

Exercise 1a – Shock Tube

(FE / FV, Strong / Weak BCs)



- Obtain various solutions and compare them with analytical solution (single-component perfect gas):
 - FE, strong BCs
 - NCFV, strong BCs
 - NCFV, weak BCs
 - CCFV, weak BCs

35

Geometric data:

The shock tube is 50.0 units long and 0.5 units wide. It is divided in two equal zones.

Materials

The tube is filled by perfect gas. The left chamber has density 10, $\gamma = 1.5$, pressure 10 bar. The right part has density 1, $\gamma = 1.5$, pressure 1 bar.

Numerical Solutions

TUBEFF

This solution is obtained with Finite Elements (FL24). Boundary conditions are imposed in a strong manner (LINK COUP BLOQ). The input file is:

```
TUBEFF
ECHO
!CONV WIN
DPLA EULE
GEOM LIBR POIN 202 FL24 100 TERM
0.00000E+00 0.00000E+00 5.00000E-01 0.00000E+00 1.00000E+00 0.00000E+00
1.50000E+00 0.00000E+00 2.00000E+00 0.00000E+00 2.50000E+00 0.00000E+00
3.00000E+00 0.00000E+00 3.50000E+00 0.00000E+00 4.00000E+00 0.00000E+00
4.50000E+00 0.00000E+00 5.00000E+00 0.00000E+00 5.50000E+00 0.00000E+00
6.00000E+00 0.00000E+00 6.50000E+00 0.00000E+00 7.00000E+00 0.00000E+00
7.50000E+00 0.00000E+00 8.00000E+00 0.00000E+00 8.50000E+00 0.00000E+00
9.00000E+00 0.00000E+00 9.50000E+00 0.00000E+00 1.00000E+01 0.00000E+00
1.05000E+01 0.00000E+00 1.10000E+01 0.00000E+00 1.15000E+01 0.00000E+00
1.20000E+01 0.00000E+00 1.25000E+01 0.00000E+00 1.30000E+01 0.00000E+00
1.35000E+01 0.00000E+00 1.40000E+01 0.00000E+00 1.45000E+01 0.00000E+00
1.50000E+01 0.00000E+00 1.55000E+01 0.00000E+00 1.60000E+01 0.00000E+00
1.65000E+01 0.00000E+00 1.70000E+01 0.00000E+00 1.75000E+01 0.00000E+00
1.80000E+01 0.00000E+00 1.85000E+01 0.00000E+00 1.90000E+01 0.00000E+00
1.95000E+01 0.00000E+00 2.00000E+01 0.00000E+00 2.05000E+01 0.00000E+00
2.10000E+01 0.00000E+00 2.15000E+01 0.00000E+00 2.20000E+01 0.00000E+00
2.25000E+01 0.00000E+00 2.30000E+01 0.00000E+00 2.35000E+01 0.00000E+00
2.40000E+01 0.00000E+00 2.45000E+01 0.00000E+00 2.50000E+01 0.00000E+00
2.55000E+01 0.00000E+00 2.60000E+01 0.00000E+00 2.65000E+01 0.00000E+00
2.70000E+01 0.00000E+00 2.75000E+01 0.00000E+00 2.80000E+01 0.00000E+00
2.85000E+01 0.00000E+00 2.90000E+01 0.00000E+00 2.95000E+01 0.00000E+00
3.00000E+01 0.00000E+00 3.05000E+01 0.00000E+00 3.10000E+01 0.00000E+00
3.15000E+01 0.00000E+00 3.20000E+01 0.00000E+00 3.25000E+01 0.00000E+00
3.30000E+01 0.00000E+00 3.35000E+01 0.00000E+00 3.40000E+01 0.00000E+00
3.45000E+01 0.00000E+00 3.50000E+01 0.00000E+00 3.55000E+01 0.00000E+00
3.60000E+01 0.00000E+00 3.65000E+01 0.00000E+00 3.70000E+01 0.00000E+00
3.75000E+01 0.00000E+00 3.80000E+01 0.00000E+00 3.85000E+01 0.00000E+00
3.90000E+01 0.00000E+00 3.95000E+01 0.00000E+00 4.00000E+01 0.00000E+00
4.05000E+01 0.00000E+00 4.10000E+01 0.00000E+00 4.15000E+01 0.00000E+00
4.20000E+01 0.00000E+00 4.25000E+01 0.00000E+00 4.30000E+01 0.00000E+00
4.35000E+01 0.00000E+00 4.40000E+01 0.00000E+00 4.45000E+01 0.00000E+00
4.50000E+01 0.00000E+00 4.55000E+01 0.00000E+00 4.60000E+01 0.00000E+00
4.65000E+01 0.00000E+00 4.70000E+01 0.00000E+00 4.75000E+01 0.00000E+00
4.80000E+01 0.00000E+00 4.85000E+01 0.00000E+00 4.90000E+01 0.00000E+00
4.95000E+01 0.00000E+00 5.00000E+01 0.00000E+00 5.00000E+01 0.00000E-01
5.00000E-01 5.00000E-01 1.00000E+00 5.00000E-01 1.50000E+00 5.00000E-01
2.00000E+00 5.00000E-01 2.50000E+00 5.00000E-01 3.00000E+00 5.00000E-01
3.50000E+00 5.00000E-01 4.00000E+00 5.00000E-01 4.50000E+00 5.00000E-01
5.00000E+00 5.00000E-01 5.50000E+00 5.00000E-01 6.00000E+00 5.00000E-01
6.50000E+00 5.00000E-01 7.00000E+00 5.00000E-01 7.50000E+00 5.00000E-01
8.00000E+00 5.00000E-01 8.50000E+00 5.00000E-01 9.00000E+00 5.00000E-01
9.50000E+00 5.00000E-01 1.00000E+01 5.00000E-01 1.05000E+01 5.00000E-01
1.10000E+01 5.00000E-01 1.15000E+01 5.00000E-01 1.20000E+01 5.00000E-01
1.25000E+01 5.00000E-01 1.30000E+01 5.00000E-01 1.35000E+01 5.00000E-01
1.40000E+01 5.00000E-01 1.45000E+01 5.00000E-01 1.50000E+01 5.00000E-01
1.55000E+01 5.00000E-01 1.60000E+01 5.00000E-01 1.65000E+01 5.00000E-01
1.70000E+01 5.00000E-01 1.75000E+01 5.00000E-01 1.80000E+01 5.00000E-01
1.85000E+01 5.00000E-01 1.90000E+01 5.00000E-01 1.95000E+01 5.00000E-01
2.00000E+01 5.00000E-01 2.05000E+01 5.00000E-01 2.10000E+01 5.00000E-01
2.15000E+01 5.00000E-01 2.20000E+01 5.00000E-01 2.25000E+01 5.00000E-01
2.30000E+01 5.00000E-01 2.35000E+01 5.00000E-01 2.40000E+01 5.00000E-01
2.45000E+01 5.00000E-01 2.50000E+01 5.00000E-01 2.55000E+01 5.00000E-01
2.60000E+01 5.00000E-01 2.65000E+01 5.00000E-01 2.70000E+01 5.00000E-01
2.75000E+01 5.00000E-01 2.80000E+01 5.00000E-01 2.85000E+01 5.00000E-01
2.90000E+01 5.00000E-01 2.95000E+01 5.00000E-01 3.00000E+01 5.00000E-01
3.05000E+01 5.00000E-01 3.10000E+01 5.00000E-01 3.15000E+01 5.00000E-01
3.20000E+01 5.00000E-01 3.25000E+01 5.00000E-01 3.30000E+01 5.00000E-01
3.35000E+01 5.00000E-01 3.40000E+01 5.00000E-01 3.45000E+01 5.00000E-01
3.50000E+01 5.00000E-01 3.55000E+01 5.00000E-01 3.60000E+01 5.00000E-01
3.65000E+01 5.00000E-01 3.70000E+01 5.00000E-01 3.75000E+01 5.00000E-01
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3.80000E+01 5.00000E-01 3.85000E+01 5.00000E-01 3.90000E+01 5.00000E-01
3.95000E+01 5.00000E-01 4.00000E+01 5.00000E-01 4.05000E+01 5.00000E-01
4.10000E+01 5.00000E-01 4.15000E+01 5.00000E-01 4.20000E+01 5.00000E-01
4.25000E+01 5.00000E-01 4.30000E+01 5.00000E-01 4.35000E+01 5.00000E-01
4.40000E+01 5.00000E-01 4.45000E+01 5.00000E-01 4.50000E+01 5.00000E-01
4.55000E+01 5.00000E-01 4.60000E+01 5.00000E-01 4.65000E+01 5.00000E-01
4.70000E+01 5.00000E-01 4.75000E+01 5.00000E-01 4.80000E+01 5.00000E-01
4.85000E+01 5.00000E-01 4.90000E+01 5.00000E-01 4.95000E+01 5.00000E-01
5.00000E+01 5.00000E-01
2 1 203 102 2 3 104 103 3 4 105 104 4 5 106 105
5 6 107 106 6 7 108 107 7 8 109 108 8 9 110 109
9 10 111 110 10 11 112 111 11 12 113 112 12 13 114 113
13 14 115 114 14 15 116 115 15 16 117 116 16 17 118 117
17 18 119 118 18 19 120 119 19 20 121 120 20 21 122 121
21 22 123 122 22 23 124 123 23 24 125 124 24 25 126 125
25 26 127 126 26 27 128 127 27 28 129 128 28 29 130 129
29 30 131 130 30 31 132 131 31 32 133 132 32 33 134 133
33 34 135 134 34 35 136 135 35 36 137 136 36 37 138 137
37 38 139 138 38 39 140 139 39 40 141 140 40 41 142 141
41 42 143 142 42 43 144 143 43 44 145 144 44 45 146 145
45 46 147 146 46 47 148 147 47 48 149 148 48 49 150 149
49 50 151 150 50 51 152 151 51 52 153 152 52 53 154 153
53 54 155 154 54 55 156 155 55 56 157 156 56 57 158 157
57 58 159 158 58 59 160 159 59 60 161 160 60 61 162 161
61 62 163 162 62 63 164 163 63 64 165 164 64 65 166 165
65 66 167 166 66 67 168 167 67 68 169 168 68 69 170 169
69 70 171 170 70 71 172 171 71 72 173 172 72 73 174 173
73 74 175 174 74 75 176 175 75 76 177 176 76 77 178 177
77 78 179 178 78 79 180 179 79 80 181 180 80 81 182 181
81 82 183 182 82 83 184 183 83 84 185 184 84 85 186 185
85 86 187 186 86 87 188 187 87 88 189 188 88 89 190 189
89 90 191 190 90 91 192 191 91 92 193 192 92 93 194 193
93 94 195 194 94 95 196 195 95 96 197 196 96 97 198 197
97 98 199 198 98 99 200 199 99 100 201 200 100 101 202 201
MATE FLUTR RO 1.0 D0 BINT 2.05 GAMM 1.5 PREF 0.0 D0 PB 0 ITER 1 ALFO 0.2
      BETO 0 KINT 0 ANGF 0 CL 0.5 CQ 0.0 PMIN 0 NUM 1
      LECT 1 PAS 1 50 TERM
      FLUTR RO 1.0 D0 BINT 2.05 GAMM 1.5 PREF 0.0 D0 PB 0 ITER 1 ALFO 0.2
      BETO 0 KINT 0 ANGF 0 CL 0.5 CQ 0.0 PMIN 0 NUM 1
      LECT 51 PAS 1 100 TERM
LINK COUP
      BLOQ 2 TOUS
      BLOQ 1 LECT 1 101 102 202 TERM
ECRI VITE ACCE FINI FEXT CONT ECR0 TPRE 30.E-3
      FICH ALIC TPRE 30.E-3
      OPTI PAS AUTO NOTE STEP 10 CSTA 0.5
      LOG 1
      CALC TINI 0 TEND 30.E-3
      *-----POST-TREATMENT
SUIT
      Post-treatment
      ECHO
      RESU ALIC GARD PSR
      SORT GRAP
      AXTE 1.0 'Time [s]'
      *-----Curve definitions
SCOU 1 'p_ef' NSTO 2 SAXE 1.0 'current_abcissa' LECT 1 PAS 1 101 TERM
      ECR0 COMP 1
SCOU 2 'r_ef' NSTO 2 SAXE 1.0 'current_abcissa' LECT 1 PAS 1 101 TERM
      ECR0 COMP 2
SCOU 3 'i_ef' NSTO 2 SAXE 1.0 'current_abcissa' LECT 1 PAS 1 101 TERM
      ECR0 COMP 4
      *-----Theoretical solutions
DCOU 51 'p_theor' 107
0.00000E+00 1.00000E+06 1.33810E+01 1.00000E+06 1.34918E+01 9.88618E+05
1.36025E+01 9.77345E+05 1.37132E+01 9.66178E+05 1.38240E+01 9.55119E+05
1.39347E+01 9.44165E+05 1.40454E+01 9.33316E+05 1.41562E+01 9.22571E+05
1.42666E+01 9.11929E+05 1.43776E+01 9.03308E+05 1.44883E+01 8.90952E+05
1.45991E+01 8.80615E+05 1.47098E+01 8.70379E+05 1.48205E+01 8.60242E+05
1.49313E+01 8.50203E+05 1.50420E+01 8.40262E+05 1.51527E+01 8.30419E+05
1.52634E+01 8.20157E+05 1.53742E+01 8.10139E+05 1.54849E+01 8.00462E+05
1.55956E+01 7.91999E+05 1.57064E+01 7.82629E+05 1.58171E+01 7.73325E+05
1.59278E+01 7.64167E+05 1.60386E+01 7.55072E+05 1.61493E+01 7.46068E+05
1.62600E+01 7.37154E+05 1.63707E+01 7.28329E+05 1.64815E+01 7.19592E+05
1.65922E+01 7.10942E+05 1.67029E+01 7.02379E+05 1.68137E+01 6.93903E+05
1.69244E+01 6.85511E+05 1.70351E+01 6.77058E+05 1.71458E+01 6.68962E+05
1.72566E+01 6.60843E+05 1.73673E+01 6.52787E+05 1.74780E+01 6.44812E+05
1.75888E+01 6.36919E+05 1.76995E+01 6.29107E+05 1.78102E+01 6.21375E+05
1.79210E+01 6.13722E+05 1.80317E+01 6.06147E+05 1.81424E+01 5.98651E+05
1.82531E+01 5.91031E+05 1.83639E+01 5.83690E+05 1.84746E+01 5.76624E+05
1.85853E+01 5.69434E+05 1.86961E+01 5.62318E+05 1.88068E+01 5.55277E+05
1.89175E+01 5.48309E+05 1.90282E+01 5.41415E+05 1.91390E+01 5.34592E+05
1.92497E+01 5.27884E+05 1.93604E+01 5.21163E+05 1.94712E+01 5.14554E+05
1.95819E+01 5.08151E+05 1.96926E+01 5.03546E+05 1.98034E+01 4.95146E+05
1.99141E+01 4.88813E+05 2.00248E+01 4.82549E+05 2.01355E+01 4.76351E+05
2.02463E+01 4.70220E+05 2.03570E+01 4.64155E+05 2.04677E+01 4.58155E+05
2.05785E+01 4.52219E+05 2.06892E+01 4.46349E+05 2.07999E+01 4.40541E+05
2.09106E+01 4.34797E+05 2.10214E+01 4.29116E+05 2.11321E+01 4.23496E+05
2.12428E+01 4.17938E+05 2.13536E+01 4.12441E+05 2.14643E+01 4.07004E+05
2.15750E+01 4.01627E+05 2.16858E+01 3.96309E+05 2.17965E+01 3.91050E+05
2.19072E+01 3.85890E+05 2.20179E+01 3.80707E+05 2.21287E+01 3.75621E+05
2.22394E+01 3.70592E+05 2.23501E+01 3.65620E+05 2.24609E+01 3.60703E+05
2.25716E+01 3.58418E+05 2.26823E+01 3.51034E+05 2.27930E+01 3.46282E+05
2.29038E+01 3.41583E+05 2.30145E+01 3.36937E+05 2.31252E+01 3.32344E+05
2.32360E+01 3.27804E+05 2.33467E+01 3.23315E+05 2.34574E+01 3.18877E+05
2.35682E+01 3.14491E+05 2.36789E+01 3.10155E+05 2.37896E+01 3.05868E+05
2.39003E+01 3.01632E+05 2.40111E+01 2.97444E+05 2.41218E+01 2.93305E+05
2.42325E+01 2.89213E+05 2.43433E+01 2.85170E+05 2.44540E+01 2.81174E+05
3.38583E+01 2.81174E+05 3.38583E+01 2.81174E+05 4.34071E+01 2.81174E+05
4.34071E+01 1.00000E+05 5.00000E+01 1.00000E+05
DCOU 52 't_theor' 107
0.00000E+00 1.00000E+01 1.33810E+01 1.00000E+01 1.34918E+01 9.92398E+00
1.36025E+01 9.84839E+00 1.37132E+01 9.77323E+00 1.38240E+01 9.69851E+00
1.39347E+01 9.62421E+00 1.40454E+01 9.55034E+00 1.41562E+01 9.47690E+00
1.42666E+01 9.40388E+00 1.43776E+01 9.33129E+00 1.44883E+01 9.25912E+00
1.45991E+01 9.18736E+00 1.47098E+01 9.11603E+00 1.48205E+01 9.04511E+00
1.49313E+01 8.97460E+00 1.50420E+01 8.90451E+00 1.51527E+01 8.83483E+00
1.52634E+01 8.76556E+00 1.53742E+01 8.69669E+00 1.54849E+01 8.62824E+00
1.55956E+01 8.56018E+00 1.57064E+01 8.49254E+00 1.58171E+01 8.42529E+00
1.59278E+01 8.35844E+00 1.60386E+01 8.29199E+00 1.61493E+01 8.22594E+00
1.62600E+01 8.16029E+00 1.63707E+01 8.09503E+00 1.64815E+01 8.03016E+00
1.65922E+01 7.96568E+00 1.67029E+01 7.90159E+00 1.68137E+01 7.83789E+00
1.69244E+01 7.77457E+00 1.70351E+01 7.71164E+00 1.71458E+01 7.64909E+00
1.72566E+01 7.58692E+00 1.73673E+01 7.52513E+00 1.74780E+01 7.46372E+00
1.75888E+01 7.40269E+00 1.76995E+01 7.34203E+00 1.78102E+01 7.28175E+00
1.79210E+01 7.22181E+00 1.80317E+01 7.16229E+00 1.81424E+01 7.10312E+00
1.82531E+01 7.04431E+00 1.83639E+01 6.98587E+00 1.84746E+01 6.92780E+00
1.85853E+01 6.87009E+00 1.86961E+01 6.81273E+00 1.88068E+01 6.75574E+00
1.89175E+01 6.69911E+00 1.90282E+01 6.64283E+00 1.91390E+01 6.58691E+00
1.92497E+01 6.53135E+00 1.93604E+01 6.47613E+00 1.94712E+01 6.42127E+00
1.95819E+01 6.36675E+00 1.96926E+01 6.31258E+00 1.98034E+01 6.25870E+00
1.99141E+01 6.20529E+00 2.00248E+01 6.15216E+00 2.01355E+01 6.09937E+00
2.02463E+01 6.04692E+00 2.03570E+01 5.99481E+00 2.04677E+01 5.94303E+00
2.05785E+01 5.89359E+00 2.06892E+01 5.84049E+00 2.07999E+01 5.78972E+00
2.09106E+01 5.79398E+00 2.10214E+01 5.69518E+00 2.11321E+01 5.63940E+00
2.12428E+01 5.58995E+00 2.13536E+01 5.54082E+00 2.14643E+01 5.49202E+00
2.15750E+01 5.44354E+00 2.16858E+01 5.39539E+00 2.17965E+01 5.34755E+00
2.19072E+01 5.30003E+00 2.20179E+01 5.25283E+00 2.21287E+01 5.20595E+00
2.22394E+01 5.15938E+00 2.23501E+01 5.11313E+00 2.24609E+01 5.06718E+00
2.25716E+01 5.02155E+00 2.26823E+01 4.97622E+00 2.27930E+01 4.93110E+00
2.29038E+01 4.88649E+00 2.30145E+01 4.84209E+00 2.31252E+01 4.79798E+00
2.32360E+01 4.79418E+00 2.33467E+01 4.74686E+00 2.34574E+01 4.66748E+00
2.35682E+01 4.64245E+00 2.36789E+01 4.58197E+00 2.37896E+01 4.53965E+00
2.39003E+01 4.49764E+00 2.40111E+01 4.45591E+00 2.41218E+01 4.41448E+00
2.42325E+01 4.37333E+00 2.43433E+01 4.33247E+00 2.44540E+01 4.29190E+00
3.38583E+01 4.29190E+00 3.38583E+01 1.92770E+00 4.34071E+01 1.92770E+00
4.34071E+01 1.00000E+00 5.00000E+00 1.00000E+00
DCOU 53 'i_theor' 107
0.00000E+00 2.00000E+05 1.33810E+01 2.00000E+05 1.34918E+01 1.99238E+05
1.36025E+01 1.98478E+05 1.37132E+01 1.97719E+05 1.38240E+01 1.96962E+05
1.39347E+01 1.96206E+05 1.40454E+01 1.95452E+05 1.41562E+01 1.94699E+05
1.42666E+01 1.93947E+05 1.43776E+01 1.93197E+05 1.44883E+01 1.92449E+05
1.45991E+01 1.91701E+05 1.47098E+01 1.90956E+05 1.48205E+01 1.90212E+05
1.49313E+01 1.89469E+05 1.50420E+01 1.88727E+05 1.51527E+01 1.87988E+05
1.52634E+01 1.87249E+05 1.53742E+01 1.86512E+05 1.54849E+01 1.85777E+05
1.55956E+01 1.85043E+05 1.57064E+01 1.84310E+05 1.58171E+01 1.83579E+05
1.59278E+01 1.82849E+05 1.60386E+01 1.82121E+05 1.61493E+01 1.81394E+05
1.62600E+01 1.80669E+05 1.63707E+01 1.79945E+05 1.64815E+01 1.79222E+05
1.65922E+01 1.78501E+05 1.67029E+01 1.77729E+05 1.68137E+01 1.77064E+05
1.69244E+01 1.76347E+05 1.70351E+01 1.75632E+05 1.71458E+01 1.74918E+05
1.72566E+01 1.74206E+05 1.73673E+01 1.73495E+05 1.74780E+01 1.72786E+05
1.75888E+01 1.72078E+05 1.76995E+01 1.71371E+05 1.78102E+01 1.70666E+05
1.79210E+01 1.69963E+05 1.80317E+01 1.69261E+05 1.81424E+01 1.68508E+05
1.82531E+01 1.67861E+05 1.83639E+01 1.67163E+05 1.84746E+01 1.66475E+05
1.85853E+01 1.65772E+05 1.86961E+01 1.65079E+05 1.88068E+01 1.64387E+05
1.89175E+01 1.63696E+05 1.90282E+01 1.63007E+05 1.91390E+01 1.62320E+05
1.92497E+01 1.61633E+05 1.93604E+01 1.60949E+05 1.94712E+01 1.60266E+05
1.95819E+01 1.59584E+05 1.96926E+01 1.58904E+05 1.98034E+01 1.58225E+05
1.99141E+01 1.57547E+05 2.00248E+01 1.56871E+05 2.01355E+01 1.56197E+05
2.02463E+01 1.55524E+05 2.03570E+01 1.54852E+05 2.04677E+01 1.54182E+05
2.05785E+01 1.53513E+05 2.06892E+01 1.52846E+05 2.07999E+01 1.52180E+05
2.09106E+01 1.51516E+05 2.10214E+01 1.50838E+05 2.11321E+01 1.50192E+05
2.12428E+01 1.49532E+05 2.13536E+01 1.48873E+05 2.14643E+01 1.48216E+05
2.15750E+01 1.47561E+05 2.16858E+01 1.46907E+05 2.17965E+01 1.46254E+05
2.19072E+01 1.45603E+05 2.20179E+01 1.44853E+05 2.21287E+01 1.44035E+05
2.22394E+01 1.43658E+05 2.23501E+01 1.43012E+05 2.24609E+01 1.42368E+05
2.25716E+01 1.41726E+05 2.26823E+01 1.41085E+05 2.27930E+01 1.40454E+05
2.29038E+01 1.39807E+05 2.30145E+01 1.39170E+05 2.31252E+01 1.38535E+05
2.32360E+01 1.38078E+05 2.33467E+01 1.37289E+05 2.34574E+01 1.36638E+05
2.35682E+01 1.36080E+05 2.36789E+01 1.35380E+05 2.37896E+01 1.34754E+05
2.39003E+01 1.34129E+05 2.40111E+01 1.33505E+05 2.41218E+01 1.32883E+05
2.42325E+01 1.32262E+05 2.43433E+01 1.31643E+05 2.44540E+01 1.31025E+05
3.38583E+01 1.31025E+05 3.38583E+01 2.97179E+05 4.34071E+01 2.97179E+05
4.34071E+01 1.00000E+05 5.00000E+01 1.00000E+05
COUR 43 't_e' DIVC 3 666.667
COUR 63 't_theor' DIVC 53 666.667
*-----Plots
TRAC 1 51 AXES 1.0 'PRESS. [PA]'
      COLO noir rouge
TRAC 2 52 AXES 1.0 'DENS. [KG/M3]'
      COLO noir rouge
TRAC 43 63 AXES 1.0 'TEMP. [K]'
      COLO noir rouge
TRAC 3 53 AXES 1.0 'EINT [J/KG]'
      COLO noir rouge
LIST 1 AXES 1.0 'PRESS. [PA]'
LIST 2 AXES 1.0 'DENS. [KG/M3]'
LIST 3 AXES 1.0 'EINT [J/KG]'
LIST 43 AXES 1.0 'TEMP. [K]'
      *-----Results qualification
EQUAL ECR0 COMP 2 LECT 25 TERM REFE 8.68046E-01 TOL 1.E-2
! ECR0 COMP 2 LECT 50 TERM REFE 4.98674E-01 TOL 1.E-2
! ECR0 COMP 2 LECT 75 TERM REFE 4.57575E-01 TOL 1.E-2
*-----
FIN
```

TUBECC

This solution is obtained with Cell-Centered Finite Volumes (Q4VF). Boundary conditions are imposed in a weak manner (no directive is needed). The input file is:

```
TUBECC
ECHO
!CONV WIN
DPLA EULE
GEOM LIBR POIN 202 Q4VF 100 TERM
...
,same mesh as before>
MATE GAZP RO 1.0 D0 GAMM 1.5 CV 666.667 PINI 1.86 PREF 0.00
      LECT 1 PAS 1 50 TERM
      GAZP RO 1.0 D0 GAMM 1.5 CV 666.667 PINI 1.85 PREF 0.00
      LECT 51 PAS 1 100 TERM
LINK COUP
      BLOQ 2 TOUS
      BLOQ 1 LECT 1 101 102 202 TERM
ECRI VITE ACCE FINI FEXT CONT ECR0 TPRE 30.E-3
      FICH ALIC TPRE 30.E-3
      OPTI PAS AUTO NOTE STEP 10 CSTA 0.5
      LOG 1
      VPCC FCOM 6 ! Solveur HLLC
      ORDR 2 ! Ordre 2 en espace
      OTPS 2 ! Ordre 2 en temps
      RECO 1 ! Reconstruction de type Green-Gauss
      LMAS 3 ! k-limiteur de Dubois (eq. masse)
      LQDM 3 ! k-limiteur de Dubois (eq. QDM)
      LENE 3 ! k-limiteur de Dubois (eq. energie)
      RMAS 0.75 ! Coefficient de limitation (eq. masse)
      RQDM 0.75 ! Coefficient de limitation (eq. QDM)
      KENE 0.75 ! Coefficient de limitation (eq. energie)
      CERNE ! Correction de l'energie interne
      CALC TINI 0 TEND 30.E-3
      *-----POST-TREATMENT
SUIT
      Post-treatment
      ECHO
      RESU ALIC GARD PSR
      SORT GRAP
      AXTE 1.0 'Time [s]'
      *-----Curve definitions
SCOU 1 'p_cc' NSTO 2 SAXE 1.0 'current_abcissa' LECT 1 PAS 1 101 TERM
      ECR0 COMP 1
SCOU 2 'r_cc' NSTO 2 SAXE 1.0 'current_abcissa' LECT 1 PAS 1 101 TERM
      ECR0 COMP 2
SCOU 3 't_ccc' NSTO 2 SAXE 1.0 'current_abcissa' LECT 1 PAS 1 101 TERM
      ECR0 COMP 7
      *-----Theoretical solutions
DCOU 51 'p_theor' 107
<same as before>
DCOU 52 'r_theor' 107
<same as before>
DCOU 53 't_theor' 107
<same as before>
COUR 43 't_cc' ADDC 3 273.15
COUR 63 't_theor' DIVC 53 666.667
*-----Plots
TRAC 1 51 AXES 1.0 'PRESS. [PA]'
      COLO noir rouge
TRAC 2 52 AXES 1.0 'DENS. [KG/M3]'
      COLO noir rouge
TRAC 43 63 AXES 1.0 'TEMP. [K]'
      COLO noir rouge
LIST 1 AXES 1.0 'PRESS. [PA]'
LIST 2 AXES 1.0 'DENS. [KG/M3]'
LIST 43 AXES 1.0 'TEMP. [K]'
      *-----Results qualification
EQUAL ECR0 COMP 2 LECT 25 TERM REFE 8.68046E-01 TOL 1.E-2
! ECR0 COMP 2 LECT 50 TERM REFE 4.98674E-01 TOL 1.E-2
! ECR0 COMP 2 LECT 75 TERM REFE 4.57575E-01 TOL 1.E-2
*-----
FIN
```

TUBENC

This solution is obtained with Node-Centered Finite Volumes (MC24). Boundary conditions are imposed in a strong manner (LINK COUP BLOQ). The input file is:

```
TUBENC
ECHO
!CONV WIN
DPLA RULE
DIME NDVC 804 TERM
GEOM LIBR POIN 202 MC24 100 TERM
...
<same mesh as before>
...
MATE MCGP NCOM 1 R 1.E4
      COMP 'aria' PM 30.E0 CV1 2.E4 CV2 0 CV3 0
      LECT tous TERM
INIT MCOM COMP 'aria' MFRA 1.0 LECT tous TERM
      PRES 1.D6 LECT 1 PAS 1 50 102 PAS 1 151 TERM
      PRES 5.D5 LECT 51 152 TERM
      PRES 1.D5 LECT 52 PAS 1 101 153 PAS 1 202 TERM
      TEMP 3.D2 LECT tous TERM
      VEL1 0.0 LECT tous TERM
      VEL2 0.0 LECT tous TERM

LINK COUP
      BLOQ 2 TOUS
      BLOQ 1 LECT 1 101 102 202 TERM
ECRI VITE ACCE FINT FEXT CONT ECRO MCVC MCVS TPRE 30.E-3
      FICH ALIC TPRE 30.E-3
OPTI PAS AUTO NOTE STEP IO CSTA 0.5
OPTI MC ORDR 2 NUFL ROE SYNC 1
      LOG 1
      CALC TINI 0 TEND 30.E-3
*-----POST-TREATMENT
SUIT
Post-treatment
ECHO
RESU ALIC GARD PSCR
SORT GRAP
AXTE 1.0 'X-Coor [m]'
*-----Curve definitions
SCOU 1 'p_nc' NSTO 2 SAXE 1.0 'current_abscissa' LECT 1 PAS 1 101 TERM
      MCRP COMP 1
SCOU 2 'r_nc' NSTO 2 SAXE 1.0 'current_abscissa' LECT 1 PAS 1 101 TERM
      MCRO COMP 1
SCOU 3 't_nc' NSTO 2 SAXE 1.0 'current_abscissa' LECT 1 PAS 1 101 TERM
      MCTE COMP 4
*-----Theoretical solutions
DCOU 51 'p_theor' 107
<same as before>

DCOU 52 'r_theor' 107
<same as before>
DCOU 53 't_theor' 107
<same as before>
COUR 63 't_theor' DIVC 53 666.667
RCOU 11 'p_ef' FICH 'tubeef.pun'
RCOU 12 'r_ef' FICH 'tubeef.pun'
RCOU 13 't_ef' FICH 'tubeef.pun'
RCOU 21 'p_cc' FICH 'tubecc.pun'
RCOU 22 'r_cc' FICH 'tubecc.pun'
RCOU 23 't_cc' FICH 'tubecc.pun'
RCOU 31 'p_ncw' FICH 'tubencw.pun'
RCOU 32 'r_ncw' FICH 'tubencw.pun'
RCOU 33 't_ncw' FICH 'tubencw.pun'
*-----Plots
TRAC 51 11 21 31 1 AXES 1.0 'PRESS. [PA]'
      COLO roug vert turq bleu noir
TRAC 52 12 22 32 2 AXES 1.0 'DENS. [KG/M3]'
      COLO roug vert turq bleu noir
TRAC 63 13 23 33 3 AXES 1.0 'TEMP. [K]'
      COLO roug vert turq bleu noir
TRAC 51 31 1 AXES 1.0 'PRESS. [PA]'
      COLO roug bleu noir
TRAC 52 32 2 AXES 1.0 'DENS. [KG/M3]'
      COLO roug bleu noir
TRAC 63 33 3 AXES 1.0 'TEMP. [K]'
      COLO roug bleu noir
LIST 1 AXES 1.0 'PRESS. [PA]'
LIST 2 AXES 1.0 'DENS. [KG/M3]'
LIST 3 AXES 1.0 'TEMP. [K]'
TRAC 51 11 21 31 1 AXES 1.0 'PRESS. [PA]'
      COLO noir noir noir noir noir
      DASH 4 3 5 2 0
TRAC 52 12 22 32 2 AXES 1.0 'DENS. [KG/M3]'
      COLO noir noir noir noir noir
      DASH 4 3 5 2 0
TRAC 63 13 23 33 3 AXES 1.0 'TEMP. [K]'
      COLO noir noir noir noir noir
      DASH 4 3 5 2 0
*-----Results qualification
!QUAL ECRO COMP 2 LECT 25 TERM REFE 8.68046E-01 TOLE 1.E-2
! ECRO COMP 2 LECT 50 TERM REFE 4.98674E-01 TOLE 1.E-2
! ECRO COMP 2 LECT 75 TERM REFE 4.57575E-01 TOLE 1.E-2
*-----
FIN
```

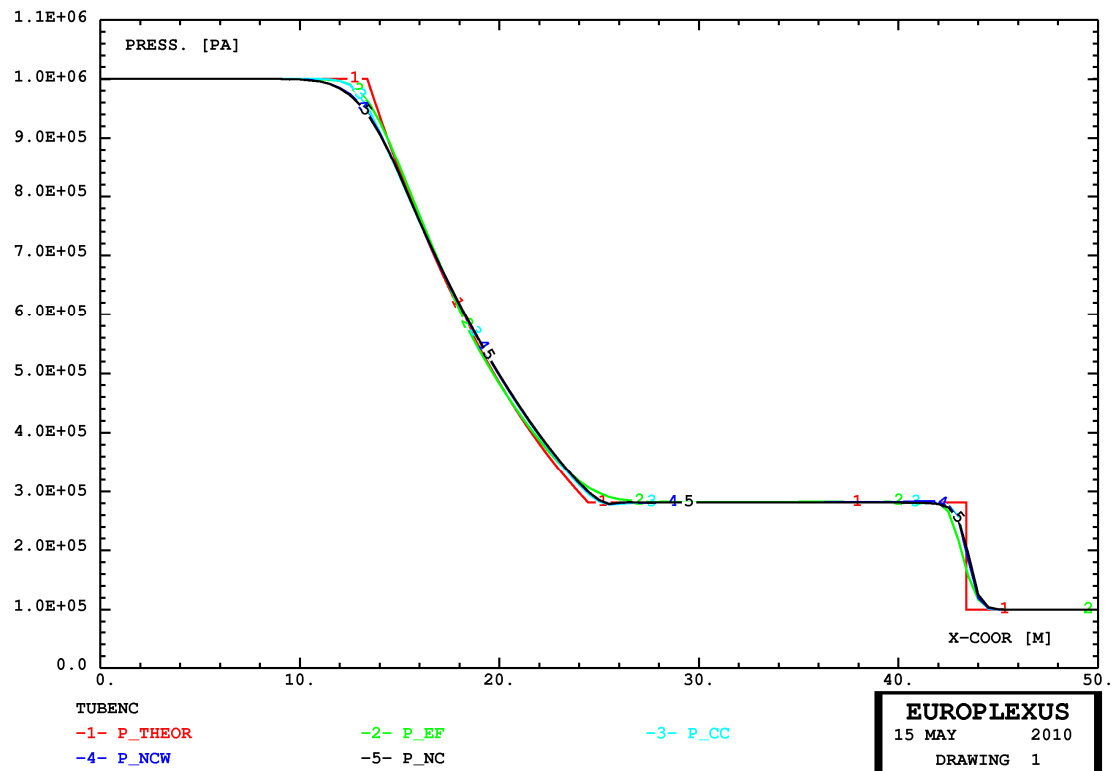
TUBENCW

This solution is obtained with Node-Centered Finite Volumes (MC24). Boundary conditions are imposed in a weak manner (OPTI MC WBC). The input file is:

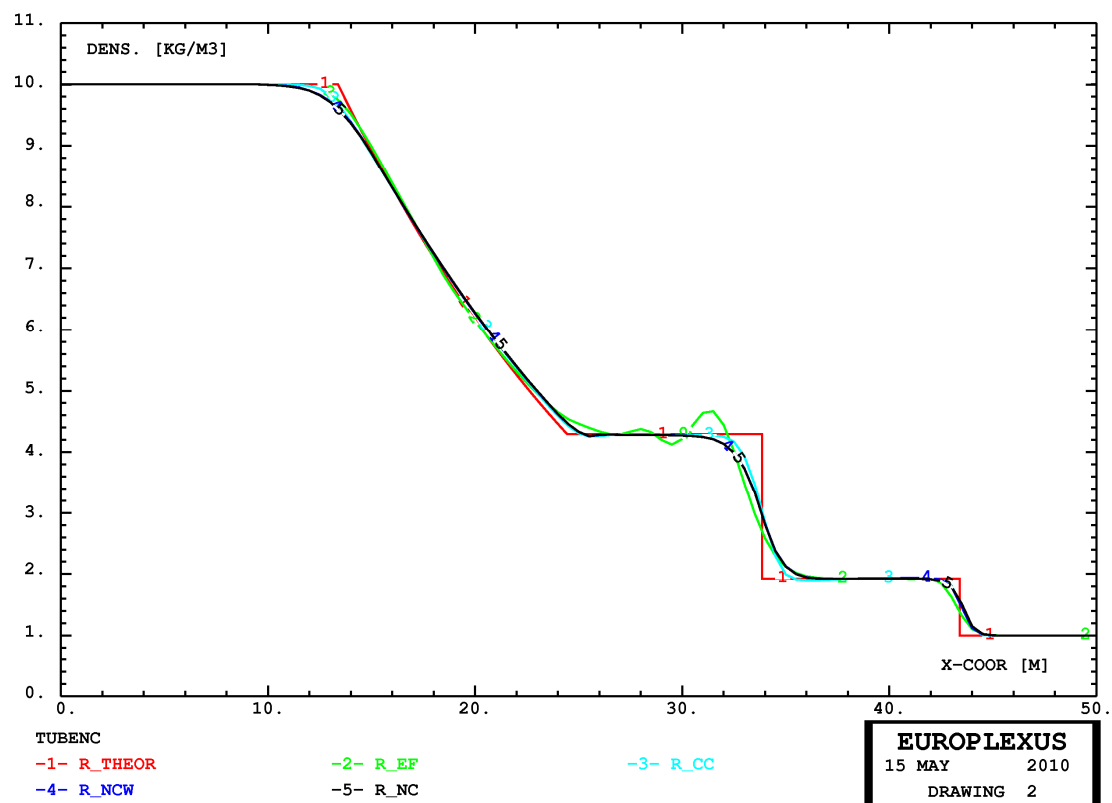
```
TUBENCW
ECHO
!CONV WIN
DPLA RULE
DIME NDVC 804 TERM
GEOM LIBR POIN 202 MC24 100 TERM
-
<same mesh as before>
-
MATE MCGP NCOM 1 R 1.E4
      COMP 'aria' PM 30.E0 CV1 2.E4 CV2 0 CV3 0
      LECT tous TERM
INIT MCOM COMP 'aria' MFRA 1.0 LECT tous TERM
      PRES 1.D6 LECT 1 PAS 1 50 102 PAS 1 151 TERM
      PRES 5.D5 LECT 51 152 TERM
      PRES 1.D5 LECT 52 PAS 1 101 153 PAS 1 202 TERM
      TEMP 3.D2 LECT tous TERM
      VEL1 0.0 LECT tous TERM
      VEL2 0.0 LECT tous TERM
ECRI VITE ACCE FINT FEXT CONT ECRO MCVC MCVS TPRE 30.E-3
      FICH ALIC TPRE 30.E-3
OPTI PAS AUTO NOTE STEP IO CSTA 0.5
OPTI MC ORDR 2 NUFL ROE SYNC 1 WBC
      LOG 1
      CALC TINI 0 TEND 30.E-3
*-----POST-TREATMENT
SUIT
Post-treatment
ECHO
RESU ALIC GARD PSCR
SORT GRAP
AXTE 1.0 'X-Coor [m]'

*-----Curve definitions
SCOU 1 'p_ncw' NSTO 2 SAXE 1.0 'current_abscissa' LECT 1 PAS 1 101 TERM
      MCRP COMP 1
SCOU 2 'r_ncw' NSTO 2 SAXE 1.0 'current_abscissa' LECT 1 PAS 1 101 TERM
      MCRO COMP 1
SCOU 3 't_ncw' NSTO 2 SAXE 1.0 'current_abscissa' LECT 1 PAS 1 101 TERM
      MCTE COMP 4
*-----Theoretical solutions
DCOU 51 'p_theor' 107
<same as before>
DCOU 52 'r_theor' 107
<same as before>
DCOU 53 't_theor' 107
<same as before>
COUR 63 't_theor' DIVC 53 666.667
*-----Plots
TRAC 1 51 AXES 1.0 'PRESS. [PA]'
      COLO noir roug
TRAC 2 52 AXES 1.0 'DENS. [KG/M3]'
      COLO noir roug
TRAC 3 63 AXES 1.0 'TEMP. [K]'
      COLO noir roug
LIST 1 AXES 1.0 'PRESS. [PA]'
LIST 2 AXES 1.0 'DENS. [KG/M3]'
LIST 3 AXES 1.0 'TEMP. [K]'
*-----Results qualification
!QUAL ECRO COMP 2 LECT 25 TERM REFE 8.68046E-01 TOLE 1.E-2
! ECRO COMP 2 LECT 50 TERM REFE 4.98674E-01 TOLE 1.E-2
! ECRO COMP 2 LECT 75 TERM REFE 4.57575E-01 TOLE 1.E-2
*-----
FIN
```

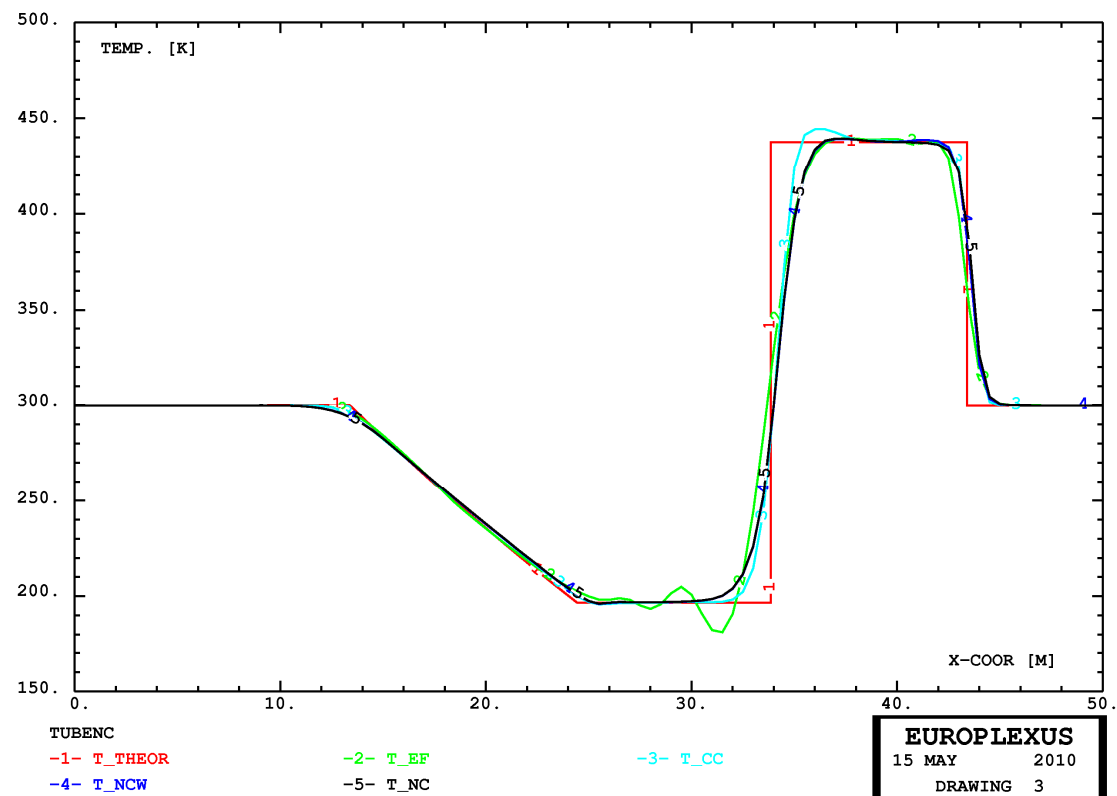
The final pressure along the tube is very similar in all solutions (in red the analytical solution)



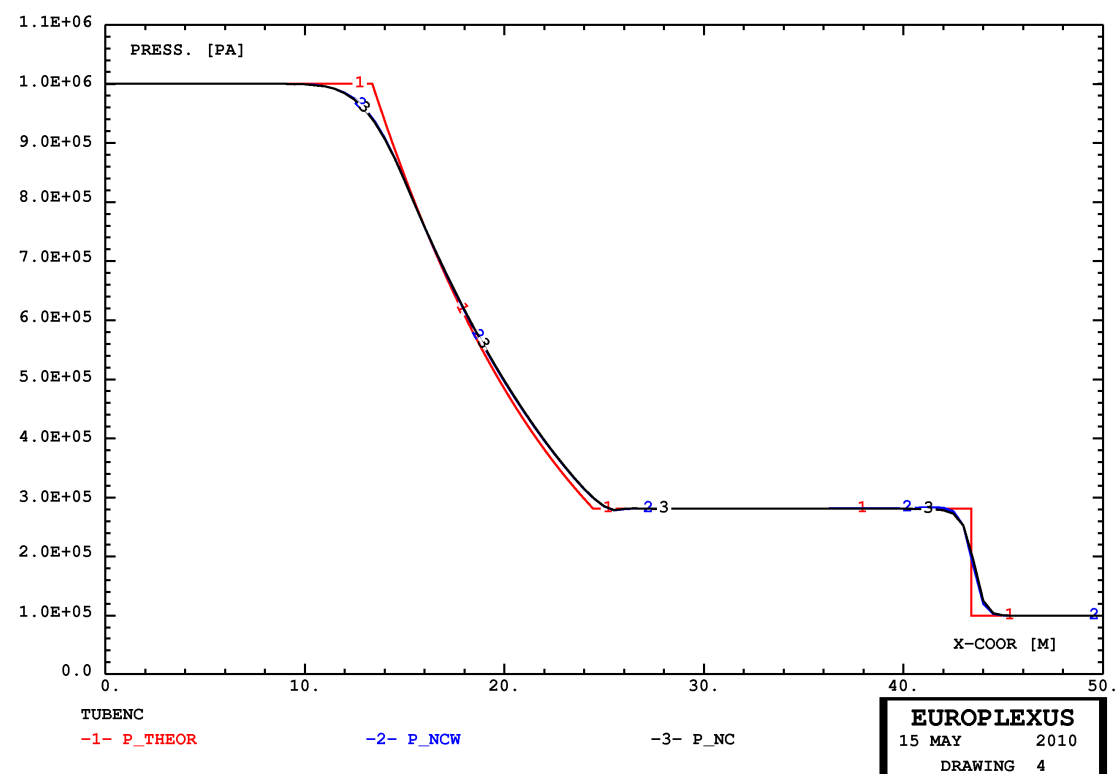
The final density along the tube is very similar in all solutions (in red the analytical solution)



Here are the temperatures



The two NCFV solutions with strong or weak boundary conditions are almost identical. Here are the pressures:



Here are the densities

