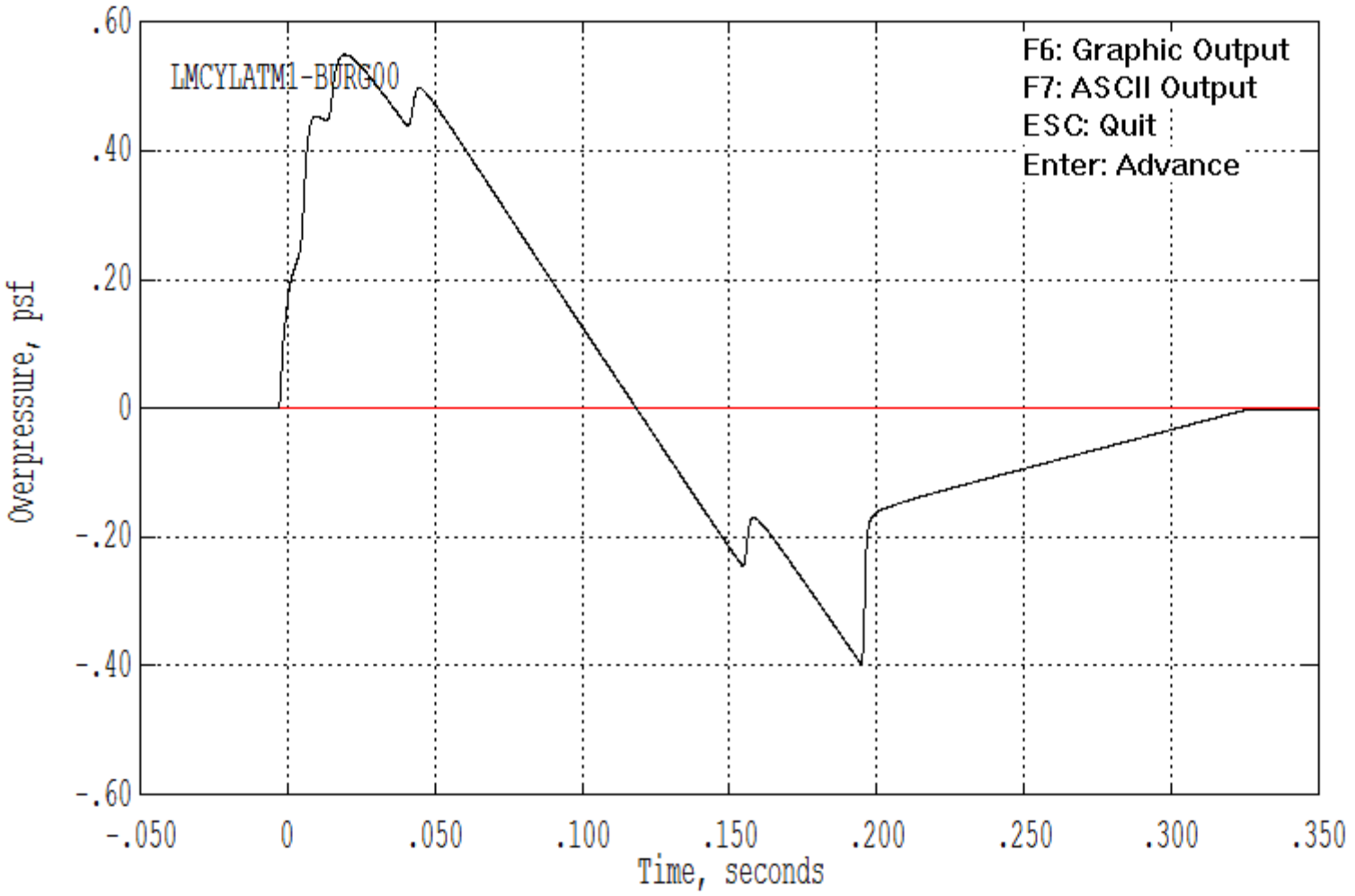

T = 32.13, Z = 30000.; Tac = 0.00, Phi = 0.0, LMCYLATM1-BURG00.ssg
Refl = 1.0, SampRate = 10000, Rise = 0.00095, Thick = 0.02700
RH = 57.%, Temperature = 222.2 deg K, LMCYLATM1-BURG00.age
Pmax = 0.50, ESEL = 109.94, CSEL = 91.56, ASEL = 74.76, PLdB = 88.38
LMCYLATM1-BURG00
F6: Graphic Output
F7: ASCII Output
ESC: Quit
Enter: Advance
Overpressure, psf
.60
.40
.20
0
-.20
-.40
-.60
-.050
0
.050
.100
.150
.200
.250
.300
.350
Time, seconds

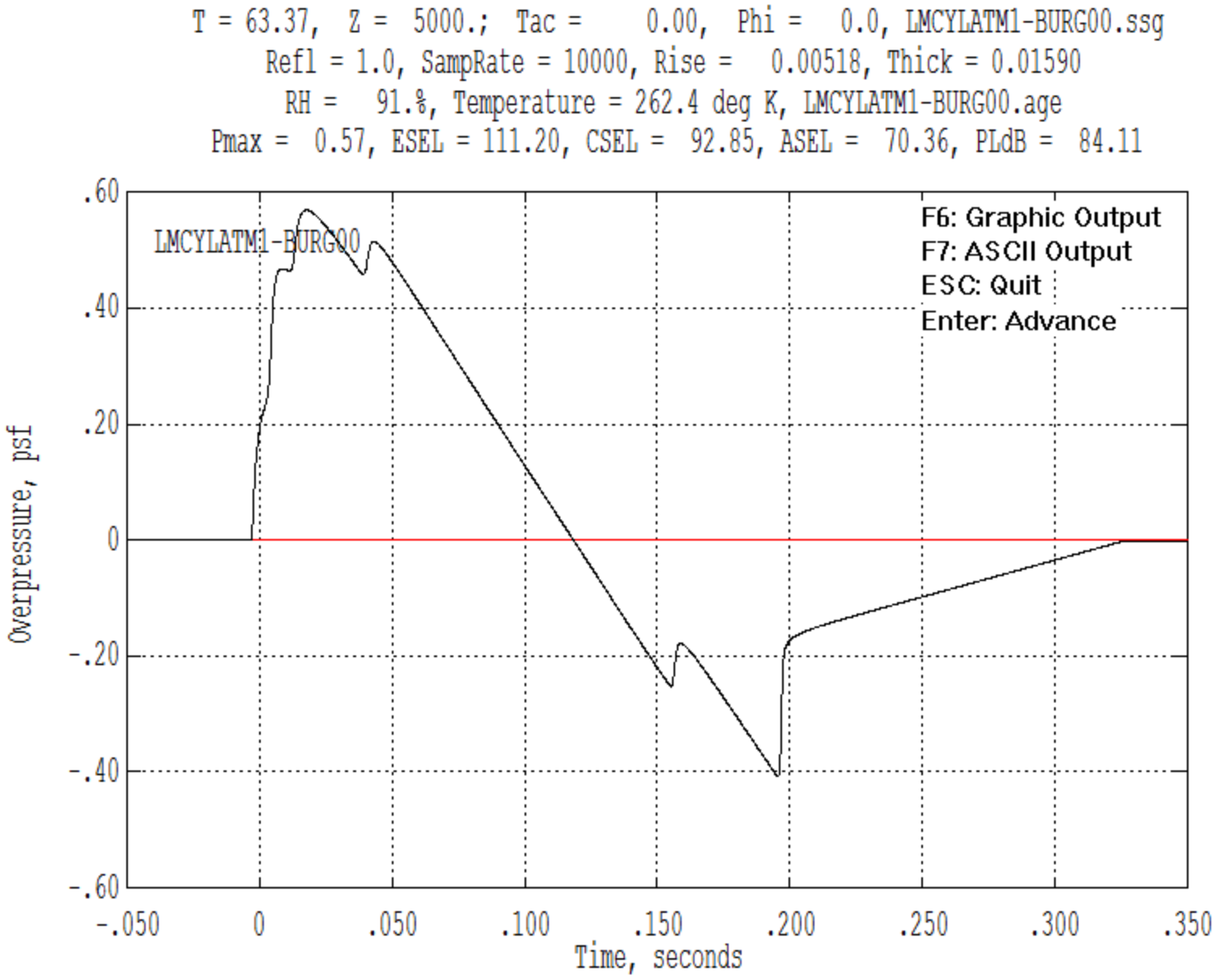

T = 38.45, Z = 25000.; Tac = 0.00, Phi = 0.0, LMCYLATM1-BURG00.ssg
Refl = 1.0, SampRate = 10000, Rise = 0.00096, Thick = 0.02380
RH = 70.%, Temperature = 233.5 deg K, LMCYLATM1-BURG00.age
Pmax = 0.51, ESEL = 110.12, CSEL = 91.56, ASEL = 74.59, PLdB = 88.01
LMCYLATM1-BURG00
F6: Graphic Output
F7: ASCII Output
ESC: Quit
Enter: Advance
Overpressure, psf
.60
.40
.20
0
-.20
-.40
-.60
-.050
0
.050
.100
.150
.200
.250
.300
.350
Time, seconds

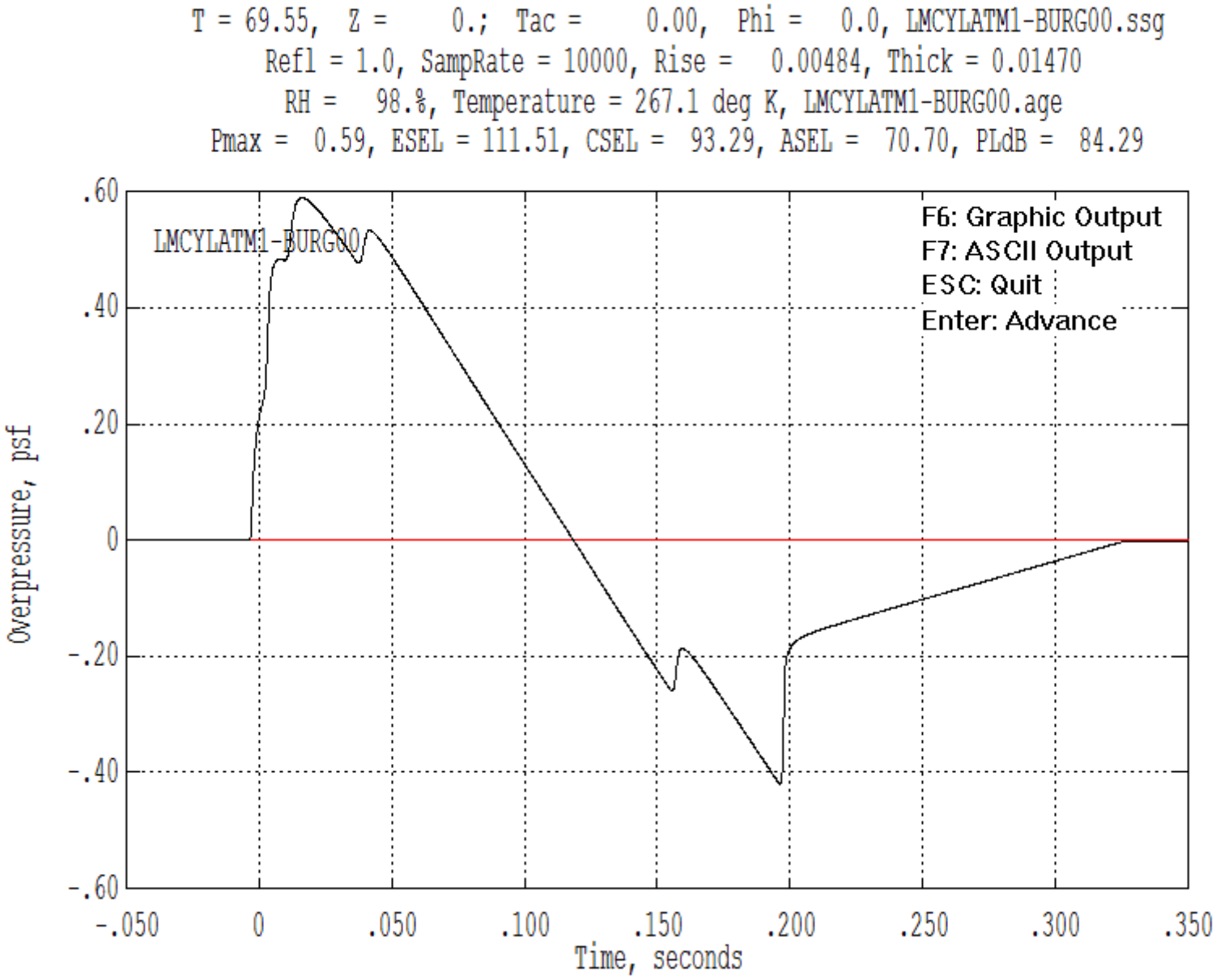

T = 44.72, Z = 20000.; Tac = 0.00, Phi = 0.0, LMCYLATM1-BURG00.ssg
Refl = 1.0, SampRate = 10000, Rise = 0.00188, Thick = 0.02140
RH = 72.%, Temperature = 245.6 deg K, LMCYLATM1-BURG00.age
Pmax = 0.52, ESEL = 110.30, CSEL = 91.52, ASEL = 70.89, PLdB = 85.34
LMCYLATM1-BURG00
F6: Graphic Output
F7: ASCII Output
ESC: Quit
Enter: Advance
Overpressure, psf
.60
.40
.20
0
-.20
-.40
-.60
-.050
0
.050
.100
.150
.200
.250
.300
.350
Time, seconds

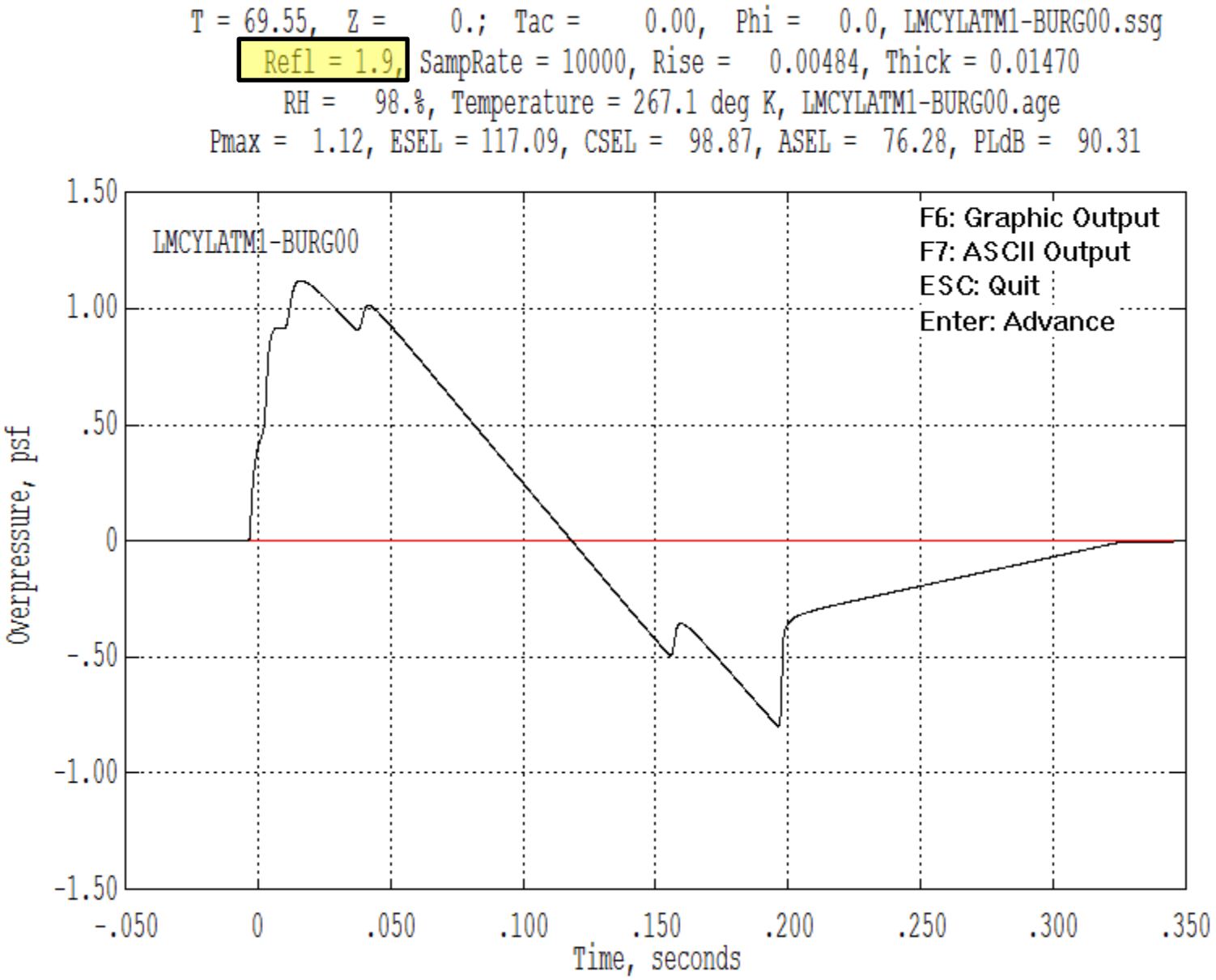

T = 50.97, Z = 15000.; Tac = 0.00, Phi = 0.0, LMCYLATM1-BURG00.ssg
Refl = 1.0, SampRate = 10000, Rise = 0.00560, Thick = 0.01920
RH = 78.%, Temperature = 254.1 deg K, LMCYLATM1-BURG00.age
Pmax = 0.53, ESEL = 110.58, CSEL = 91.91, ASEL = 69.38, PLdB = 83.35
LMCYLATM1-BURG00
F6: Graphic Output
F7: ASCII Output
ESC: Quit
Enter: Advance
Overpressure, psf
.60
.40
.20
0
-.20
-.40
-.60
-.050
0
.050
.100
.150
.200
.250
.300
.350
Time, seconds

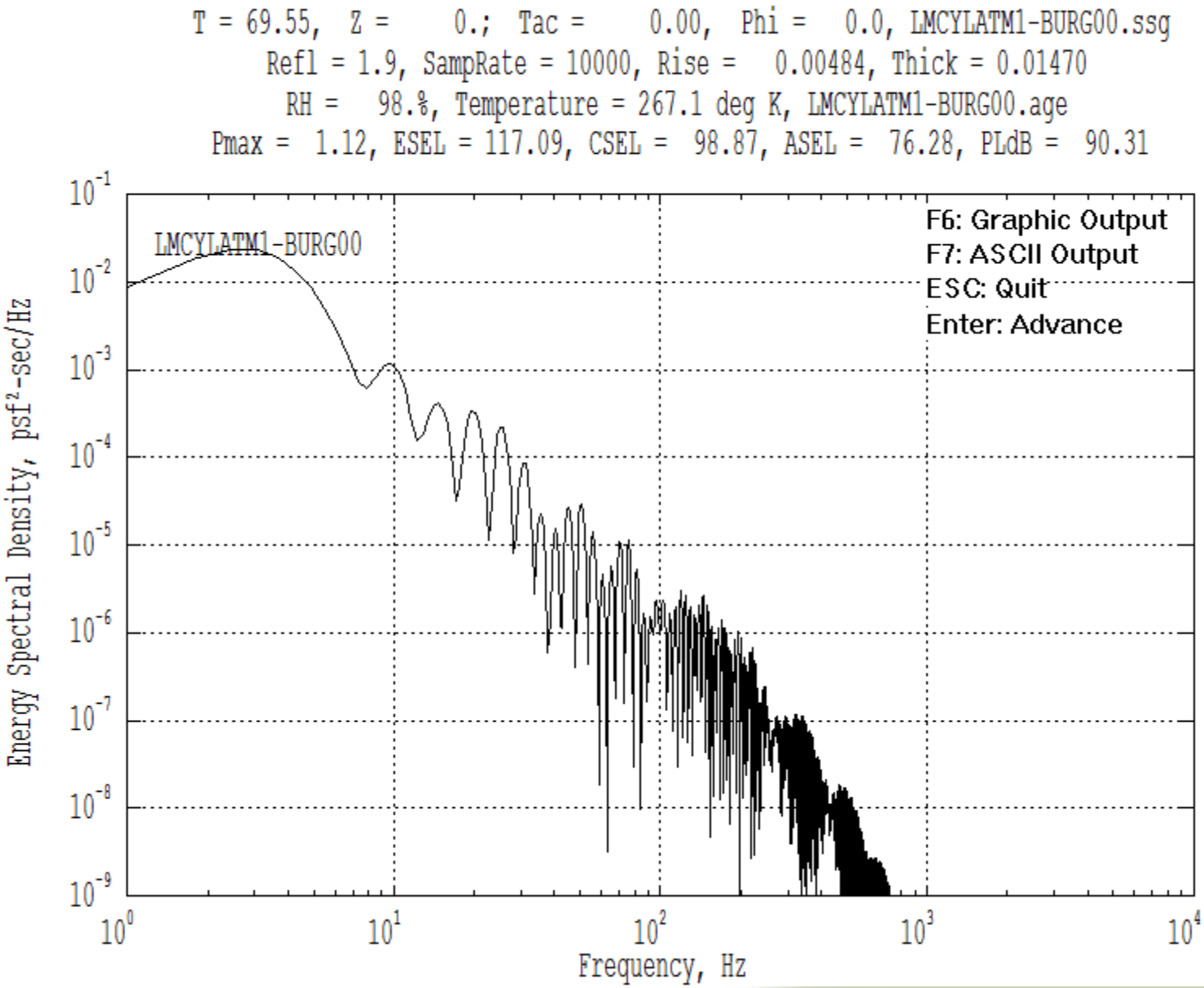
T = 57.18, Z = 10000.; Tac = 0.00, Phi = 0.0, LMCYLATM1-BURG00.ssg
Refl = 1.0, SampRate = 10000, Rise = 0.00554, Thick = 0.01740
RH = 86.%, Temperature = 259.6 deg K, LMCYLATM1-BURG00.age
Pmax = 0.55, ESEL = 110.87, CSEL = 92.37, ASEL = 69.80, PLdB = 83.52




T = 63.37, Z = 5000.; Tac = 0.00, Phi = 0.0, LMCYLATM1-BURG00.ssg
Refl = 1.0, SampRate = 10000, Rise = 0.00518, Thick = 0.01590
RH = 91.%, Temperature = 262.4 deg K, LMCYLATM1-BURG00.age
Pmax = 0.57, ESEL = 111.20, CSEL = 92.85, ASEL = 70.36, PLdB = 84.11
LMCYLATM1-BURG00
F6: Graphic Output
F7: ASCII Output
ESC: Quit
Enter: Advance
Overpressure, psf
.60
.40
.20
0
-.20
-.40
-.60
-.050
0
.050
.100
.150
.200
.250
.300
.350
Time, seconds


T = 69.55, Z = 0.; Tac = 0.00, Phi = 0.0, LMCYLATM1-BURG00.ssg
Refl = 1.0, SampRate = 10000, Rise = 0.00484, Thick = 0.01470
RH = 98.%, Temperature = 267.1 deg K, LMCYLATM1-BURG00.age
Pmax = 0.59, ESEL = 111.51, CSEL = 93.29, ASEL = 70.70, PLdB = 84.29
LMCYLATM1-BURG00
F6: Graphic Output
F7: ASCII Output
ESC: Quit
Enter: Advance
Overpressure, psf
.60
.40
.20
0
-.20
-.40
-.60
-.050
0
.050
.100
.150
.200
.250
.300
.350
Time, seconds


T = 69.55, Z = 0.; Tac = 0.00, Phi = 0.0, LMCYLATM1-BURG00.ssg
Refl = 1.9, SampRate = 10000, Rise = 0.00484, Thick = 0.01470
RH = 98.%, Temperature = 267.1 deg K, LMCYLATM1-BURG00.age
Pmax = 1.12, ESEL = 117.09, CSEL = 98.87, ASEL = 76.28, PLdB = 90.31
LMCYLATM1-BURG00
F6: Graphic Output
F7: ASCII Output
ESC: Quit
Enter: Advance
Overpressure, psf
1.50
1.00
.50
0
-.50
-1.00
-1.50
-.050
0
.050
.100
.150
.200
.250
.300
.350
Time, seconds


T = 69.55, Z = 0.; Tac = 0.00, Phi = 0.0, LMCYLATM1-BURG00.ssg
Refl = 1.9, SampRate = 10000, Rise = 0.00484, Thick = 0.01470
RH = 98.%, Temperature = 267.1 deg K, LMCYLATM1-BURG00.age
Pmax = 1.12, ESEL = 117.09, CSEL = 98.87, ASEL = 76.28, PLdB = 90.31
LMCYLATM1-BURG00
F6: Graphic Output
F7: ASCII Output
ESC: Quit
Enter: Advance
Energy Spectral Density, psf²-sec/Hz
Frequency, Hz

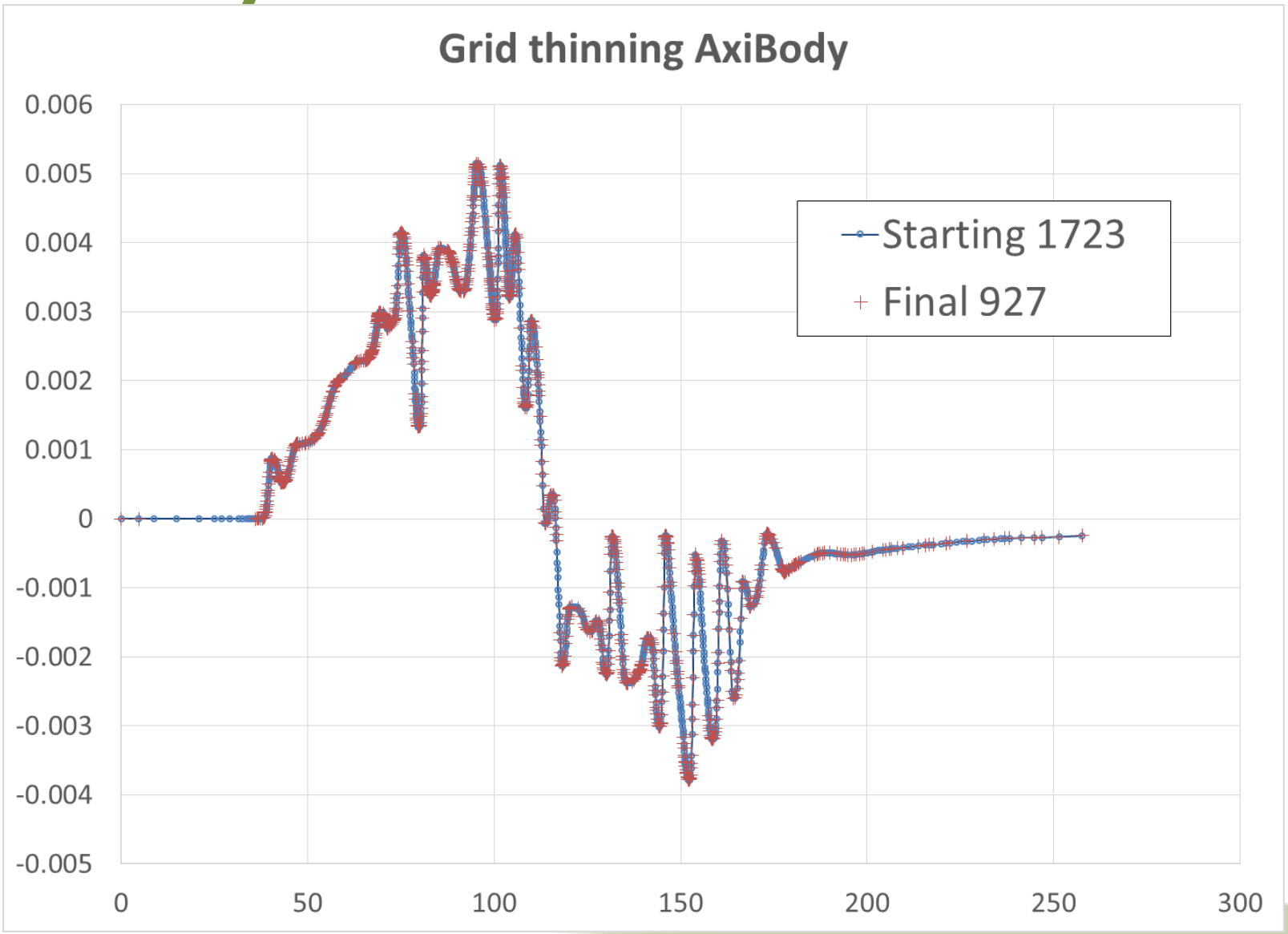
Cylinder Preparation – AxiBody

- Simple axisymmetric point thinning algorithm
- User defines # points to be examined, one point gets deleted within this # points
- Compute local slope with and without deleted point
- Ensure local Max and Min are preserved
- Delete the point with causes minimum slope change – aka delete the point in the straightest segment of # points
- 50% frame overlap
- Move down the signature
- Repeat N times

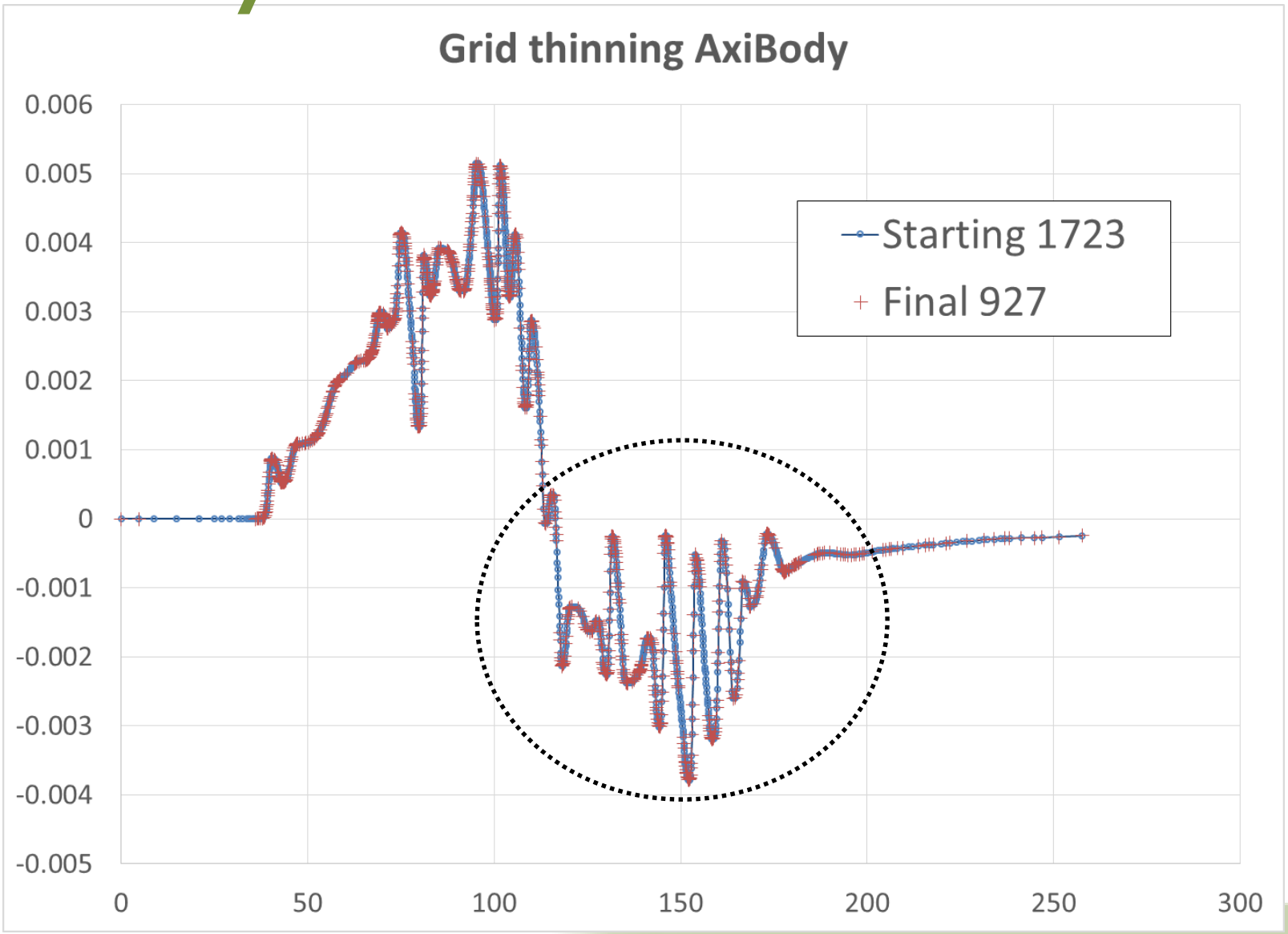
AxiBody Thinning

- Process for Linear Solution – No Molecular Relaxation
- Varied smoothing parameters (# Points, # Thin Passes)
- Examined FOBoom results
  - Needed 203 points or less at the ground
  - Consistent input for all azimuths, all atmospheres
- FINAL: # Points = 40, N Passes = 12
- 927 points in the Cylinder → 196 pts at Phi = 0

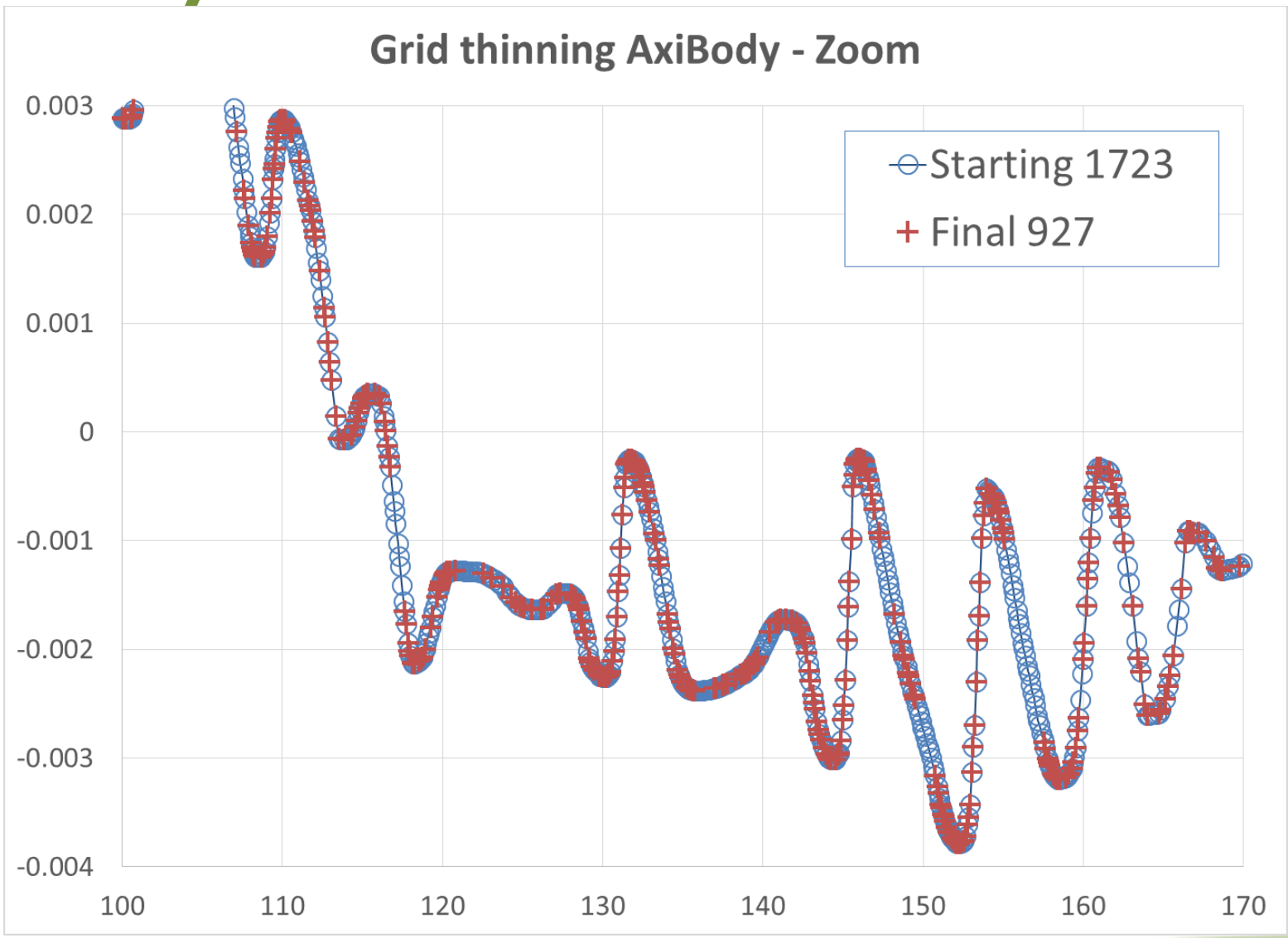
AxiBody Final Selection – 927 Points



AxiBody Final Selection – 927 Points

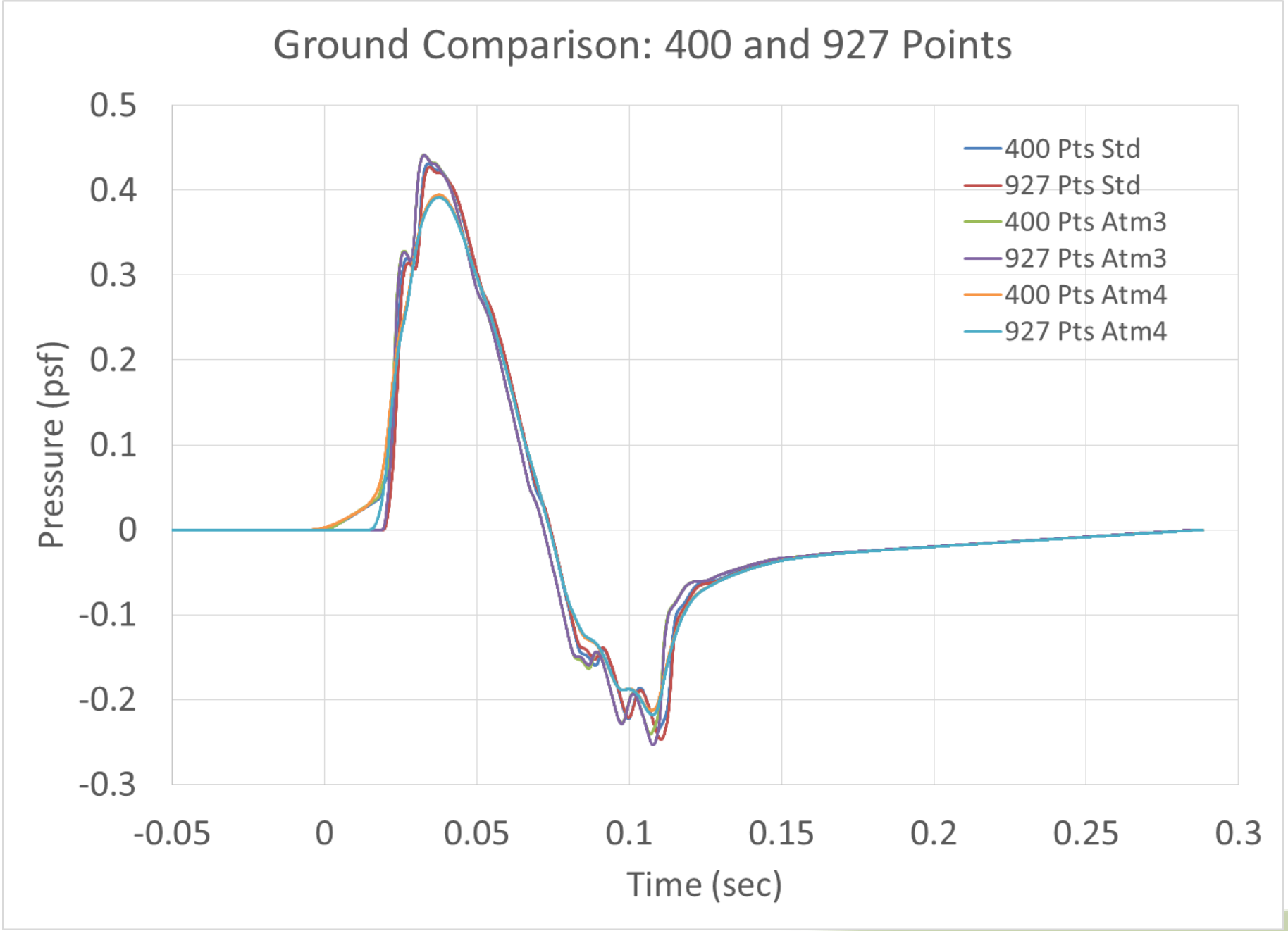


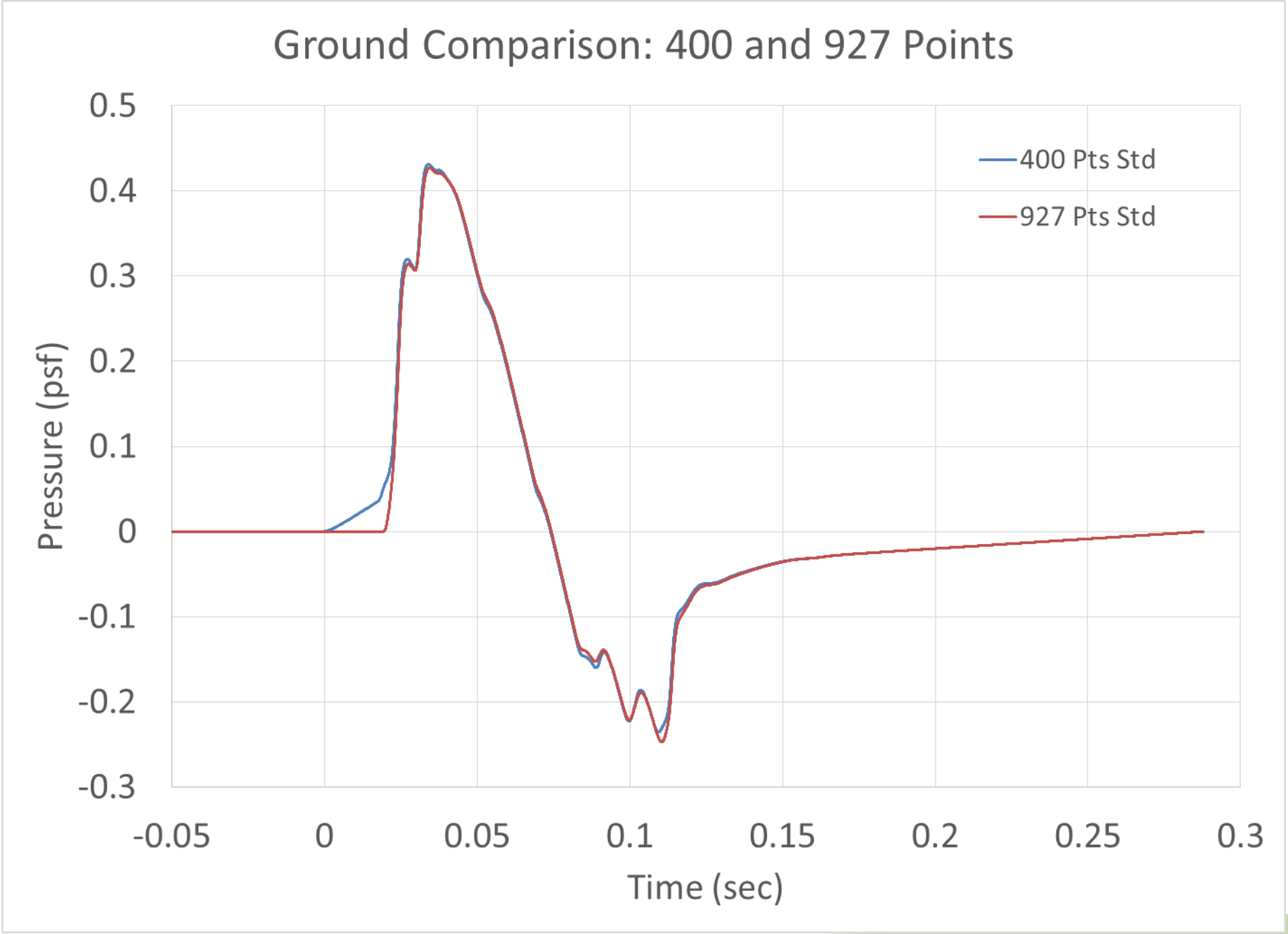
AxiBody Final Selection – 927 Points

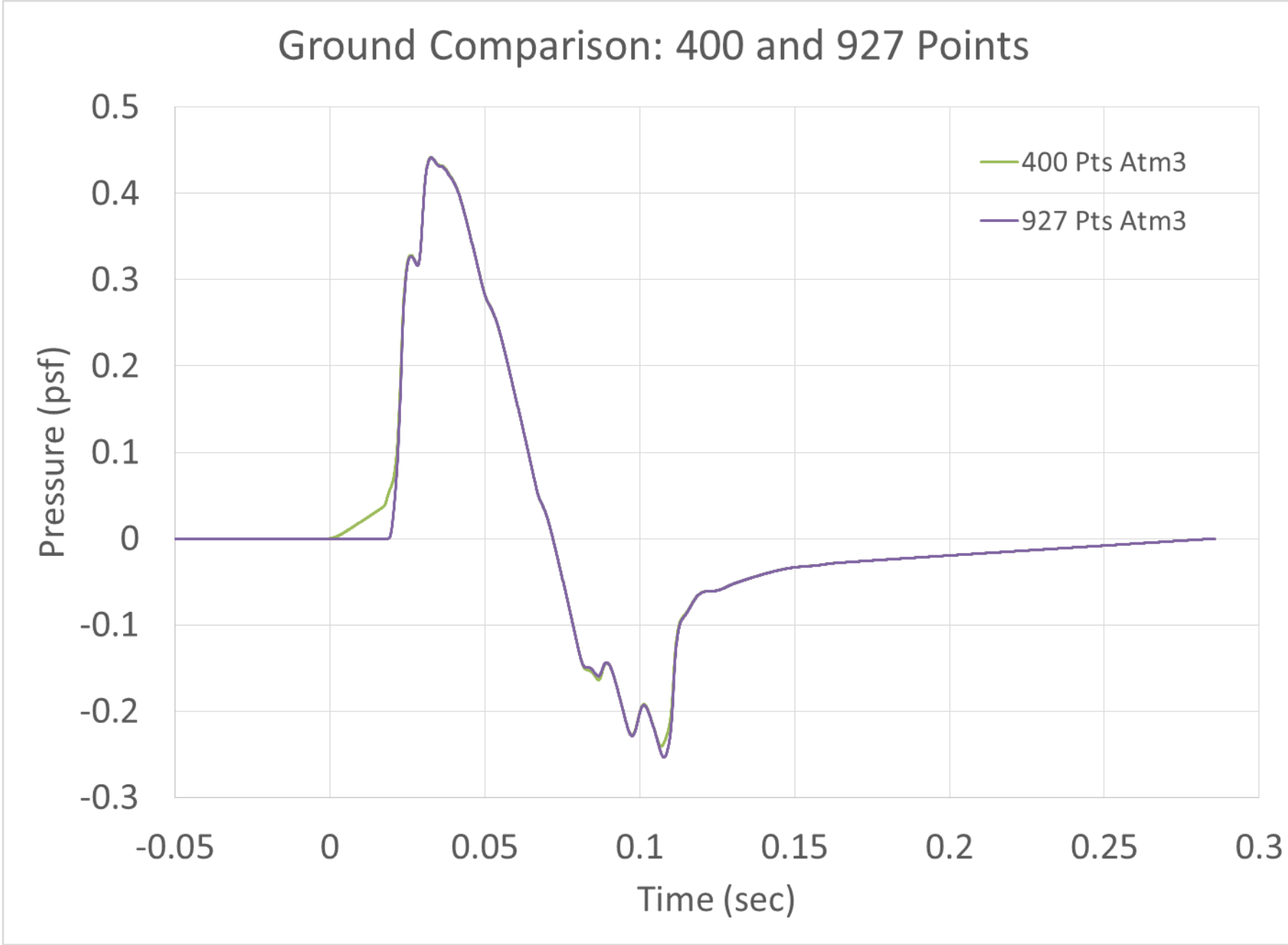


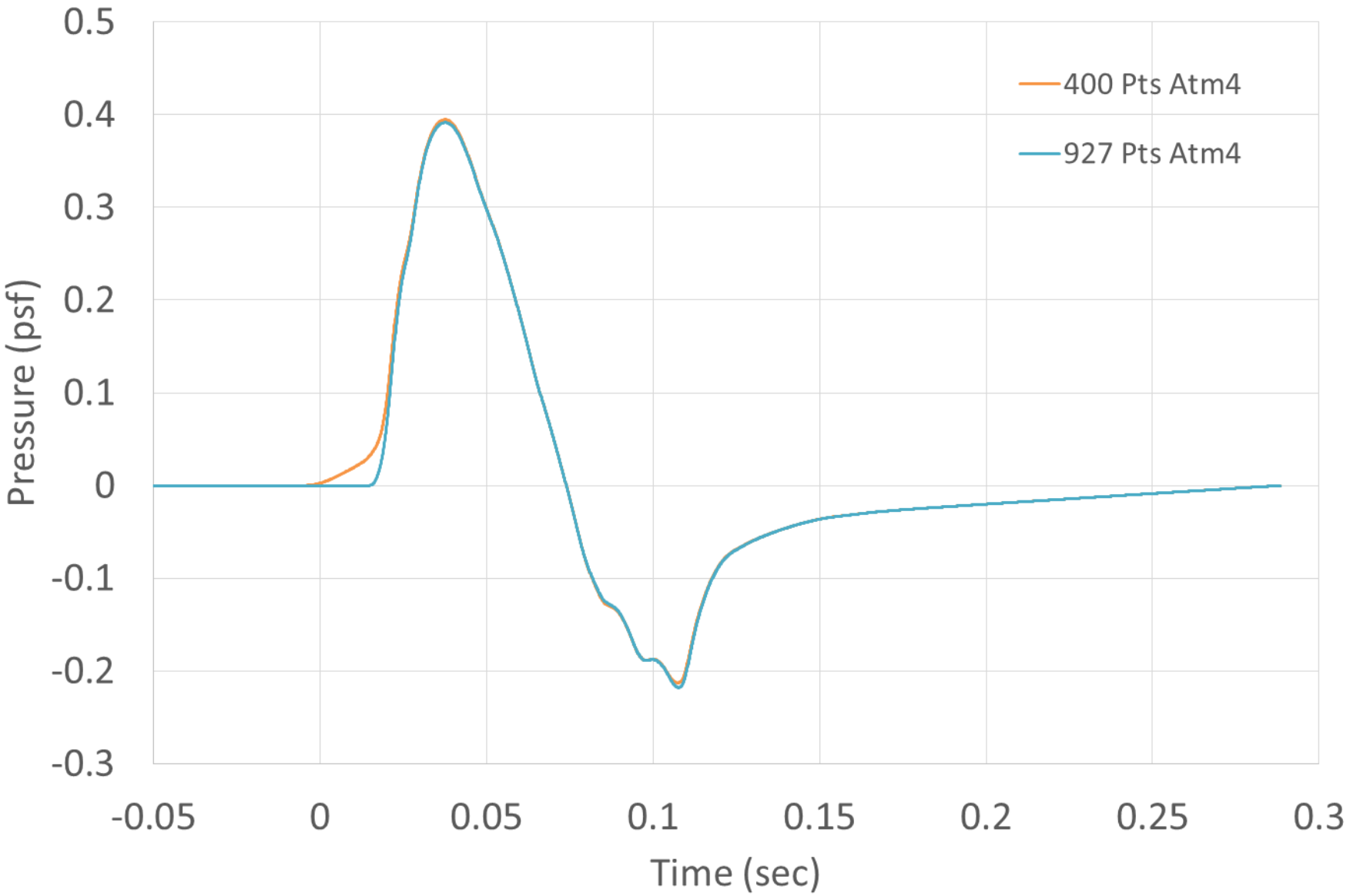
Metric Comparison 400, 805 and 927 Pts

Phi	Atmo	Sig Pts	Sampling Rate	Pmax	Esel	Csel	Asel	PLdB
0	Std70	400	10000.0	0.43	105.22	91.12	64.67	78.44
0	Std70	805	10000.0	0.43	105.18	91.89	64.90	79.25
0	Std70	927	10000.0	0.43	105.18	91.80	64.91	79.25
0	Std	400	10000.0	0.43	105.21	91.23	65.39	79.18
0	Std	805	10000.0	0.43	105.17	91.91	65.59	79.98
0	Std	927	10000.0	0.43	105.17	91.91	65.59	79.99
0	Atm4	400	10000.0	0.39	104.75	89.39	54.27	67.84
0	Atm4	805	10000.0	0.39	104.69	89.93	55.06	68.98
0	Atm4	927	10000.0	0.39	104.68	89.93	55.07	68.98
0	Atm3	400	10000.0	0.44	105.26	91.64	65.96	79.80
0	Atm3	805	10000.0	0.44	105.24	92.34	66.35	80.62
0	Atm3	927	10000.0	0.44	105.25	92.36	66.43	80.69

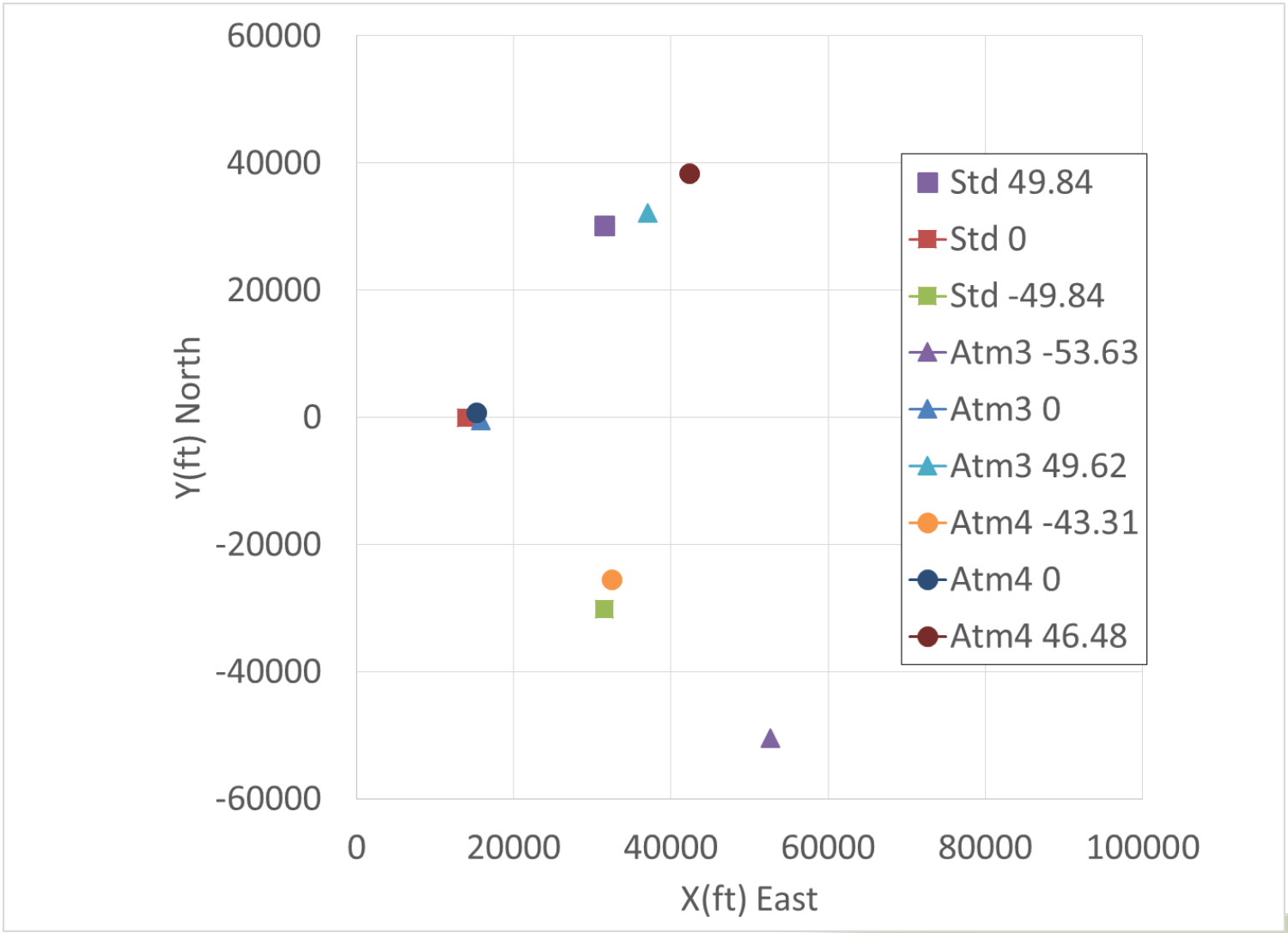

Ground Comparison: 400 and 927 Points
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
Pressure (psf)
-0.05
0
0.05
0.1
0.15
0.2
0.25
0.3
Time (sec)
400 Pts Std
927 Pts Std
400 Pts Atm3
927 Pts Atm3
400 Pts Atm4
927 Pts Atm4


Ground Comparison: 400 and 927 Points
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
Pressure (psf)
-0.05
0
0.05
0.1
0.15
0.2
0.25
0.3
Time (sec)
400 Pts Std
927 Pts Std

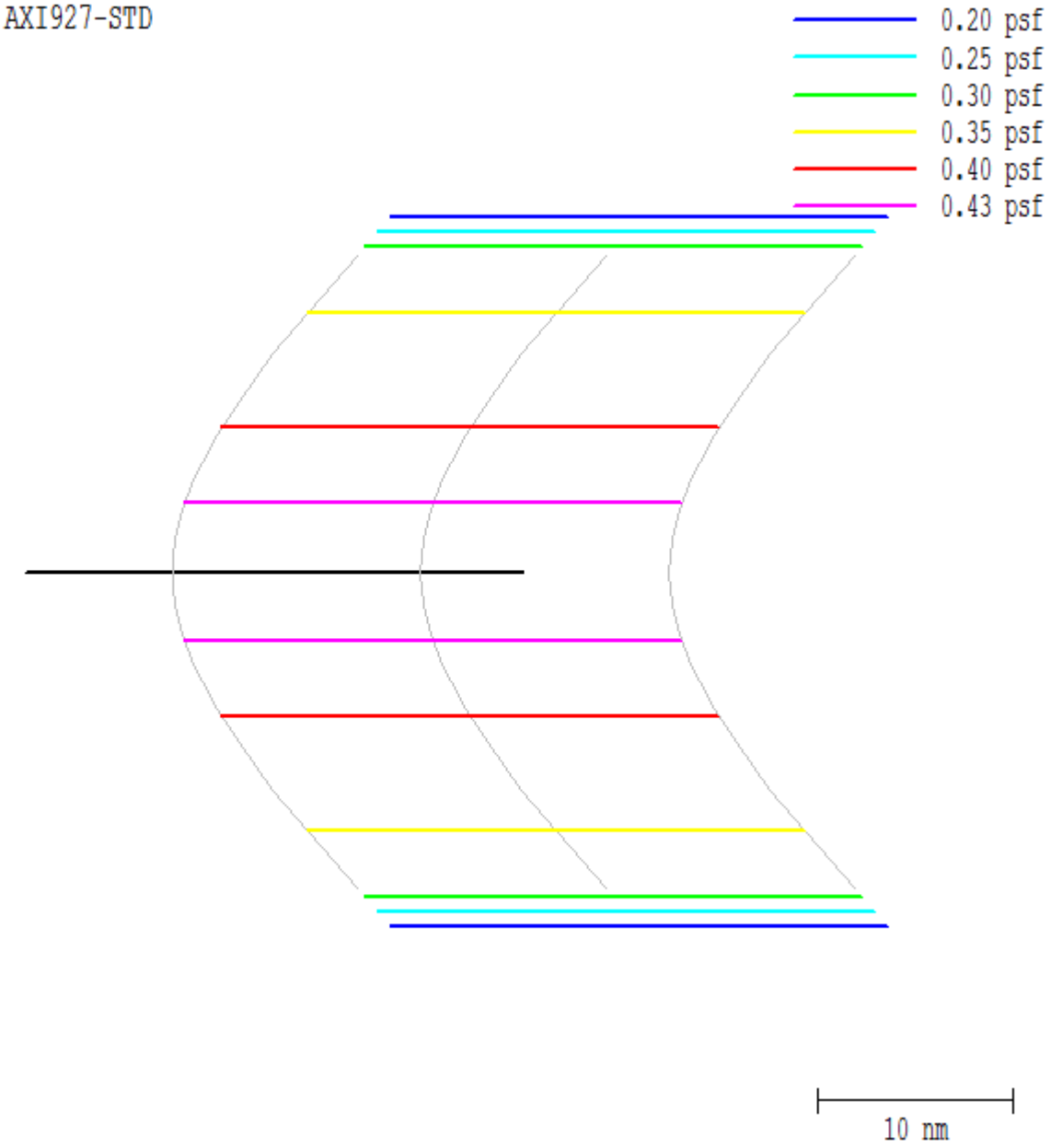

Ground Comparison: 400 and 927 Points
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
Pressure (psf)
-0.05
0
0.05
0.1
0.15
0.2
0.25
0.3
Time (sec)
400 Pts Atm3
927 Pts Atm3


Ground Comparison: 400 and 927 Points
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
Pressure (psf)
-0.05
0
0.05
0.1
0.15
0.2
0.25
0.3
Time (sec)
400 Pts Atm4
927 Pts Atm4

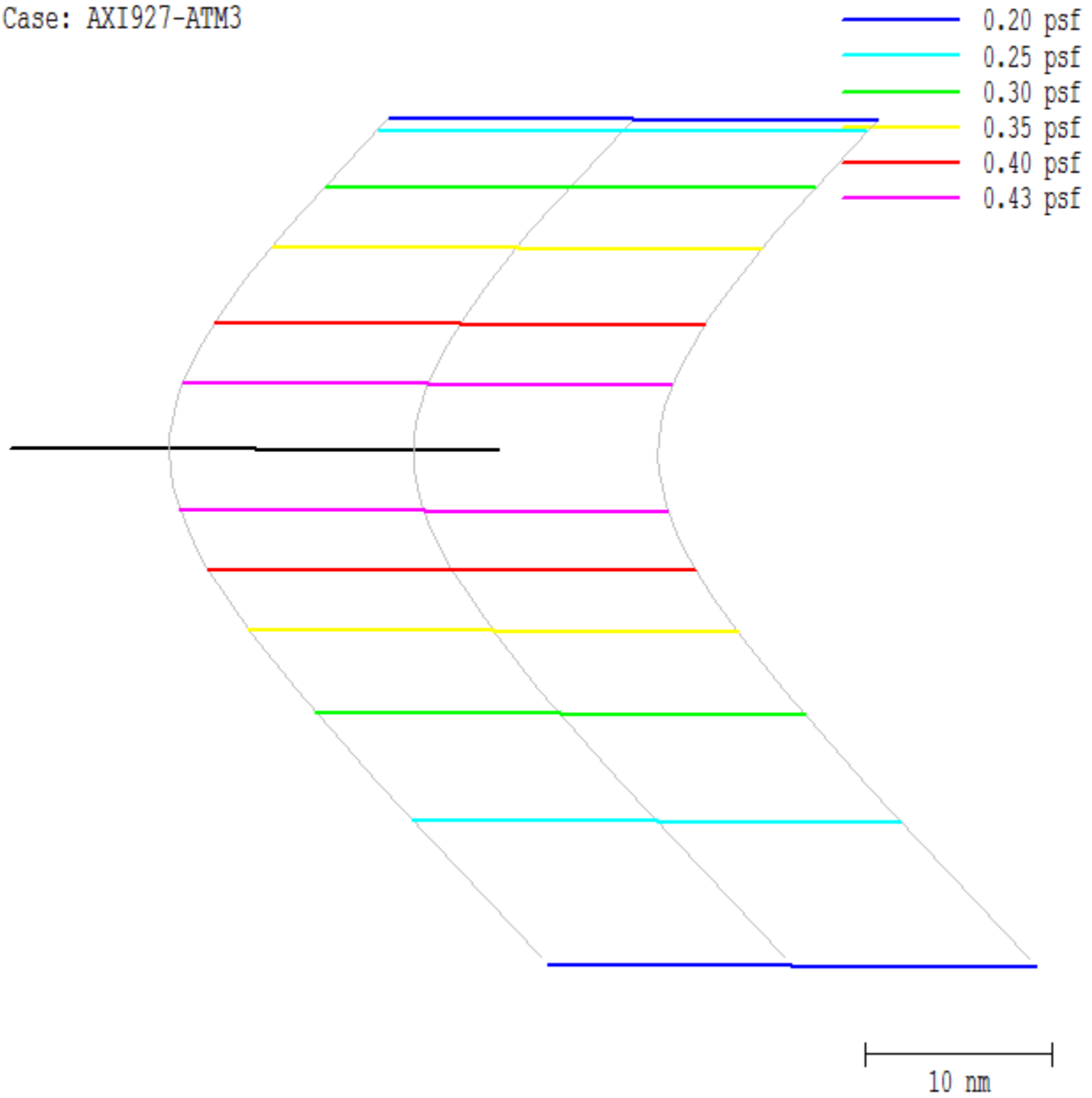
Cutoff Ranges AxiBody Std, Atm3, Atm4



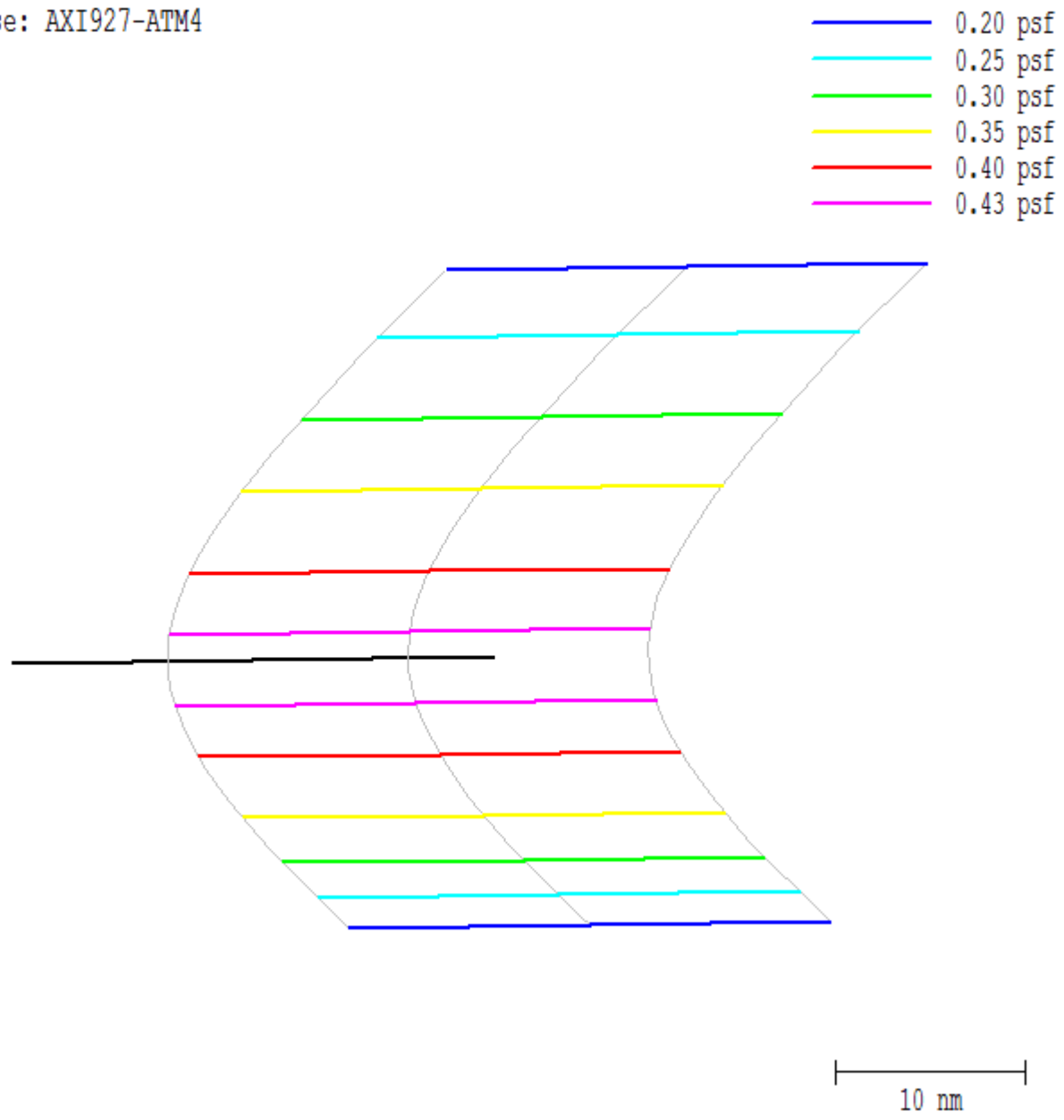
AxiBody Std FOBoom



AxiBody Atm 3 FoBoom



AxiBody Atm 3 FoBoom



AxiBody Burgers Analysis

- Starting signature smoothed by 9-pt Hann weighted average to eliminate single sample jumps at shocks and avoid Gibbs phenomena artifacts
- Program advances 1000 Ft altitude layer subdivided into smaller delta T steps: dT = steepest segment shock formation time (Whitham's rule) * dTfact
- Default dTfact = .05 sec, dTfact = .002 for Atm4
- Burgers Propagation starting at 48,000 Ft. (Flt Alt = 52,000 Ft.)

AxiBody Loudness Convergence Atm 3

Phi	Atmo	Sampling Rate	Pmax	Esel	Csel	Asel	PLdB
-45	Atm3	10000.0	0.29	101.90	89.03	62.40	76.80
-45	Atm3	25600.0	0.29	101.96	89.07	62.77	77.12
-45	Atm3	51200.0	0.29	101.98	89.10	68.23	77.22
0	Atm3	10000.0	0.44	105.25	92.36	66.43	80.69
0	Atm3	25600.0	0.44	105.27	92.38	66.98	81.30
0	Atm3	51200.0	0.44	105.29	92.39	67.13	81.45
45	Atm3	10000.0	0.32	102.63	89.97	63.62	78.35
45	Atm3	25600.0	0.32	102.68	89.98	63.94	78.59
45	Atm3	51200.0	0.32	102.69	89.99	64.03	78.67

AxiBody Loudness Convergence Atm4

Phi	Atmo	Sampling Rate	Pmax	Esel	Csel	Asel	PLdB
-43	Atm4	10000.0	0.19	98.79	83.23	44.51	52.10
-43	Atm4	25600.0	0.19	98.83	83.24	44.48	51.99
-43	Atm4	51200.0	0.19	98.84	83.24	44.46	51.97
0	Atm4	10000.0	0.39	104.68	89.93	55.07	68.98
0	Atm4	25600.0	0.39	104.73	89.96	55.47	69.55
0	Atm4	51200.0	0.39	104.74	89.96	55.54	69.66
45	Atm4	10000.0	0.21	99.63	83.66	43.52	49.43
45	Atm4	25600.0	0.21	99.69	83.70	43.59	49.53
45	Atm4	51200.0	0.21	99.71	83.71	43.61	49.57

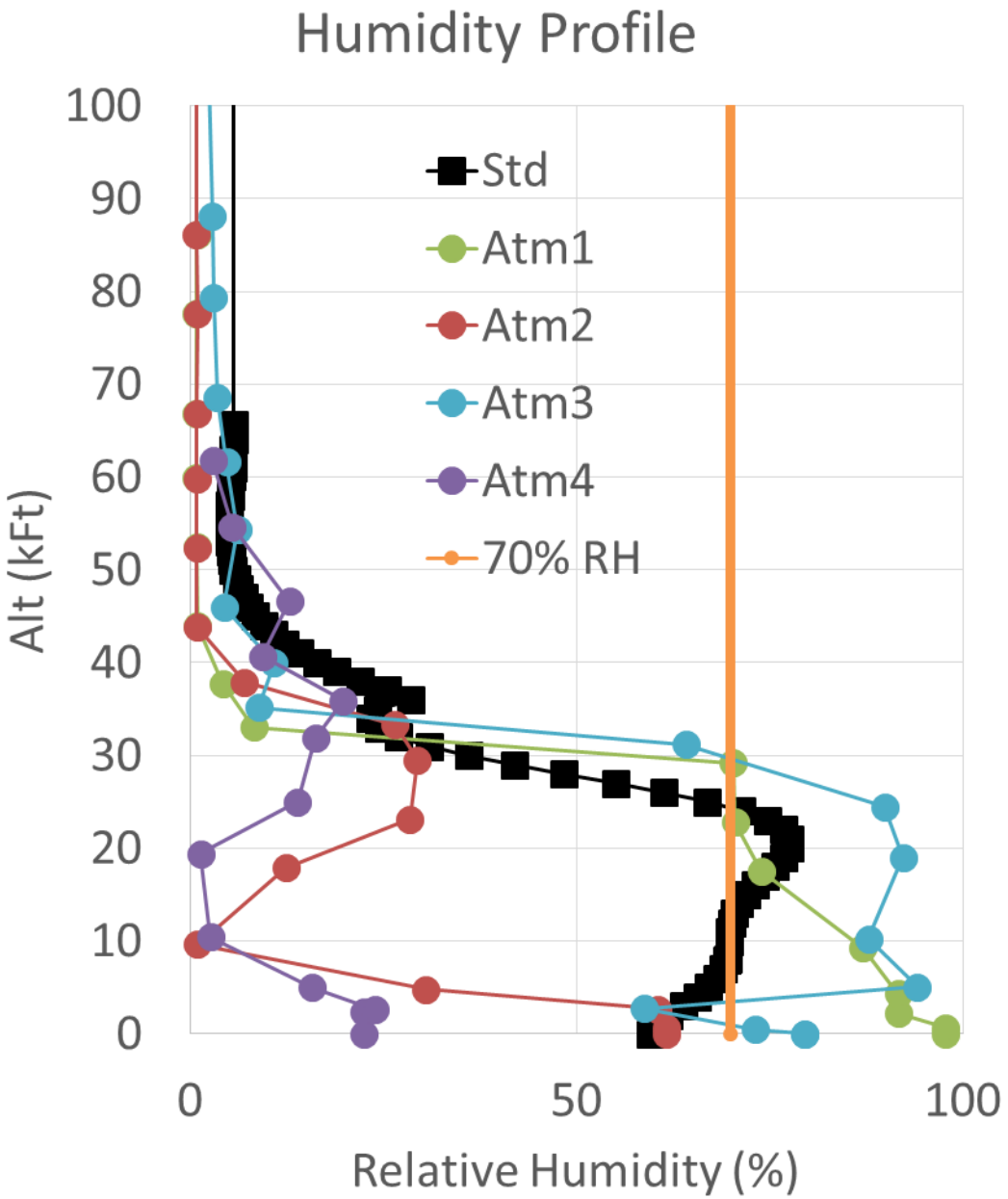
AxiBody Loudness Conv. Std RH

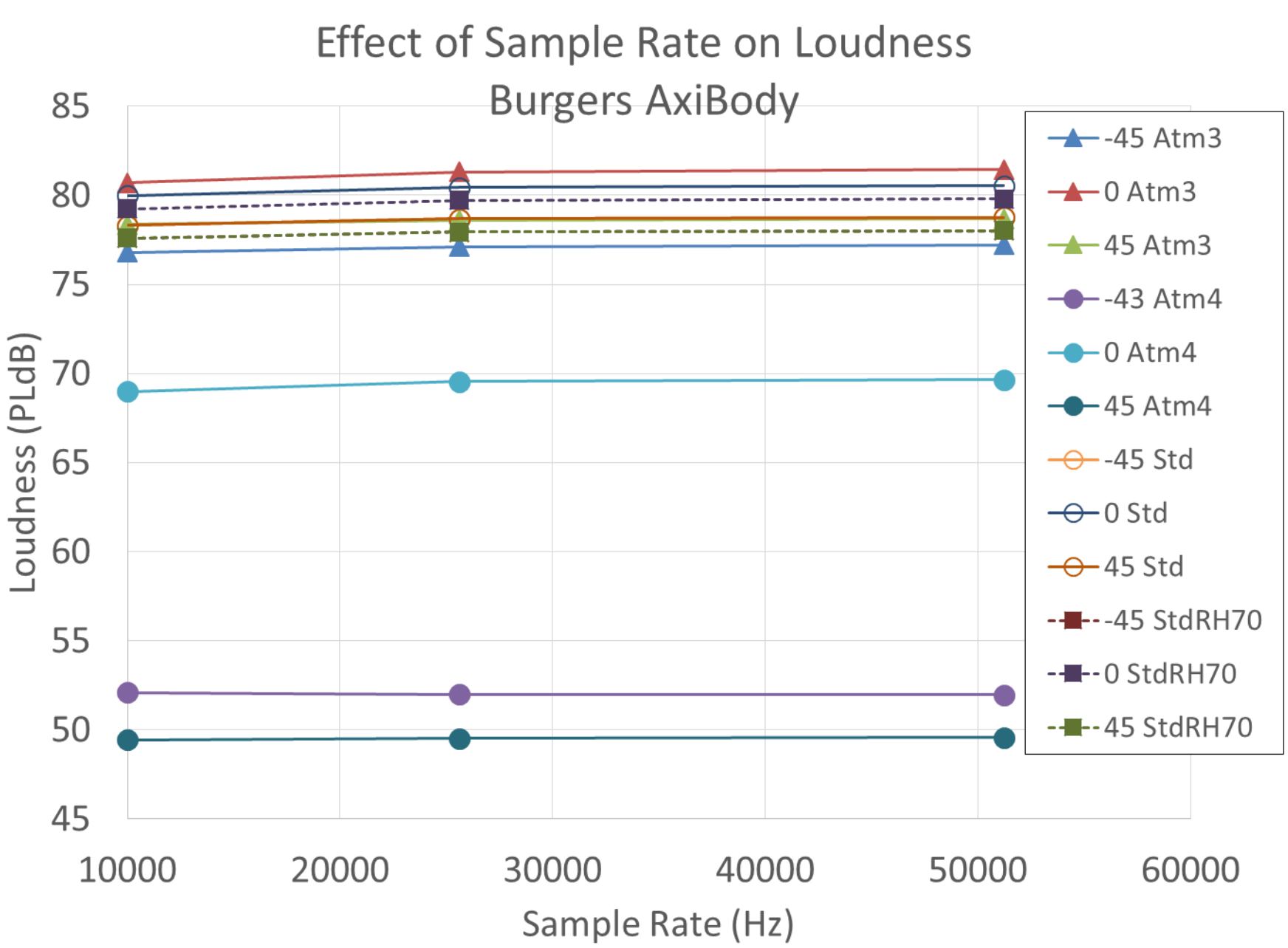
Phi	Atmo	Sampling Rate	Pmax	Esel	Csel	Asel	PLdB
-45	Std	10000.0	0.34	103.28	90.19	64.03	78.31
-45	Std	25600.0	0.34	103.34	90.22	64.44	78.69
-45	Std	51200.0	0.34	103.36	90.24	64.51	78.77
0	Std	10000.0	0.43	105.17	91.91	65.59	79.99
0	Std	25600.0	0.43	105.22	91.95	66.05	80.44
0	Std	51200.0	0.43	105.23	91.96	66.14	80.53
45	Std	10000.0	0.34	103.28	90.19	64.03	78.31
45	Std	25600.0	0.34	103.34	90.22	64.44	78.69
45	Std	51200.0	0.34	103.36	90.24	64.51	78.77

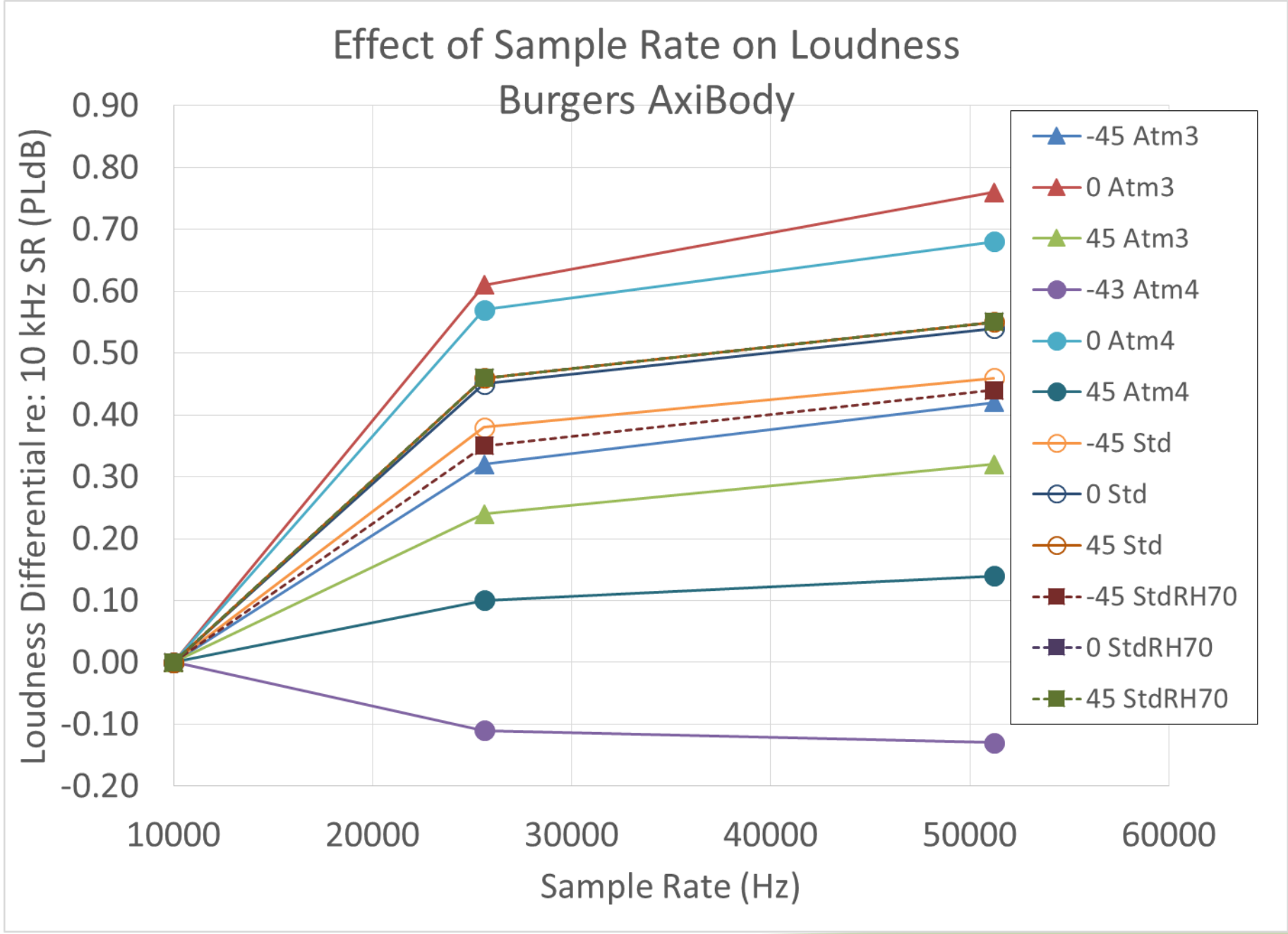
AxiBody Loudness Conv. Std RH70%

Phi	Atmo	Sampling Rate	Pmax	Esel	Csel	Asel	PLdB
-45	StdRH70	10000.0	0.34	103.31	90.11	63.14	77.58
-45	StdRH70	25600.0	0.34	103.36	90.15	63.53	77.93
-45	StdRH70	51200.0	0.34	103.38	90.19	63.59	78.02
0	StdRH70	10000.0	0.43	105.18	91.80	64.91	79.25
0	StdRH70	25600.0	0.43	105.23	91.83	65.34	79.71
0	StdRH70	51200.0	0.43	105.24	91.84	65.44	79.80
45	StdRH70	10000.0	0.34	103.31	90.11	63.14	77.58
45	StdRH70	25600.0	0.34	103.36	90.15	63.53	77.93
45	StdRH70	51200.0	0.34	103.38	90.19	63.59	78.02

Std Atmo ANSI vs. Const %RH




Effect of Sample Rate on Loudness
Burgers AxiBody
Loudness (PLdB)
85
80
75
70
65
60
55
50
45
10000
20000
30000
40000
50000
60000
Sample Rate (Hz)
-45 Atm3
0 Atm3
45 Atm3
-43 Atm4
0 Atm4
45 Atm4
-45 Std
0 Std
45 Std
-45 StdRH70
0 StdRH70
45 StdRH70


Effect of Sample Rate on Loudness
Burgers AxiBody
Loudness Differential re: 10 kHz SR (PLdB)
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
10000
20000
30000
40000
50000
60000
Sample Rate (Hz)
-45 Atm3
0 Atm3
45 Atm3
-43 Atm4
0 Atm4
45 Atm4
-45 Std
0 Std
45 Std
-45 StdRH70
0 StdRH70
45 StdRH70

Observations

- Higher sampling rates needed for converged loudness calculations than past linear loudness practices
- Focusing with Real atmospheres can get complex

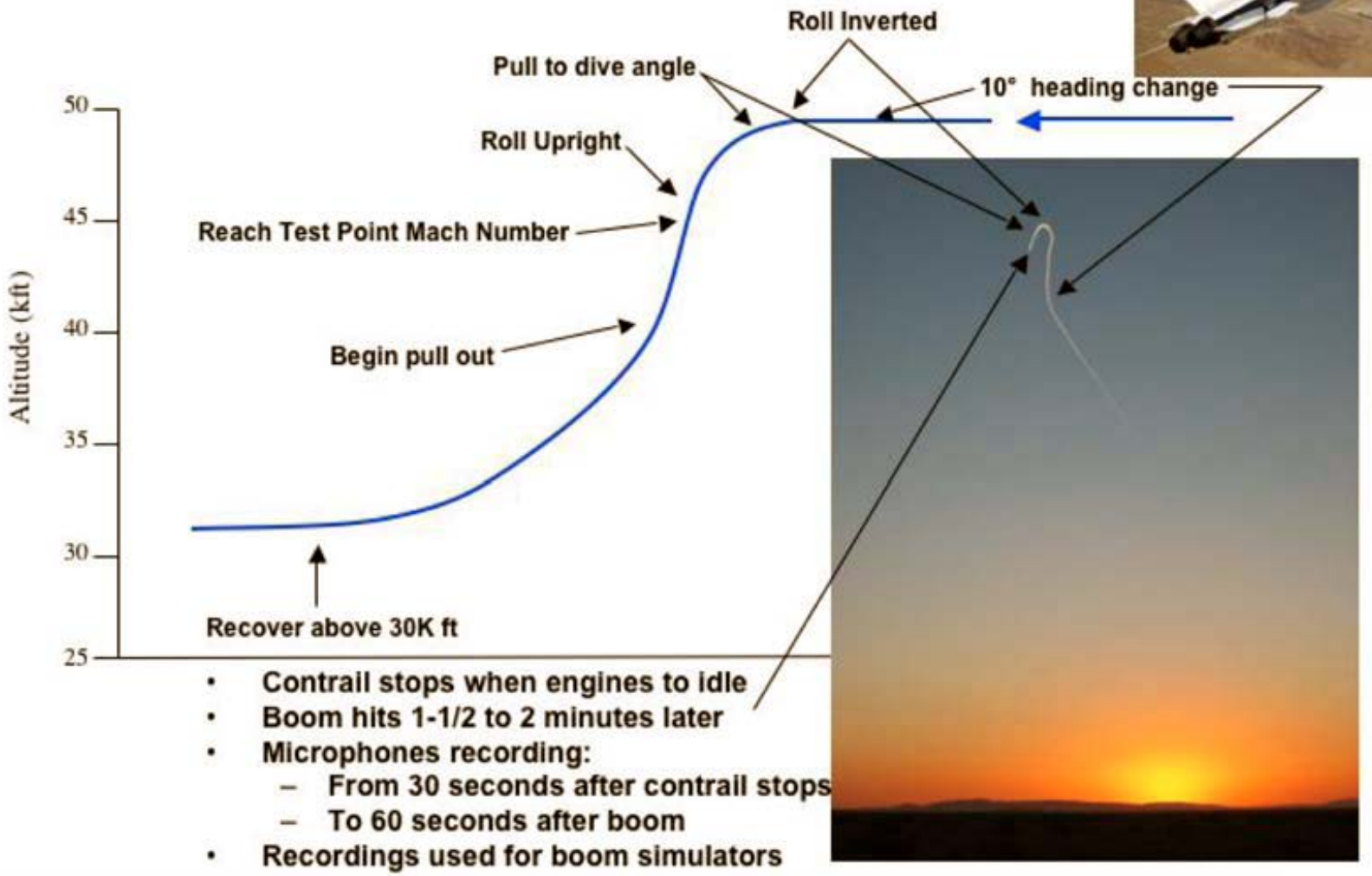
PCBoom Considerations

- Need to increase the array sizes passing from FOBoom to PCBFoot & WCON
- Need a batch Burgers Solver w/ automated Gibbs artifact Checking

Possible Future Analyses

- Maneuvers with focusing → Ray Paths and Signature Prediction using real atmospheres

Dive Flight Maneuver



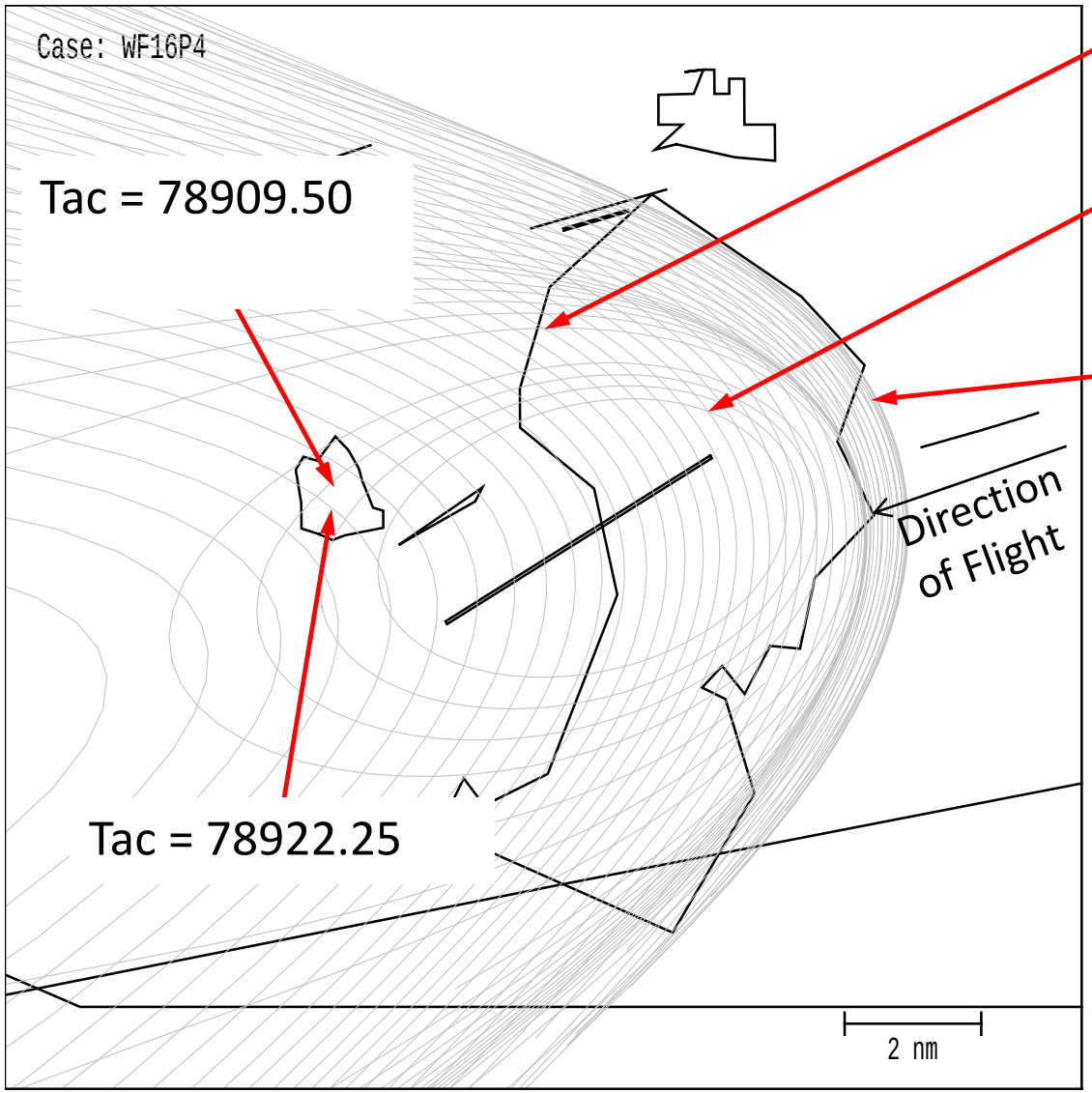
- Contrail stops when engines to idle
- Boom hits 1-1/2 to 2 minutes later
- Microphones recording:
  - From 30 seconds after contrail stops
  - To 60 seconds after boom
- Recordings used for boom simulators

DRYDEN FLIGHT RESEARCH CENTER

"...to separate the real from the imagined." - Dr. Hugh L. Dryden

NASA

A Closer Look



Tac = 78910.25

Tac = 78909 (1st supersonic point)

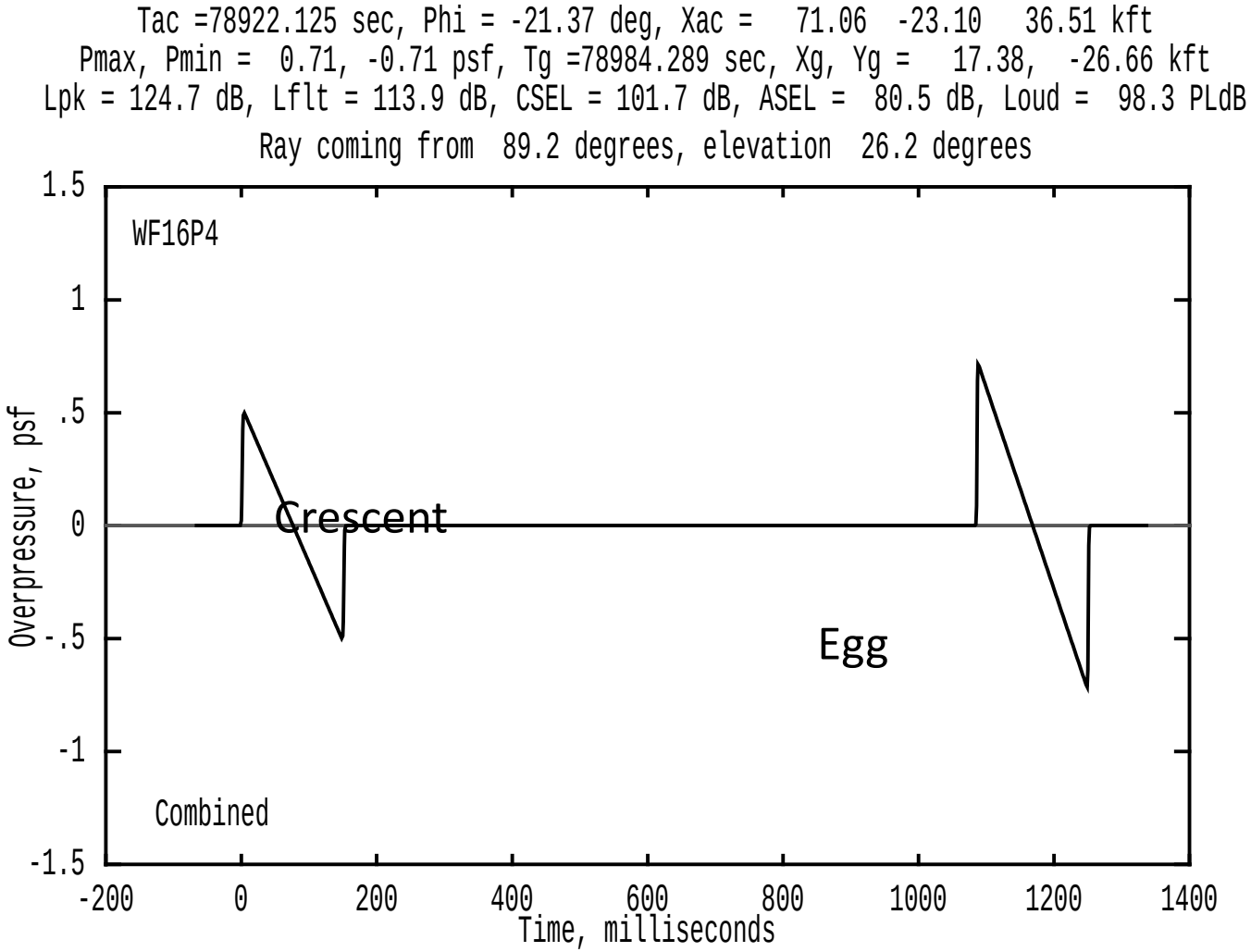
Tac = 78915

Two carpet boom regions:

- Early "eggs" as aircraft is pointing down
- Customary crescents later on
- Boom arrival times in overlap area much closer than generation times

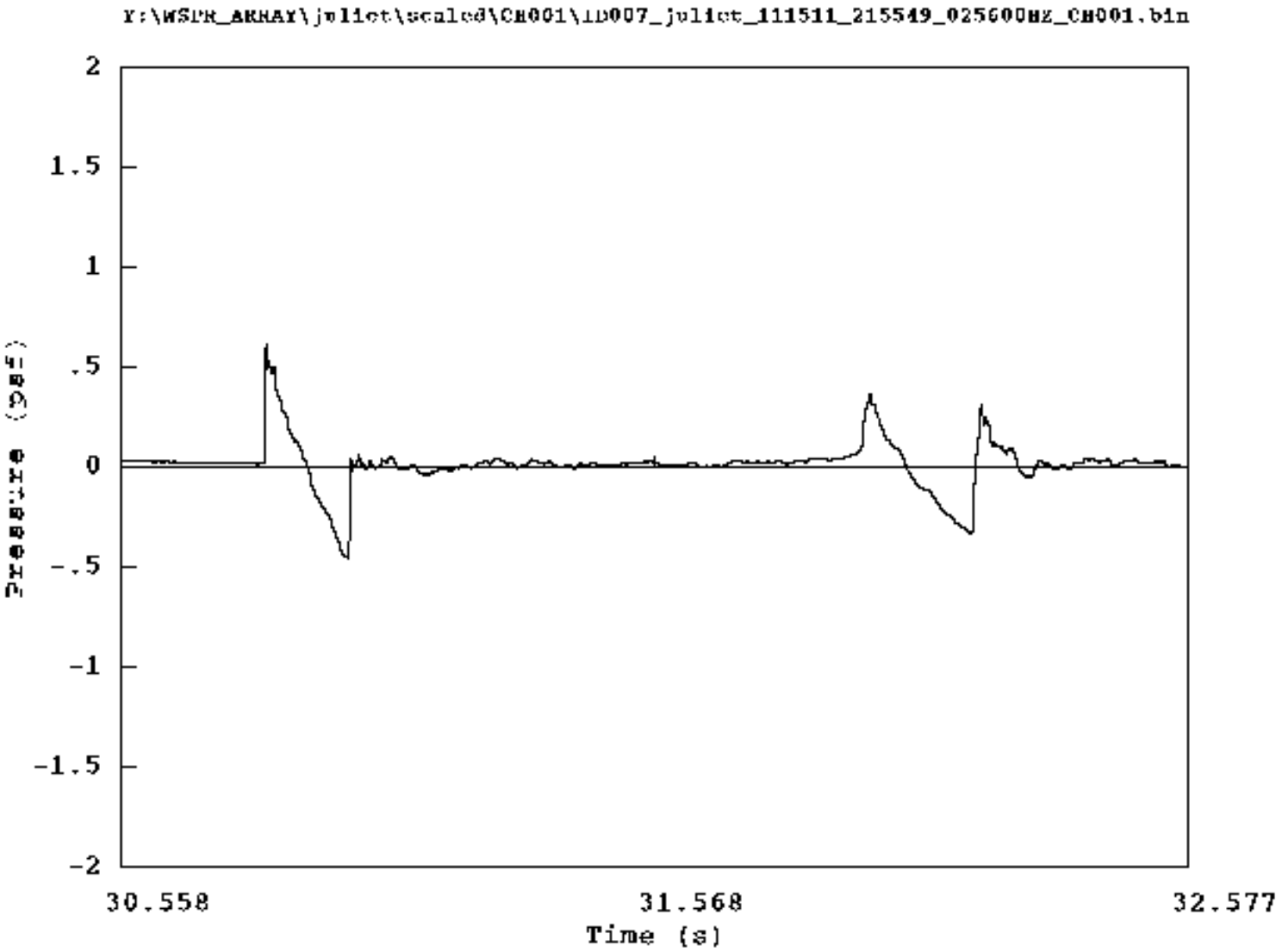
WSPR Flight 16, Pass 4, Boom 65

Predicted Double Booms



WSPR Flight 16, Pass 1, Boom 62, Site J

Measured Double Boom



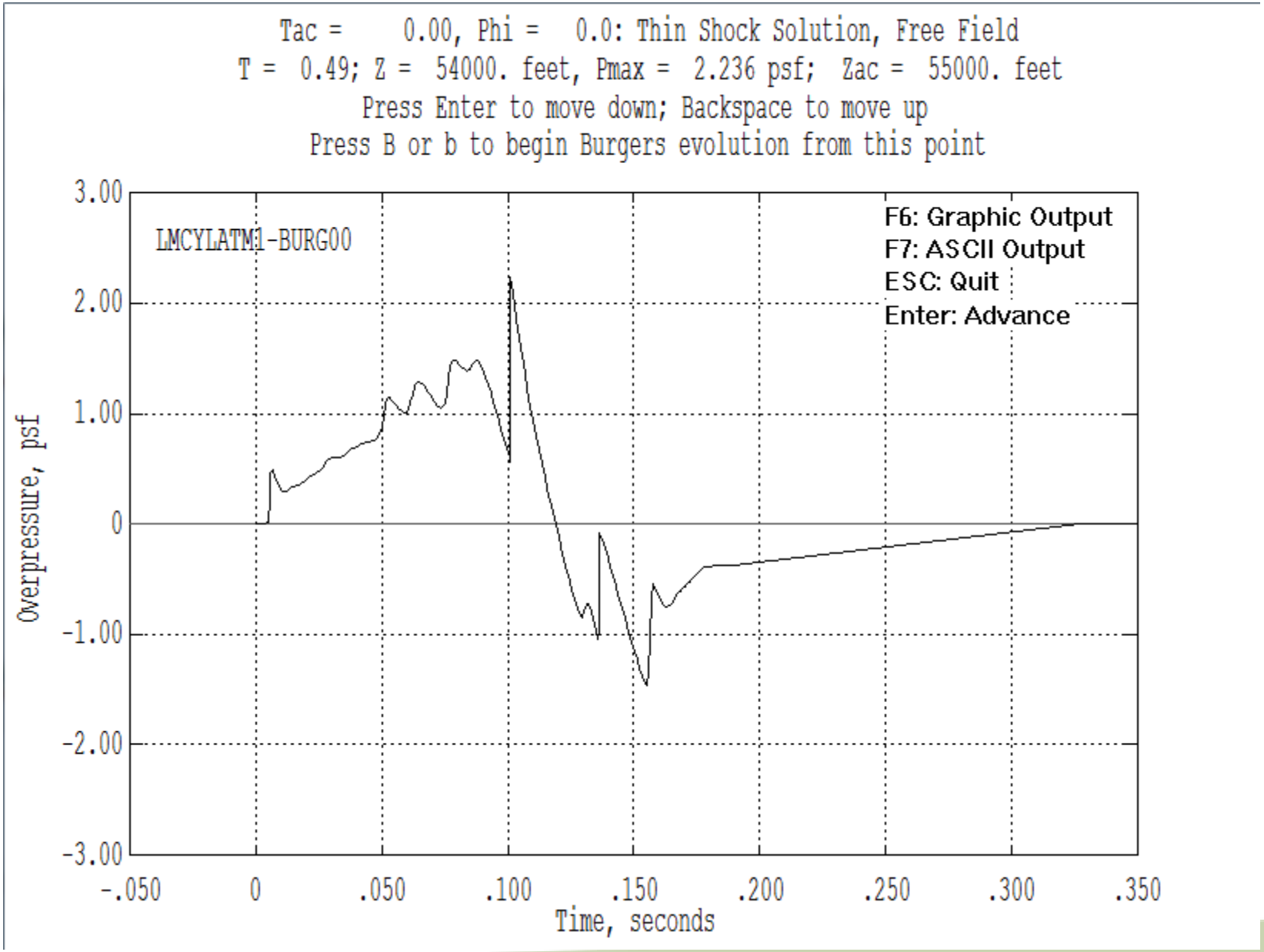
WSPR Flight 16, Pass 1, Boom 62, Site J

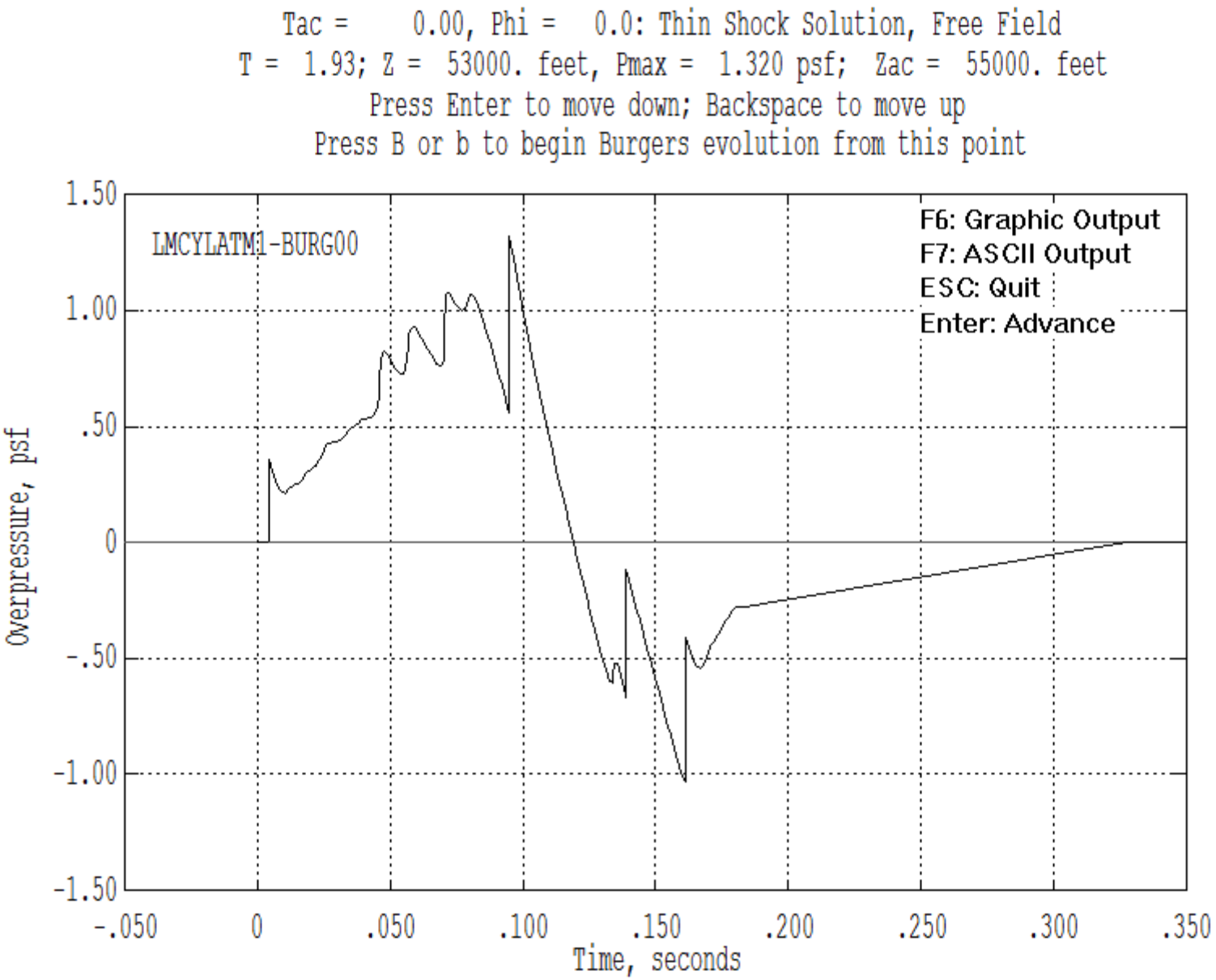
Questions?

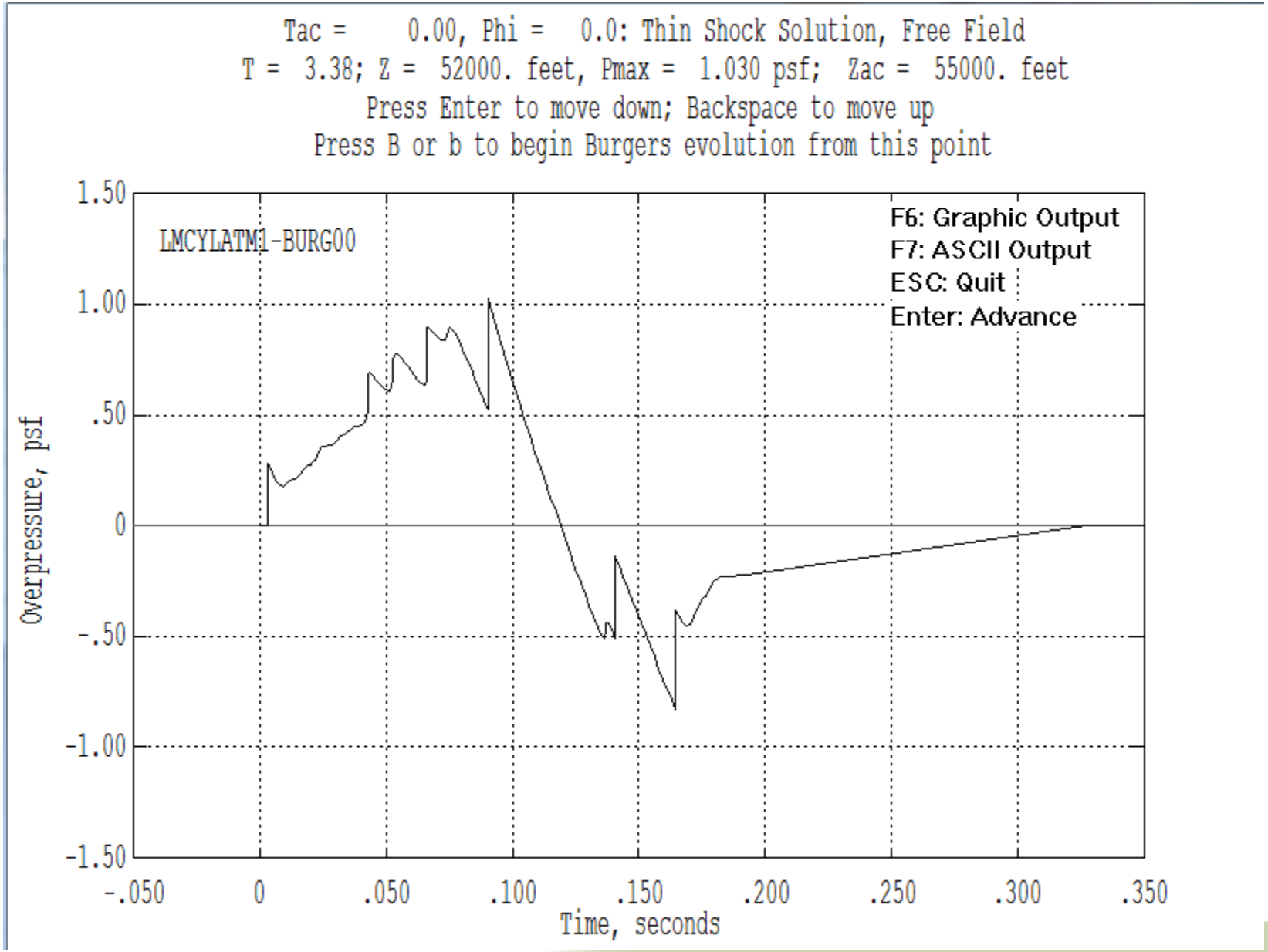
Backup Slides

LM1021 FOBoom Propagation (no relax.)

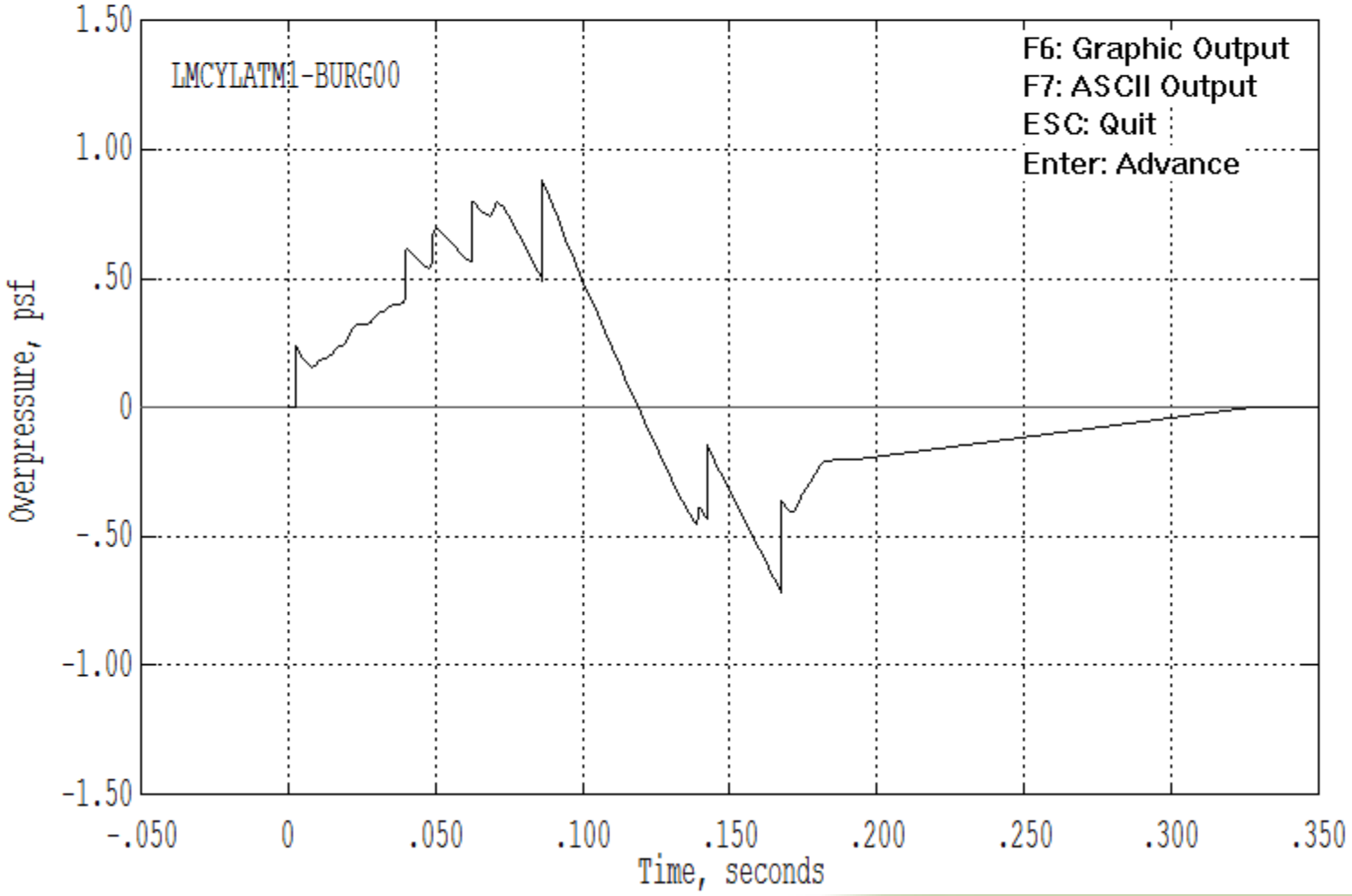
- LM 1021
- Standard Atmo (no Hydrostatic Pressure)
- Phi = 0 deg

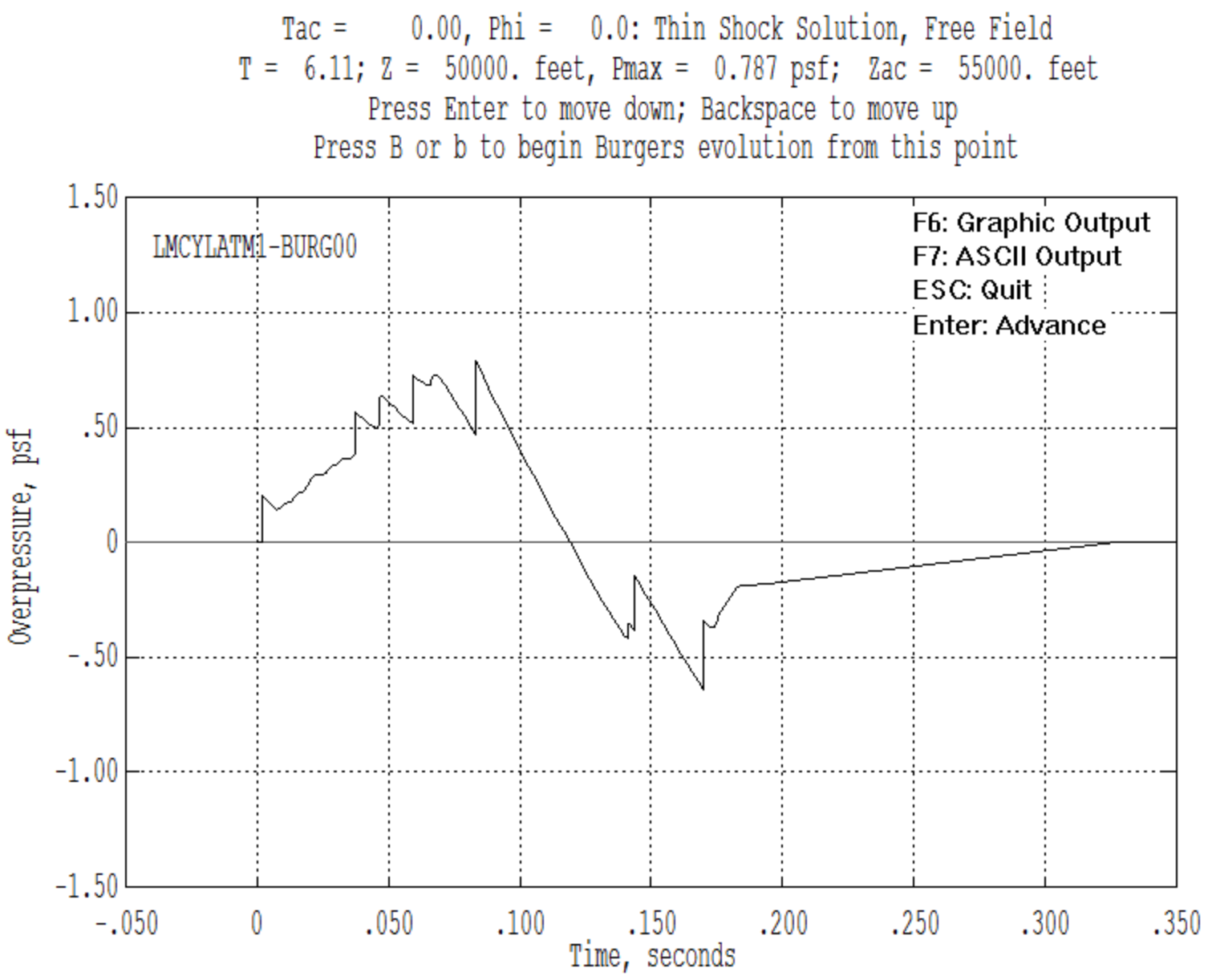

Tac = 0.00, Phi = 0.0: Thin Shock Solution, Free Field
T = 0.49; Z = 54000. feet, Pmax = 2.236 psf; Zac = 55000. feet
Press Enter to move down; Backspace to move up
Press B or b to begin Burgers evolution from this point
LMCYLATM1-BURG00
F6: Graphic Output
F7: ASCII Output
ESC: Quit
Enter: Advance
Overpressure, psf
3.00
2.00
1.00
0
-1.00
-2.00
-3.00
-.050
0
.050
.100
.150
.200
.250
.300
.350
Time, seconds

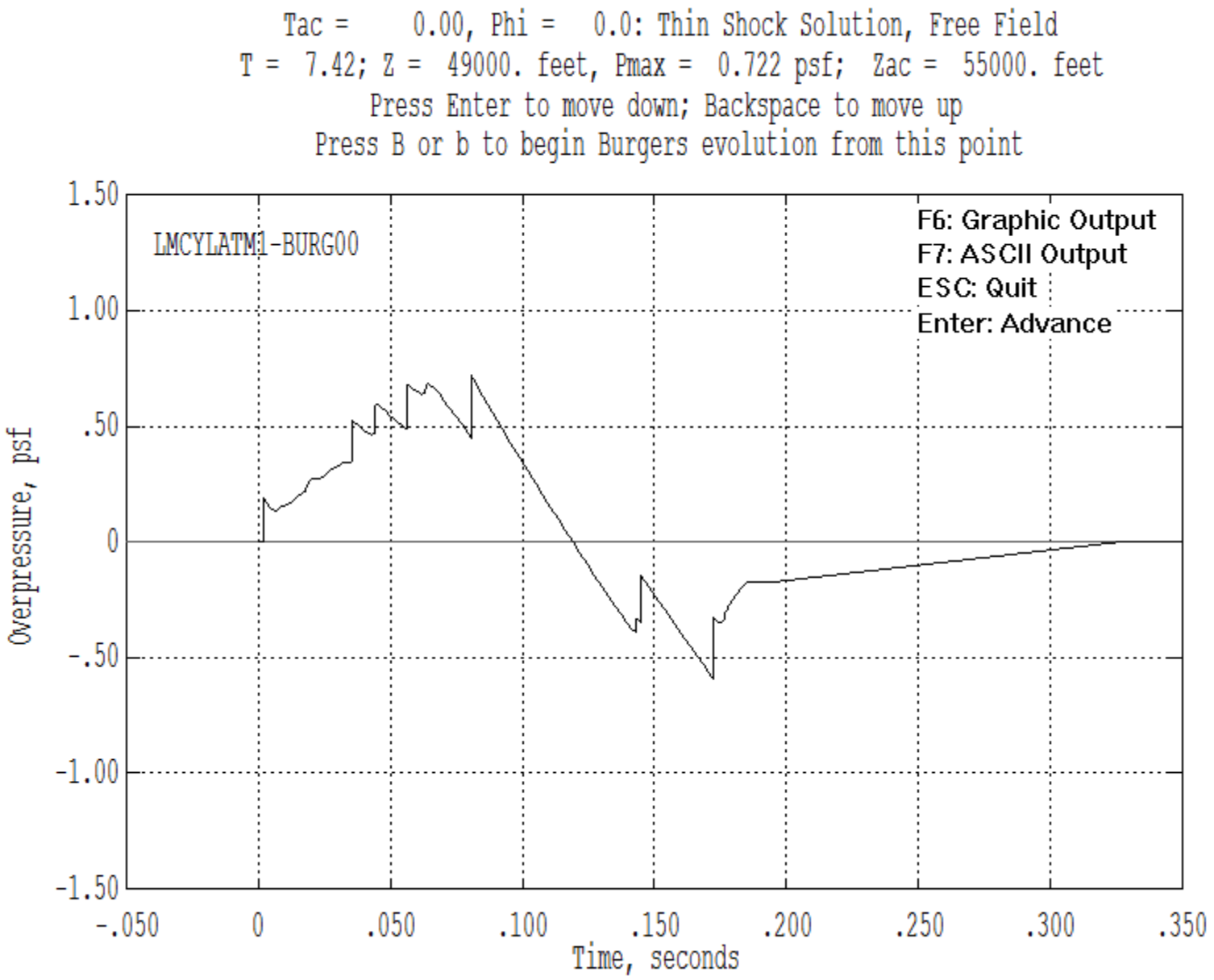

Tac = 0.00, Phi = 0.0: Thin Shock Solution, Free Field
T = 1.93; Z = 53000. feet, Pmax = 1.320 psf; Zac = 55000. feet
Press Enter to move down; Backspace to move up
Press B or b to begin Burgers evolution from this point
LMCYLATM1-BURG00
F6: Graphic Output
F7: ASCII Output
ESC: Quit
Enter: Advance
Overpressure, psf
1.50
1.00
.50
0
-.50
-1.00
-1.50
-.050
0
.050
.100
.150
.200
.250
.300
.350
Time, seconds

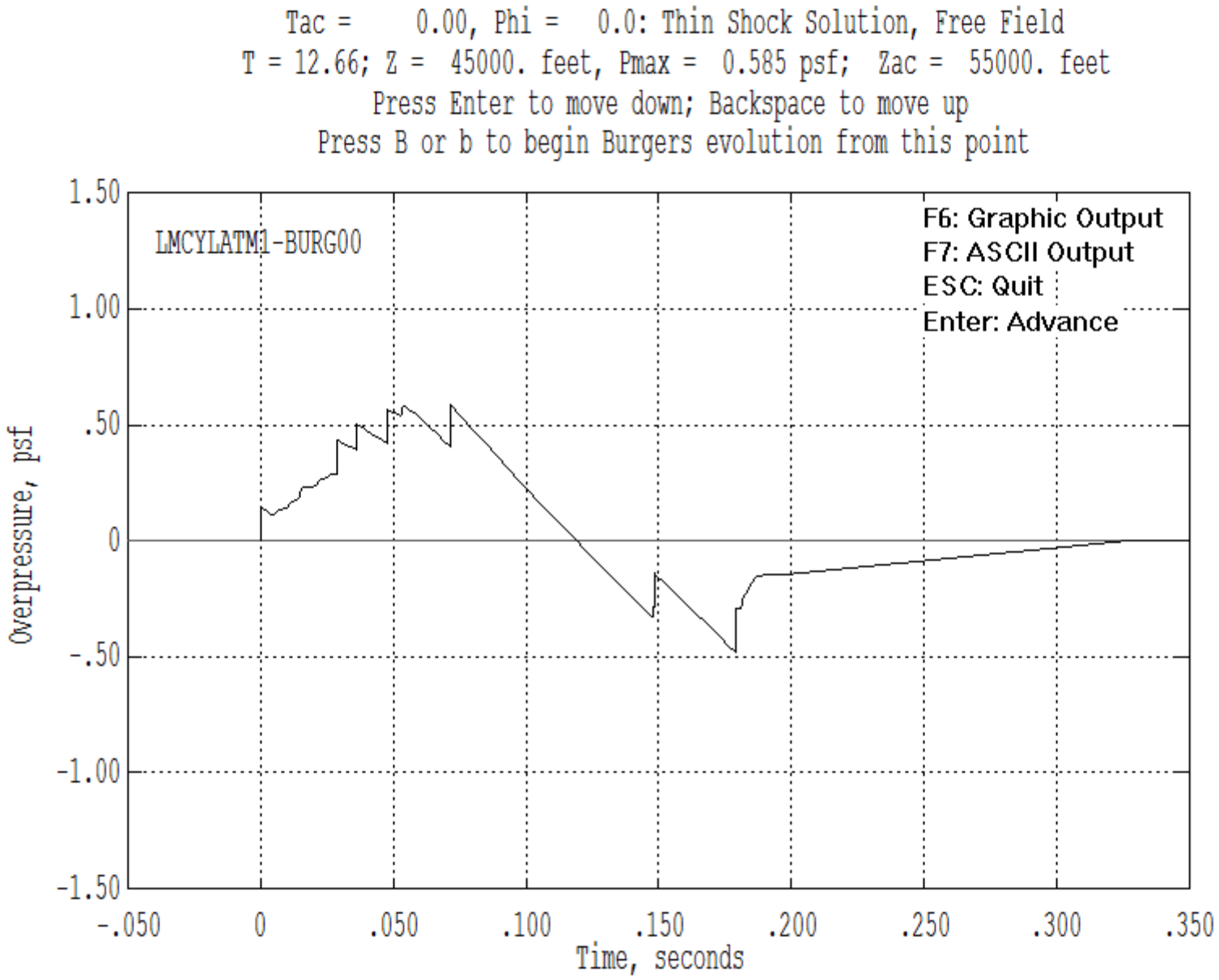

Tac = 0.00, Phi = 0.0: Thin Shock Solution, Free Field
T = 3.38; Z = 52000. feet, Pmax = 1.030 psf; Zac = 55000. feet
Press Enter to move down; Backspace to move up
Press B or b to begin Burgers evolution from this point
LMCYLATM1-BURG00
F6: Graphic Output
F7: ASCII Output
ESC: Quit
Enter: Advance
Overpressure, psf
1.50
1.00
.50
0
-.50
-1.00
-1.50
-.050
0
.050
.100
.150
.200
.250
.300
.350
Time, seconds

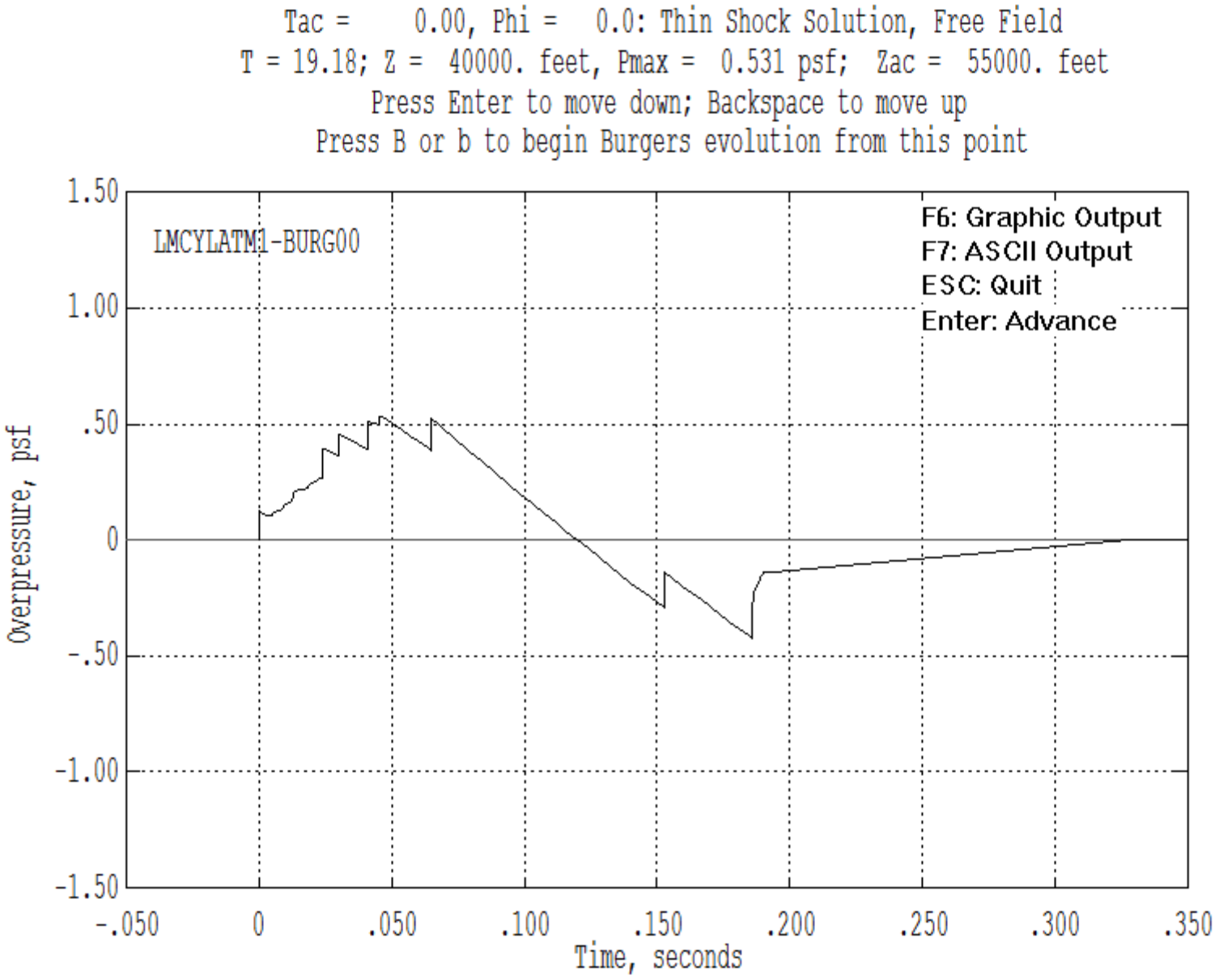
Tac = 0.00, Phi = 0.0: Thin Shock Solution, Free Field
T = 4.79; Z = 51000. feet, Pmax = 0.880 psf; Zac = 55000. feet
Press Enter to move down; Backspace to move up
Press B or b to begin Burgers evolution from this point

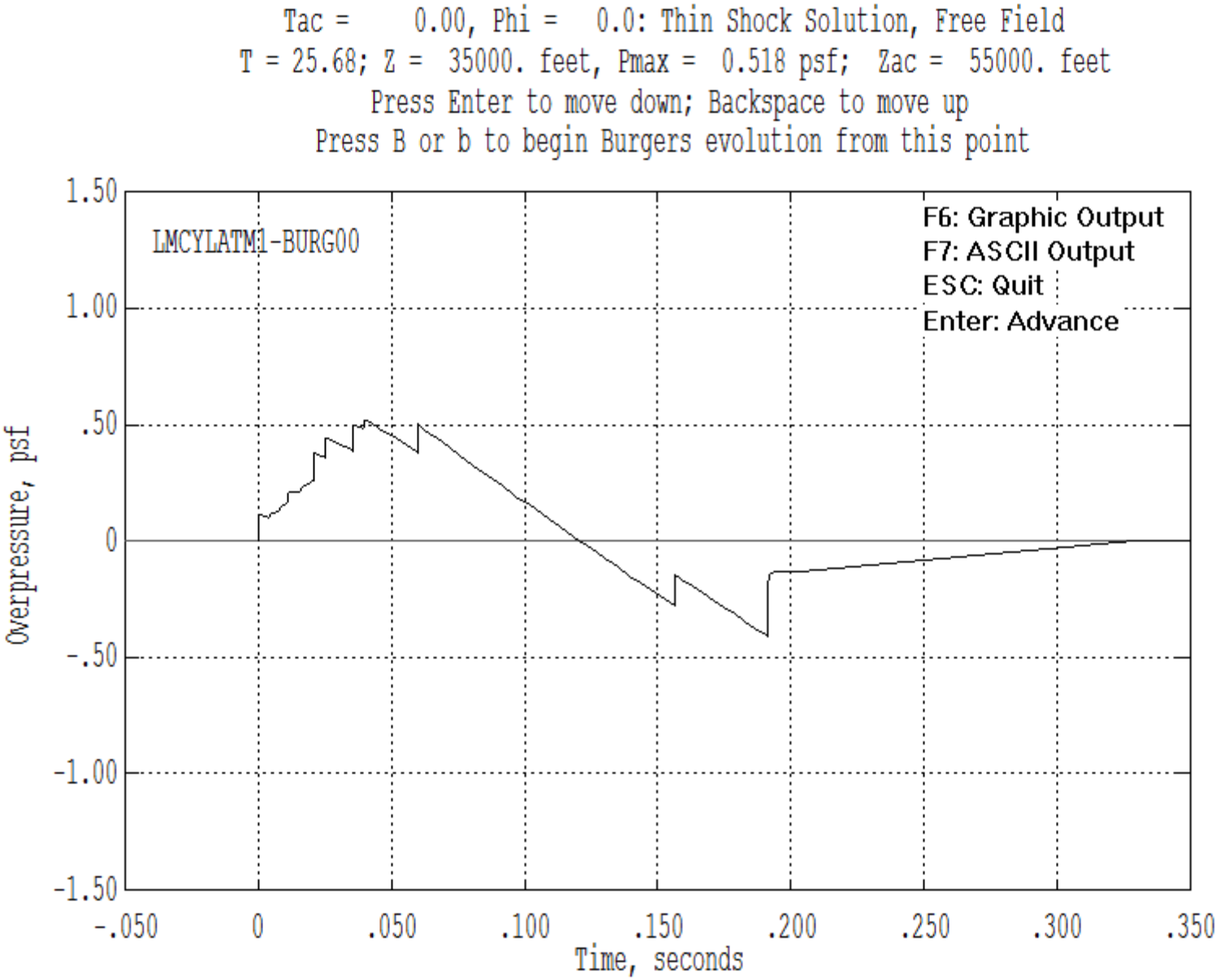


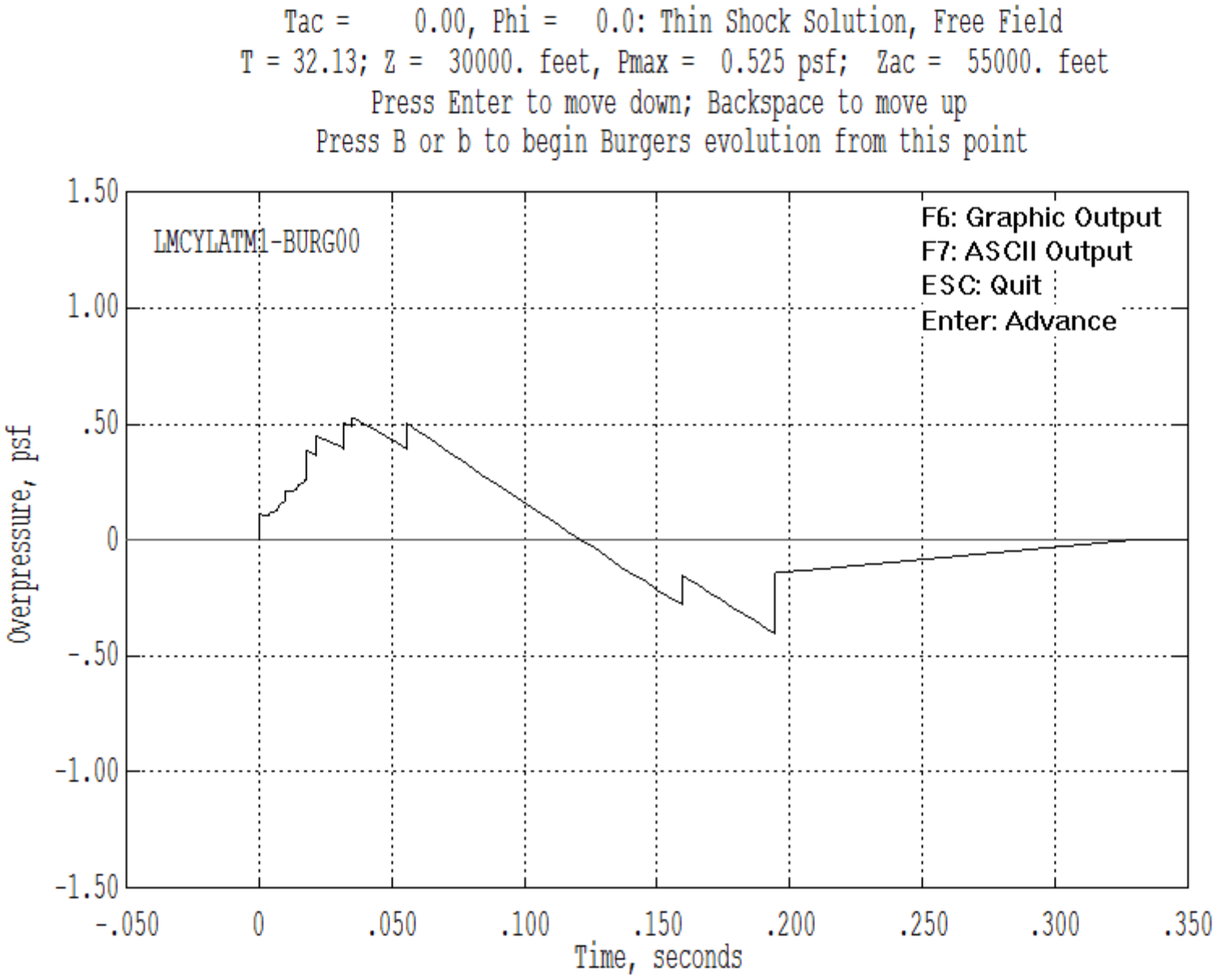

Tac = 0.00, Phi = 0.0: Thin Shock Solution, Free Field
T = 6.11; Z = 50000. feet, Pmax = 0.787 psf; Zac = 55000. feet
Press Enter to move down; Backspace to move up
Press B or b to begin Burgers evolution from this point
LMCYLATM1-BURG00
F6: Graphic Output
F7: ASCII Output
ESC: Quit
Enter: Advance
Overpressure, psf
1.50
1.00
.50
0
-.50
-1.00
-1.50
-.050
0
.050
.100
.150
.200
.250
.300
.350
Time, seconds

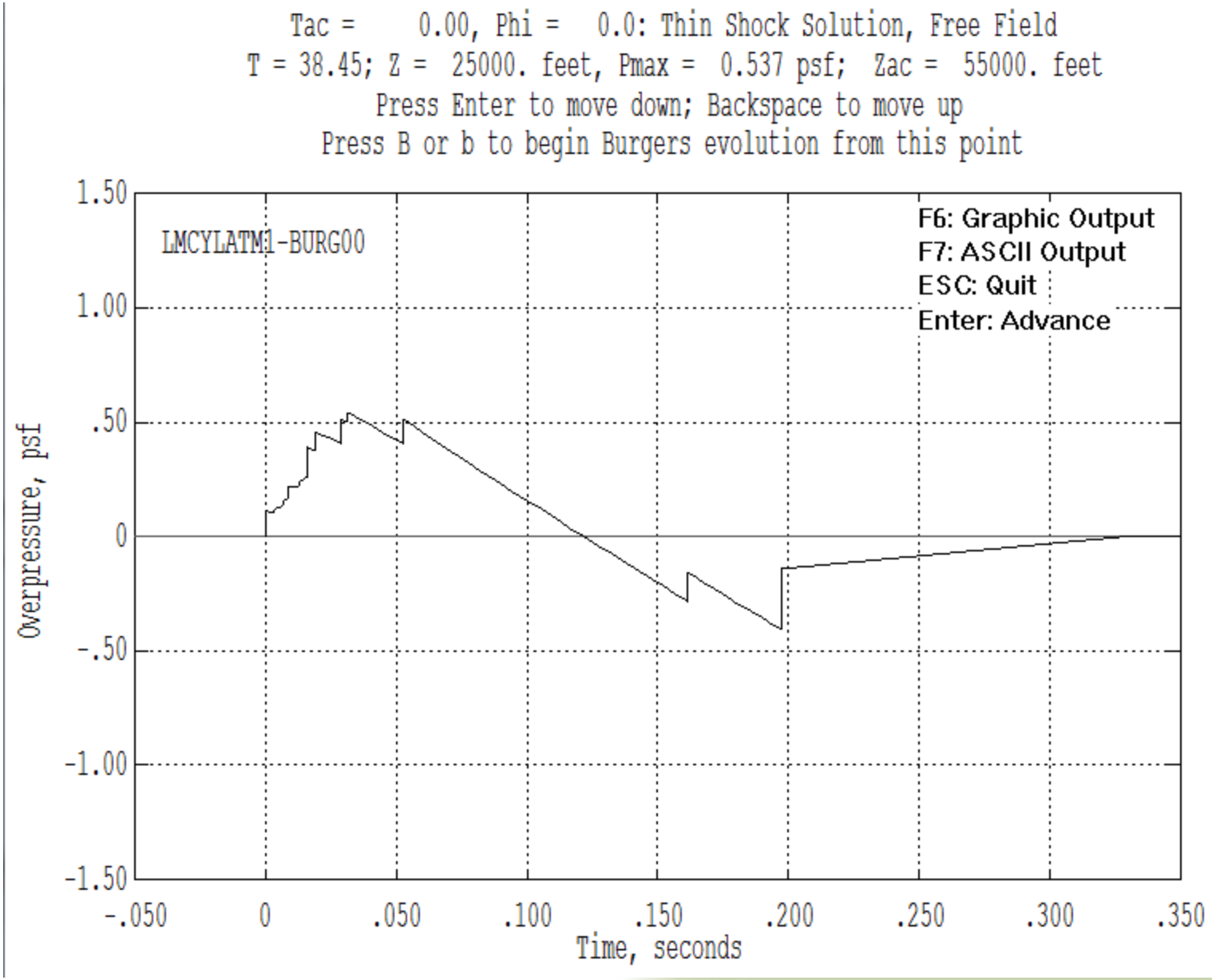

Tac = 0.00, Phi = 0.0: Thin Shock Solution, Free Field
T = 7.42; Z = 49000. feet, Pmax = 0.722 psf; Zac = 55000. feet
Press Enter to move down; Backspace to move up
Press B or b to begin Burgers evolution from this point
LMCYLATM1-BURG00
F6: Graphic Output
F7: ASCII Output
ESC: Quit
Enter: Advance
Overpressure, psf
1.50
1.00
.50
0
-.50
-1.00
-1.50
-.050
0
.050
.100
.150
.200
.250
.300
.350
Time, seconds


Tac = 0.00, Phi = 0.0: Thin Shock Solution, Free Field
T = 12.66; Z = 45000. feet, Pmax = 0.585 psf; Zac = 55000. feet
Press Enter to move down; Backspace to move up
Press B or b to begin Burgers evolution from this point
LMCYLATM1-BURG00
F6: Graphic Output
F7: ASCII Output
ESC: Quit
Enter: Advance
Overpressure, psf
1.50
1.00
.50
0
-.50
-1.00
-1.50
-.050
0
.050
.100
.150
.200
.250
.300
.350
Time, seconds


Tac = 0.00, Phi = 0.0: Thin Shock Solution, Free Field
T = 19.18; Z = 40000. feet, Pmax = 0.531 psf; Zac = 55000. feet
Press Enter to move down; Backspace to move up
Press B or b to begin Burgers evolution from this point
LMCYLATM1-BURG00
F6: Graphic Output
F7: ASCII Output
ESC: Quit
Enter: Advance
Overpressure, psf
1.50
1.00
.50
0
-.50
-1.00
-1.50
-.050
0
.050
.100
.150
.200
.250
.300
.350
Time, seconds


Tac = 0.00, Phi = 0.0: Thin Shock Solution, Free Field
T = 25.68; Z = 35000. feet, Pmax = 0.518 psf; Zac = 55000. feet
Press Enter to move down; Backspace to move up
Press B or b to begin Burgers evolution from this point
LMCYLATM1-BURG00
F6: Graphic Output
F7: ASCII Output
ESC: Quit
Enter: Advance
Overpressure, psf
1.50
1.00
.50
0
-.50
-1.00
-1.50
-.050
0
.050
.100
.150
.200
.250
.300
.350
Time, seconds


Tac = 0.00, Phi = 0.0: Thin Shock Solution, Free Field
T = 32.13; Z = 30000. feet, Pmax = 0.525 psf; Zac = 55000. feet
Press Enter to move down; Backspace to move up
Press B or b to begin Burgers evolution from this point
LMCYLATM1-BURG00
F6: Graphic Output
F7: ASCII Output
ESC: Quit
Enter: Advance
Overpressure, psf
1.50
1.00
.50
0
-.50
-1.00
-1.50
-.050
0
.050
.100
.150
.200
.250
.300
.350
Time, seconds


Tac = 0.00, Phi = 0.0: Thin Shock Solution, Free Field
T = 38.45; Z = 25000. feet, Pmax = 0.537 psf; Zac = 55000. feet
Press Enter to move down; Backspace to move up
Press B or b to begin Burgers evolution from this point
LMCYLATM1-BURG00
F6: Graphic Output
F7: ASCII Output
ESC: Quit
Enter: Advance
Overpressure, psf
1.50
1.00
.50
0
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-1.50
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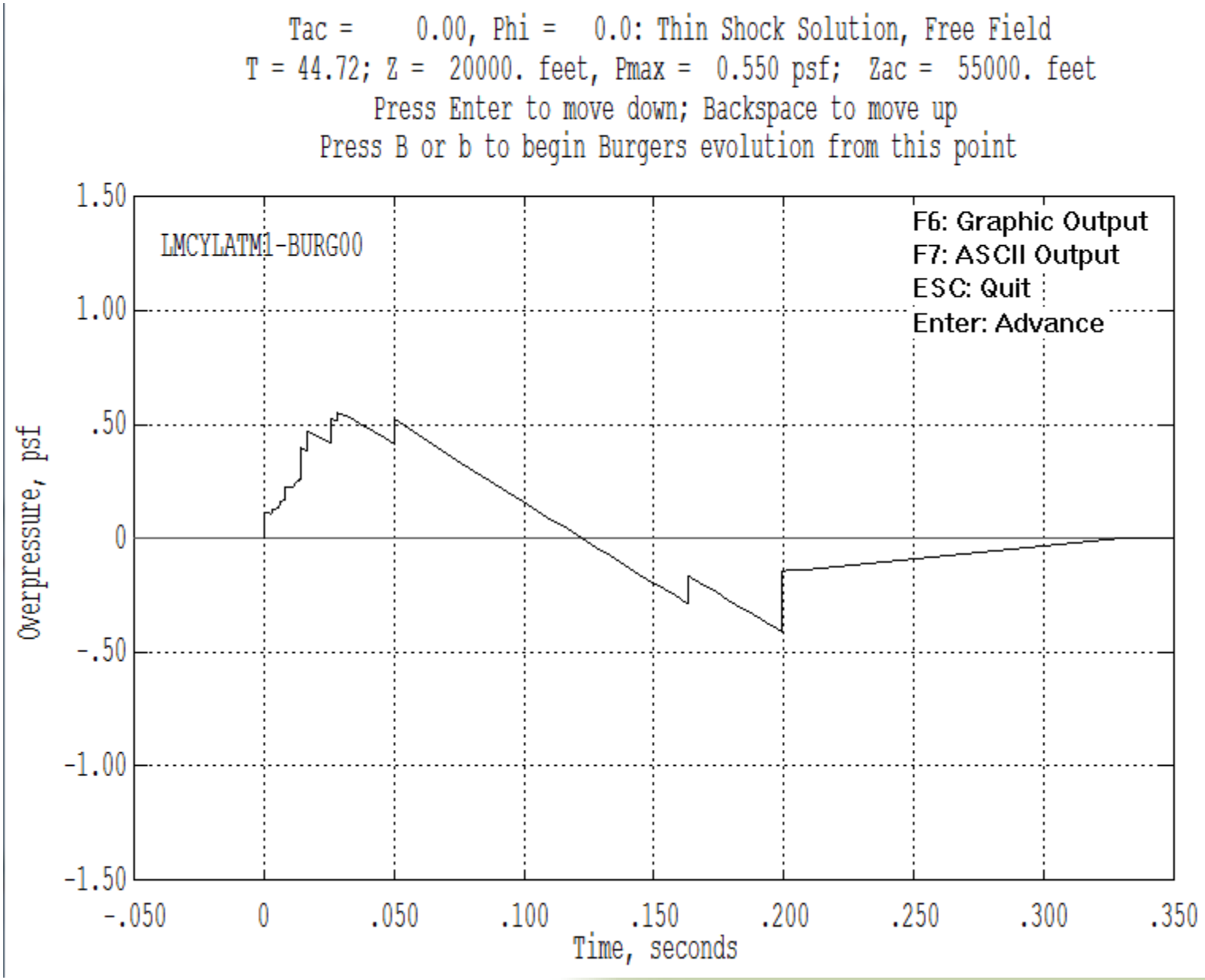
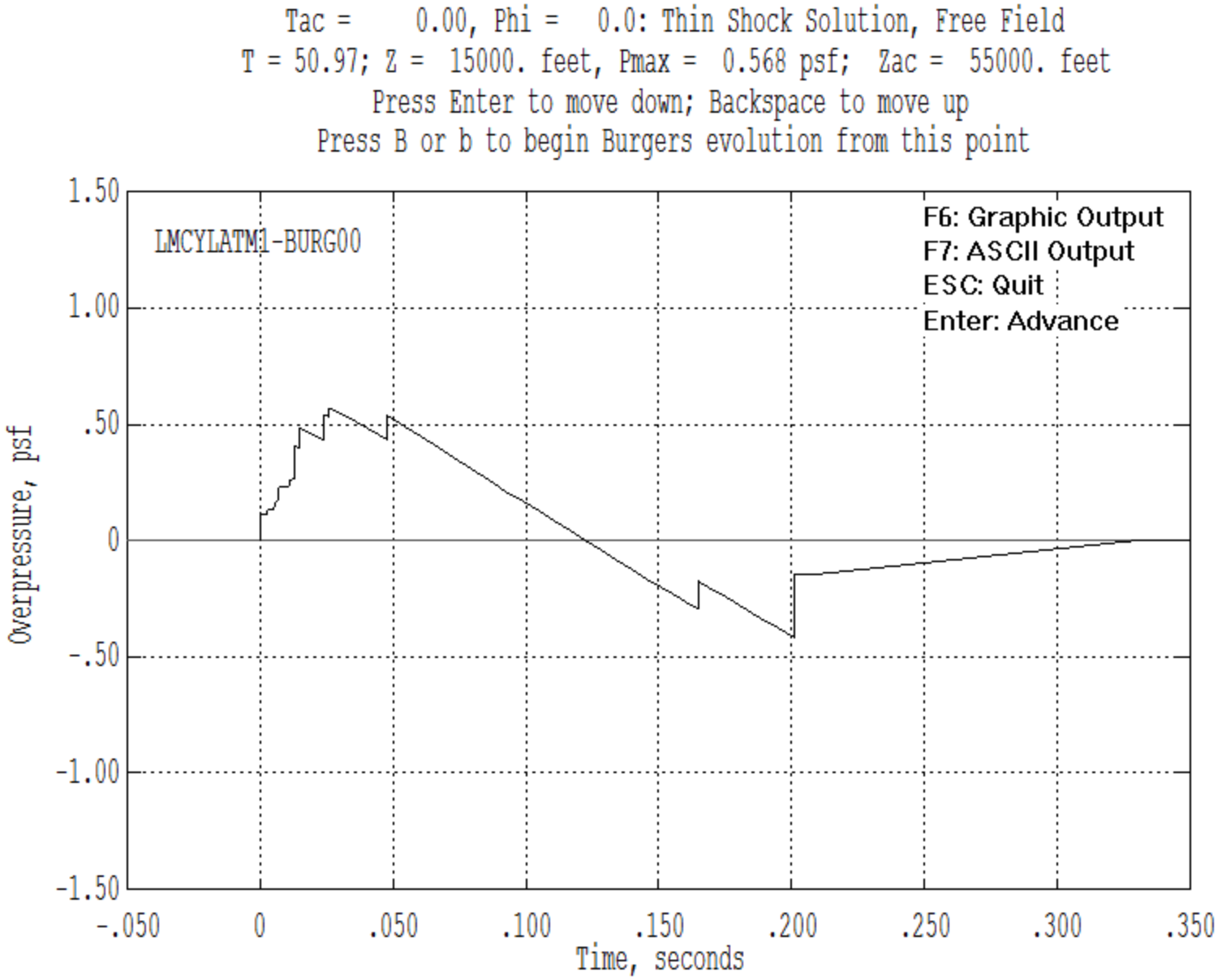
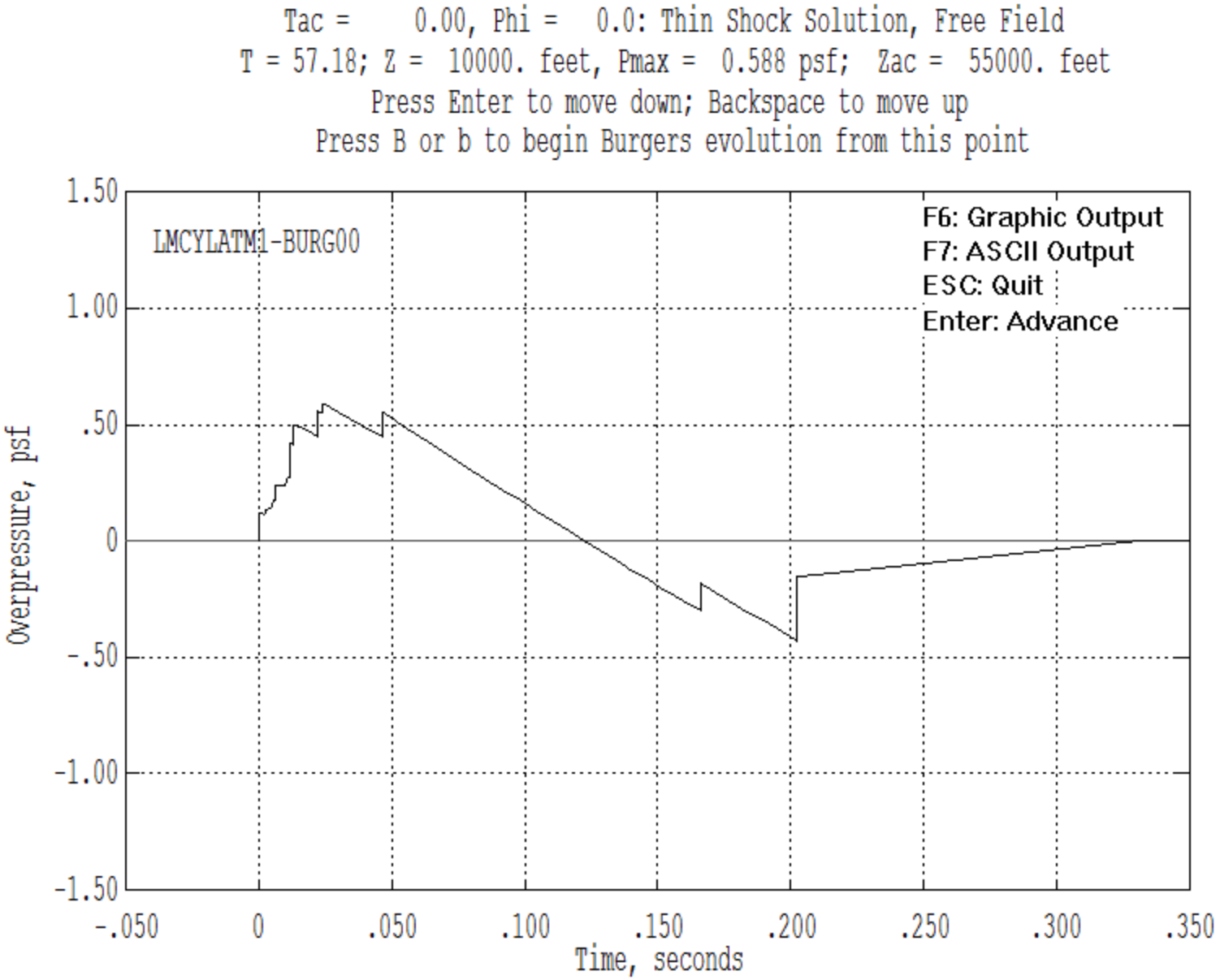
.050
.100
.150
.200
.250
.300
.350
Time, seconds


Tac = 0.00, Phi = 0.0: Thin Shock Solution, Free Field
T = 44.72; Z = 20000. feet, Pmax = 0.550 psf; Zac = 55000. feet
Press Enter to move down; Backspace to move up
Press B or b to begin Burgers evolution from this point
LMCYLATM1-BURG00
F6: Graphic Output
F7: ASCII Output
ESC: Quit
Enter: Advance
Overpressure, psf
1.50
1.00
.50
0
-.50
-1.00
-1.50
-.050
0
.050
.100
.150
.200
.250
.300
.350
Time, seconds


Tac = 0.00, Phi = 0.0: Thin Shock Solution, Free Field
T = 50.97; Z = 15000. feet, Pmax = 0.568 psf; Zac = 55000. feet
Press Enter to move down; Backspace to move up
Press B or b to begin Burgers evolution from this point
LMCYLATM1-BURG00
F6: Graphic Output
F7: ASCII Output
ESC: Quit
Enter: Advance
Overpressure, psf
1.50
1.00
.50
0
-.50
-1.00
-1.50
-.050
0
.050
.100
.150
.200
.250
.300
.350
Time, seconds


Tac = 0.00, Phi = 0.0: Thin Shock Solution, Free Field
T = 57.18; Z = 10000. feet, Pmax = 0.588 psf; Zac = 55000. feet
Press Enter to move down; Backspace to move up
Press B or b to begin Burgers evolution from this point
LMCYLATM1-BURG00
F6: Graphic Output
F7: ASCII Output
ESC: Quit
Enter: Advance
Overpressure, psf
1.50
1.00
.50
0
-.50
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-1.50
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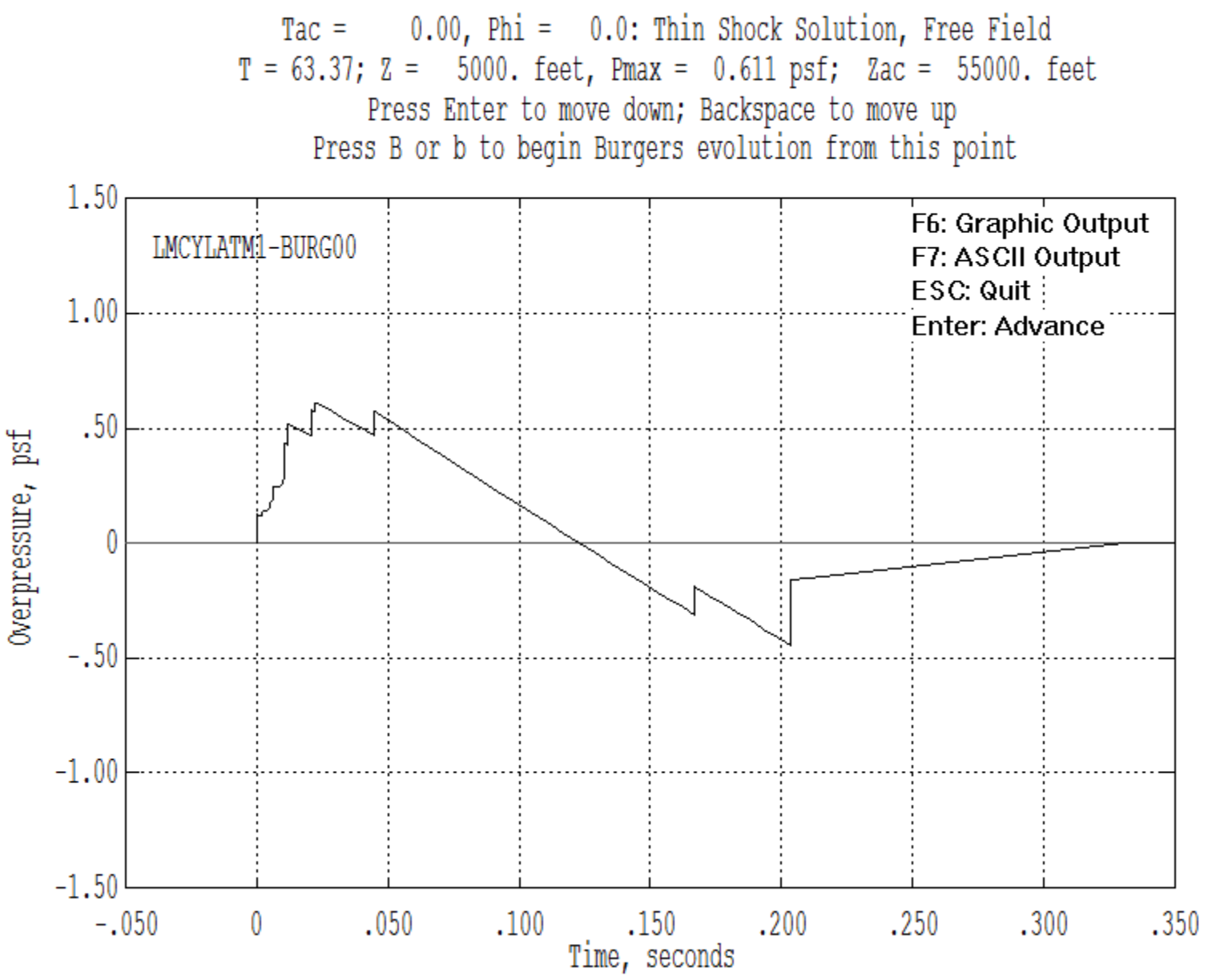
.050
.100
.150
.200
.250
.300
.350
Time, seconds


Tac = 0.00, Phi = 0.0: Thin Shock Solution, Free Field
T = 63.37; Z = 5000. feet, Pmax = 0.611 psf; Zac = 55000. feet
Press Enter to move down; Backspace to move up
Press B or b to begin Burgers evolution from this point
LMCYLATM1-BURG00
F6: Graphic Output
F7: ASCII Output
ESC: Quit
Enter: Advance
Overpressure, psf
1.50
1.00
.50
0
-.50
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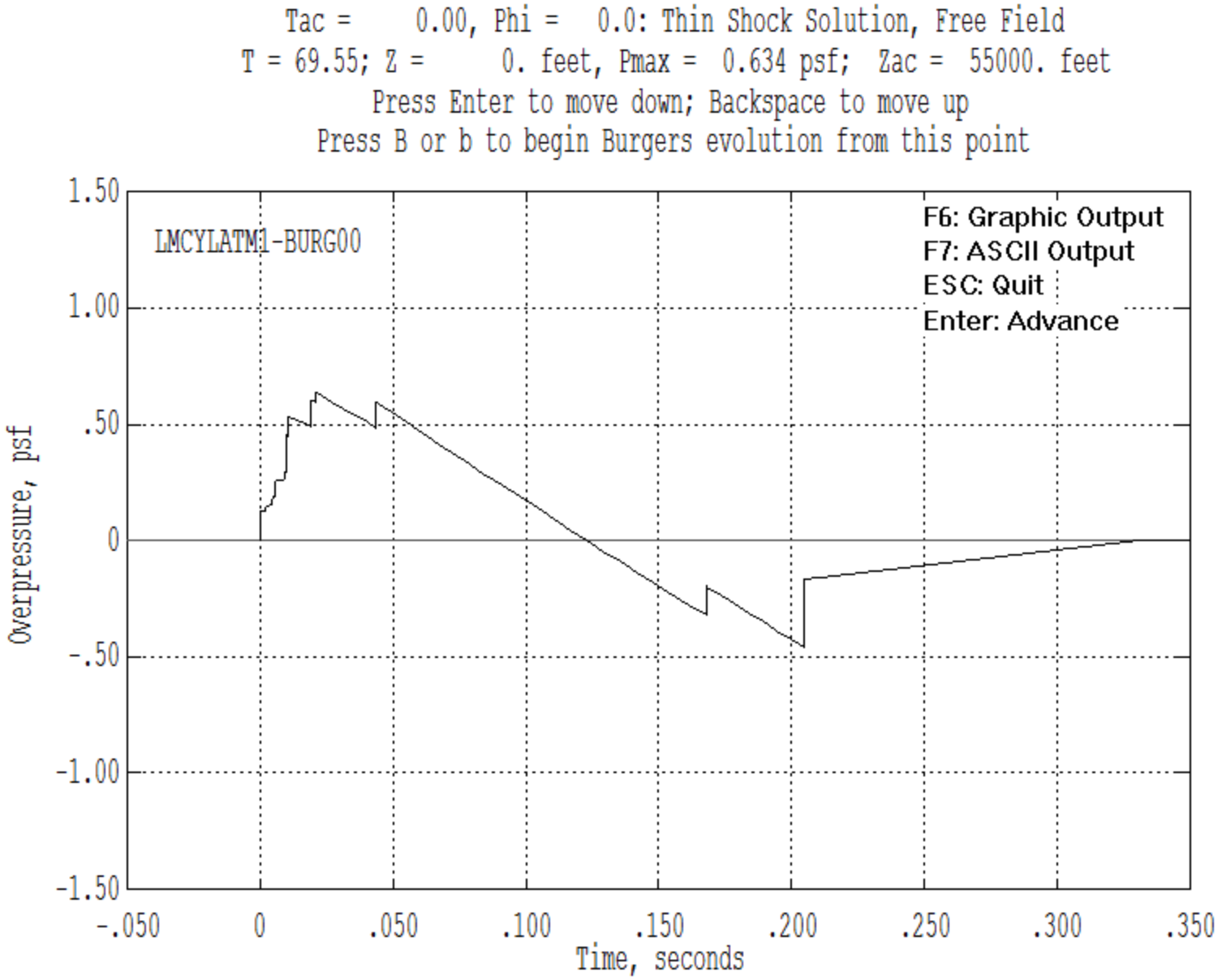
.050
.100
.150
.200
.250
.300
.350
Time, seconds


Tac = 0.00, Phi = 0.0: Thin Shock Solution, Free Field
T = 69.55; Z = 0. feet, Pmax = 0.634 psf; Zac = 55000. feet
Press Enter to move down; Backspace to move up
Press B or b to begin Burgers evolution from this point
LMCYLATM1-BURG00
F6: Graphic Output
F7: ASCII Output
ESC: Quit
Enter: Advance
Overpressure, psf
1.50
1.00
.50
0
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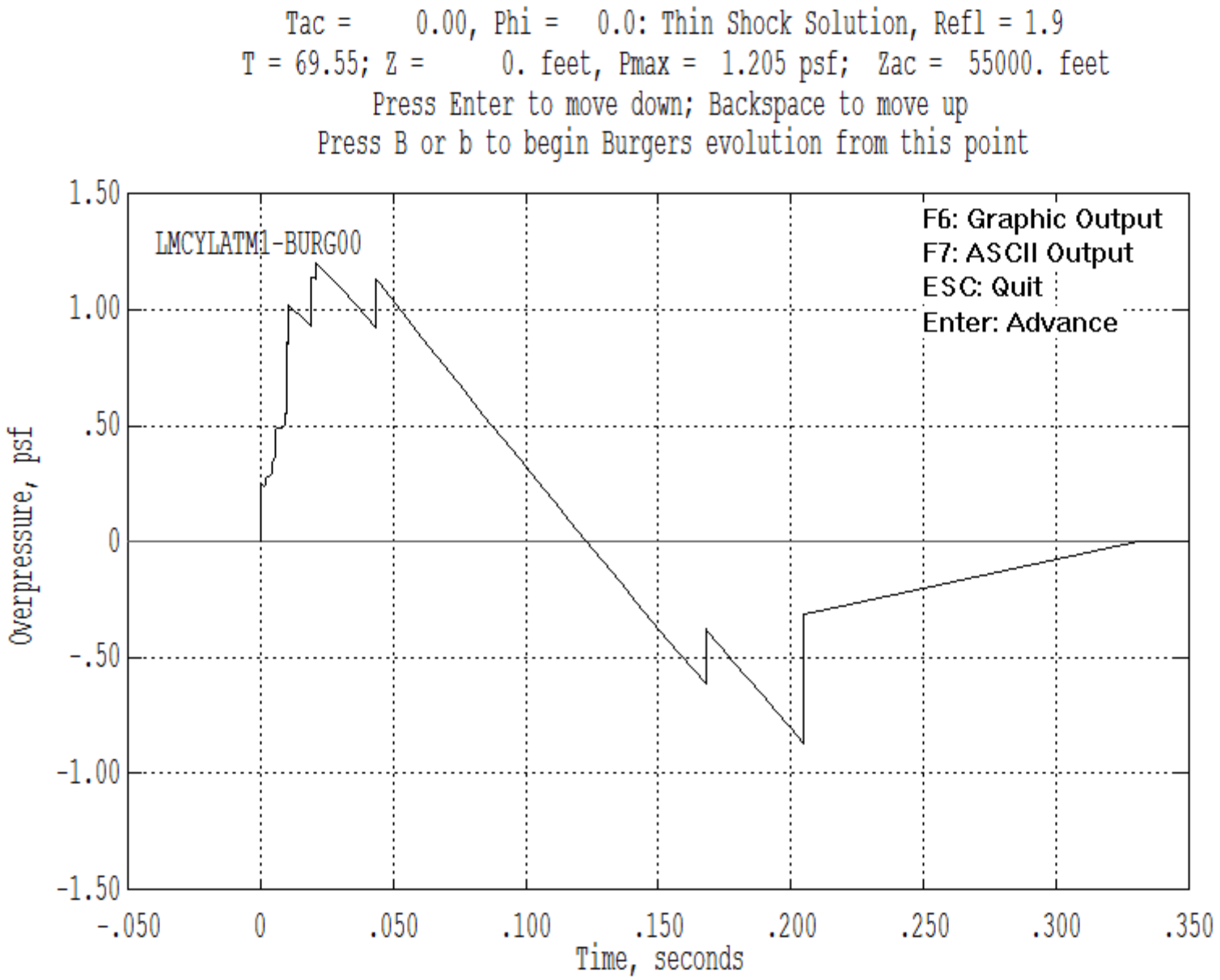
0
.050
.100
.150
.200
.250
.300
.350
Time, seconds


Tac = 0.00, Phi = 0.0: Thin Shock Solution, Refl = 1.9
T = 69.55; Z = 0. feet, Pmax = 1.205 psf; Zac = 55000. feet
Press Enter to move down; Backspace to move up
Press B or b to begin Burgers evolution from this point
LMCYLATM1-BURG00
F6: Graphic Output
F7: ASCII Output
ESC: Quit
Enter: Advance
Overpressure, psf
1.50
1.00
.50
0
-.50
-1.00
-1.50
-.050
0
.050
.100
.150
.200
.250
.300
.350
Time, seconds