

# Depressurization and Repressurization Loads on AMS02 Tracker Structures

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## 1 Introduction

This report describes the calculation of the pressure loads on the AMS02 tracker structures induced by depressurization and repressurization during launch and re-entry with space shuttle.

## 2 Tracker volumes and venting apertures

Figure 1 shows a sketch of the tracker supporting structure. For convenience of the calculation, two volumes (to be emptied or filled) are treated independently:

A) For the whole volume (1.14 m<sup>3</sup>), air can be expelled or admitted through four bell shaped labyrinths (*light tight venting traps*) with nominal section of 20 cm<sup>2</sup> each and hydraulic diameter ( $d_h$ ) of 14 mm. The light trap is shown on fig 2. The pressure load in that case applies on the lateral shells, on the conical flanges and on planes 1 and 5.

B) For pressure loads on plane 2 (or 4), one considers the volume (0.262 m<sup>3</sup>) limited by planes 2 and 3 (or 4 and 3). Apertures available for air flow in these planes are of 3 types:

- *Open slots*: (4 not occupied by cables) of quasi rectangular shape  
Surface =  $4 \times 486 = 1944 \text{ mm}^2$ ,  $d_h = 12.5 \text{ mm}$ .
- *Occupied slots* (ignored): Equipment and cables make the air flow very complicated.  
Surface =  $24 \times 130 = 3120 \text{ mm}^2$ ,  $d_h = 6.6 \text{ mm}$ .
- *Clearance (or Slit)*: The clearance between planes and shells has mainly the shape of a 1 mm slit. Surface  $> 4600 \text{ mm}^2$ ,  $d_h = 2 \text{ mm}$ .

This separation (A/B) is justified by the fact that pressure load is much smaller for case B).

## 3 Properties of apertures (calculation and measurements)

For a fluid flowing with average velocity  $w$  through an aperture, when gravity can be neglected and for low Mach number, the pressure loss  $\Delta P = P_{in} - P_{out}$  is usually expressed as:

$$P_{in} - P_{out} = \Delta P = \zeta \frac{\rho w^2}{2} \quad (1)$$

where the pressure loss (head loss) coefficient  $\zeta$  depends only on the shape of the aperture and on Reynold's number  $Re = w\rho d_h/\eta$  where  $\eta$  is the dynamic viscosity of the fluid and  $d_h$  is the *hydraulic diameter* (4 area/perimeter) of the aperture. At high  $Re$ , when inertial forces dominate,  $\zeta$  varies slowly with  $Re$ . At low  $Re$ , in the viscous regime,  $\zeta$  behaves as  $1/Re$ .

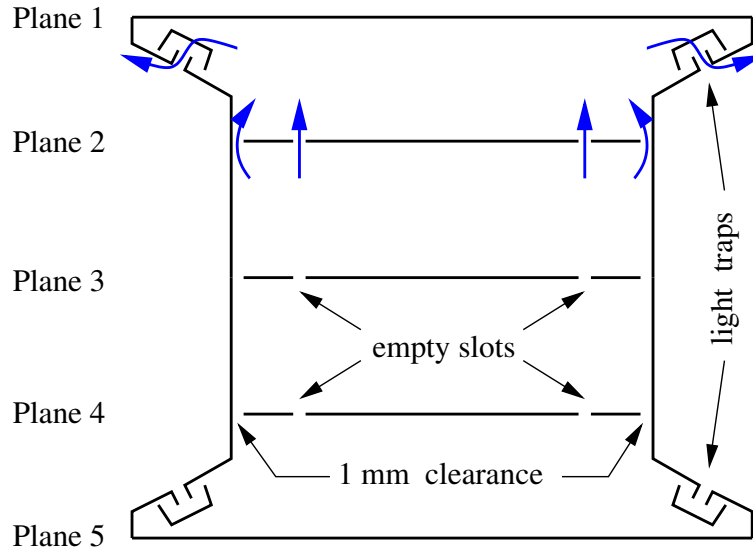


Figure 1: AMS02 tracker structure and apertures for air flow

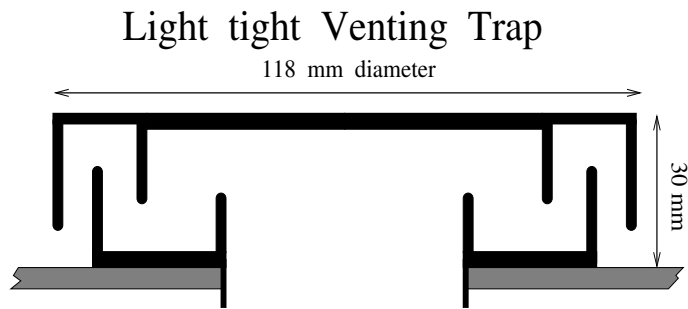


Figure 2: Cross-section of the light trap

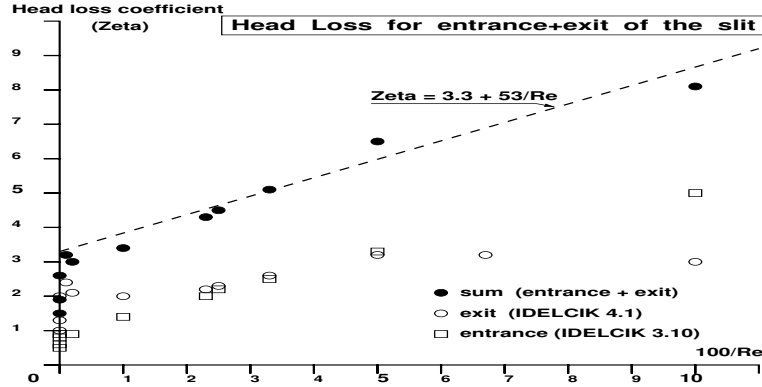
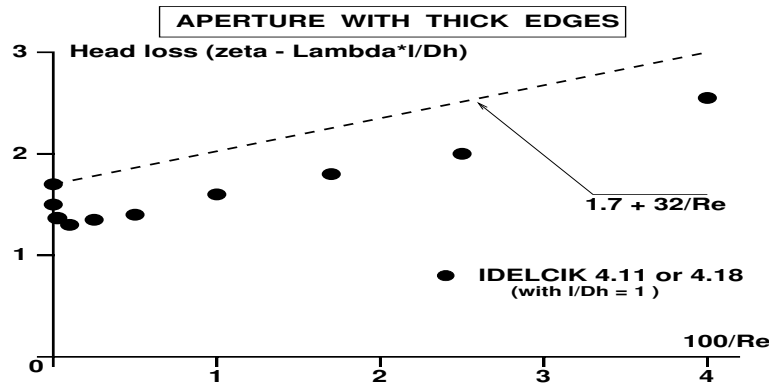
Figure 3: Calculated  $\zeta$  coefficients for entrance/exit from the slit (clearance)

Figure 4: Calculated head loss coefficients for thick aperture (open slots)

### 3.1 Calculation of $\zeta$ coefficient (from literature)

For simple geometries like *Slit/Clearance* or *Open slot*, the head loss factor  $\zeta$  can be evaluated using the literature (*IDELCIK*). We summed the contributions of the entrance, exit and body of the aperture, taking into account the dependence on the Reynolds's number.

- *Slit or Clearance* ( $d_h = 2\text{mm}$ ). The diagrams 3.10 and 4.1 of *IDELCIK* are used to evaluate sudden reduction or enlargement of section in a duct. Figure 3 shows the  $\zeta$  coefficients plotted against  $1/Re$ . The sum can be maximized by the expression  $3.3 + 53/Re$ . We then add the contribution of the 13 mm depth of the slit with:  $\zeta = 1.5 \cdot (0.08 + 64/Re) \cdot (l/d_h) = 0.78 + 624/Re$ . The total for the slit becomes:  $\zeta = 4.1 + 677/Re$
- *Open slots* ( $d_h = 12.5\text{mm}$ ). For an aperture with thick edges, values obtained from the diagrams 4.11 or 4.18 of *IDELCIK* are shown on figure 4. They are maximized by:  $\zeta = 1.7 + 32/Re$ . Adding the contribution of a rectangular pipe with  $l/d_h = 1$ , we obtain:  $\zeta < 1.82 + 128/Re$ . If we use the same procedure as for the slit, we obtain a pessimistic expression:  $\zeta < 3.42 + 149/Re$ .

### 3.2 Measurements of $\zeta$

No information was found in literature for the complicated geometry of the light trap. Measurements were performed for *slots* and *light trap* over a large range of Reynold numbers. For large  $Re$ , measurements with air at room temperature were performed at the *Laboratoire d'Aérotechnique de l'Ecole d'Ingénieurs de Genève*, with 1/1 models. For lower  $Re$ , we used liquid and reduced size models (1/7 and 1/10 for slots, 1/4 for light trap). Liquid was water with various sucrose concentrations in order to vary the viscosity.

Results are shown on figures 5 and 6 where one can see the good connexion between air and liquid measurements. Uncertainties reach 25 % for the measurement at high  $Re$  and 30 % for horizontal scale due to viscosity uncertainties. The good agreement with calculations from litterature can be seen for the *slot* case.

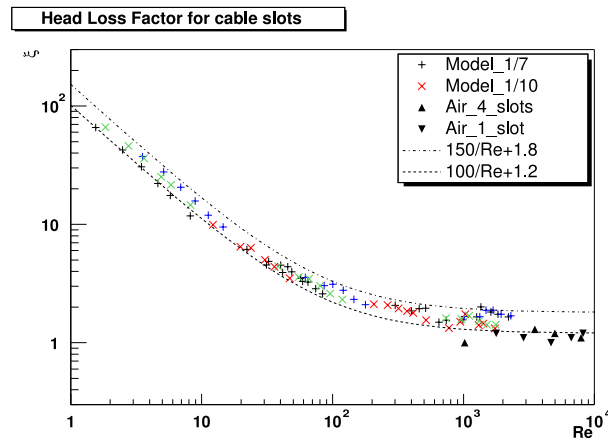


Figure 5: Measured head loss coefficient for cable slots

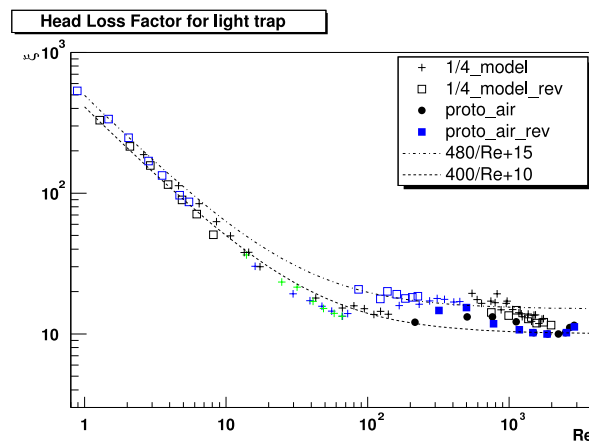


Figure 6: Measured head loss coefficient for light trap

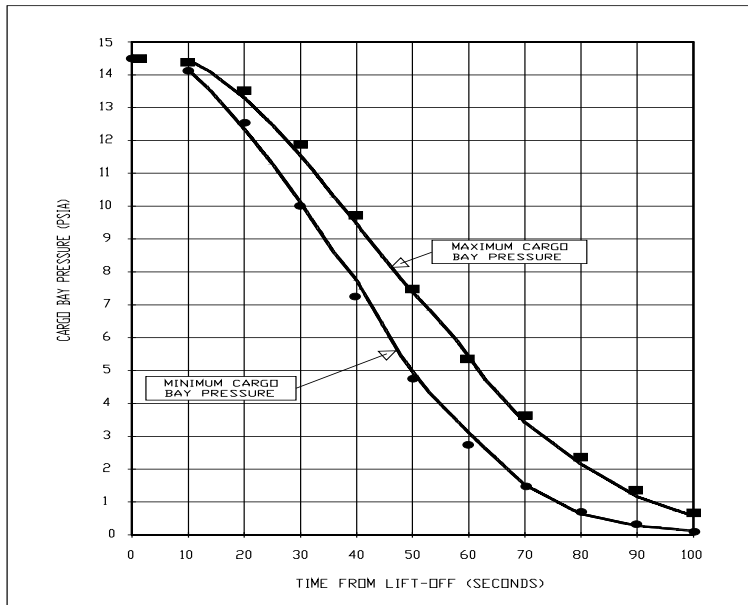


Figure 7: Solid lines: cargo bay pressure from NSTS-21000-IDD-ISS. Black squares and dots: values obtained with the simple gaussian formula of equation (2).

## 4 Depressurization (Launch)

The relevant information is found in section 10.6 of NSTS-21000-IDD-ISS document available on: [shuttlepayloads.jsc.nasa.gov/data/PayloadDocs/PayloadDocs.htm](http://shuttlepayloads.jsc.nasa.gov/data/PayloadDocs/PayloadDocs.htm) containing a link to: [www.unitedspacealliance.com/icd/ssidd/contents.html](http://www.unitedspacealliance.com/icd/ssidd/contents.html).

Figures 7 and 8 show the cargo bay pressure and the rate of depressurization obtained from the above document.

Considering a constant acceleration of the vertical motion of the shuttle at the beginning of the flight and a simple exponential model of the atmosphere, the time evolution of the pressure can be described by a gaussian-like expression:

$$P(t) = P_o \exp[-(t - t_o)^2 / \tau^2] \quad (2)$$

where  $P_o = 14.5$  [PSI] is the atmospheric pressure. The good agreement can be seen on figure 7 for the black squares with offset  $t_o = 5$  [sec] and characteristic time  $\tau = 55$  [sec]. For the black dots the values are:  $t_o = 2.5$  and  $\tau = 45$ .

The figure 8 shows that the instantaneous decay rate  $\dot{P}(t)$  of the pressure can reach values  $\sim 1.7$  time larger than the simple time derivative of equation (2) for the smooth case. This has to be taken into account when calculations of pressure loads are made assuming a "smooth" decrease of the cargo bay pressure.

### 4.1 Small pressure load approximation (for launch)

For an ideal gaz expelled from a reservoir of volume  $V$  through an hole of area  $A$ , the average gaz velocity in the hole is:

$$w = (V/A) \cdot (\dot{\rho}_{in} / \rho_{in}) = (V/A) \cdot (\dot{P}_{in} / P_{in}) \quad (3)$$

If the hole is large enough ( $\Delta P \ll P$ ), the inner pressure  $P_{in}$  follows the outer pressure. With  $P_o = 10^5$  [Pa] and  $\rho_o = 1.25$  [kg/m<sup>3</sup>] as initial pressure and air density, evolution of the

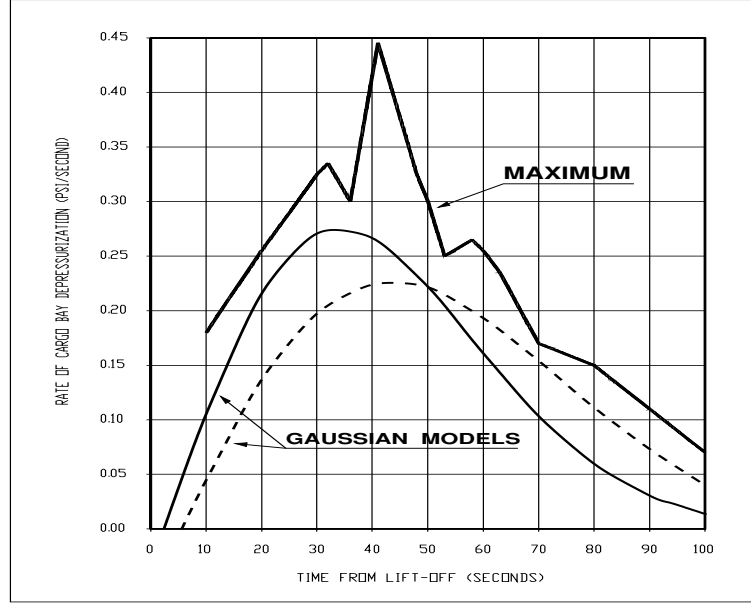


Figure 8: Rate of depressurization. The maximum is from NSTS-21000-IDD-ISS, the smooth curves are obtained by the gaussian formula.

inner pressure can also be described by:  $P(t) = P_o \exp(-t^2/\tau^2)$  and  $\rho(t) = \rho_o \exp(-t^2/\tau^2)$ . The velocity and Reynold's number become:

$$w = \frac{V}{A} \cdot \frac{\dot{P}}{P} = 2 \frac{V/A}{\tau} \cdot \frac{t}{\tau} \quad (4)$$

$$R_e = \frac{\rho w d_h}{\eta} = \frac{V/A}{\tau} \frac{\rho_o d_h}{\eta} \cdot 2 \frac{t}{\tau} \exp(-t^2/\tau^2) \quad (5)$$

The velocity increases linearly with time. For  $\tau \simeq 50 \text{ sec}$  and  $V/A \simeq 100 \text{ m}$ , it stays well subsonic.  $R_e$  is maximum for  $t = \tau/\sqrt{2}$ . At room temperature ( $\eta = 1.9 \cdot 10^{-5} [\text{MKS}]$ ) with a diameter  $d_h = 10 \text{ mm}$ , it can reach  $R_e = 1130$ .

When viscous effects can be neglected ( $\zeta \simeq \text{constant}$ ), the pressure load becomes:

$$\Delta P = \zeta \frac{\rho}{2} w^2 = \zeta \cdot \frac{V^2}{A^2} \cdot \frac{\rho_o}{2} \cdot \frac{\dot{P}^2(t)}{P_o P(t)} = \zeta \frac{\rho_o}{2} \cdot \frac{(V/A)^2}{\tau^2} \cdot 4 \frac{t^2}{\tau^2} \exp(-t^2/\tau^2) \quad (6)$$

The latter expression is maximum when  $t = \tau$ . Using  $\tau = 50 \text{ sec}$ , we get:

$$\Delta P_{max} = \zeta \cdot (V/A)^2 \cdot 3.68 \cdot 10^{-4} \quad [\text{SI units}] \quad (7)$$

In case of several holes of various types, the term  $\zeta/A^2$  is replaced by:  $(\sum A_i/\sqrt{\zeta_i})^{-2}$ . Recalling (from section 4 figure 8) that the instantaneous rate of depressurization can be  $\sim 1.7 \simeq \sqrt{3}$  larger than the average rate, an additional safety factor of 3 has to be taken into account.

The dynamic viscosity of air is independent of pressure or density. When viscous effects dominate, the pressure load increases linearly with time like the velocity in equation (4) as long as  $\Delta P \ll P$ . This condition is no longer valid at the maximum of the pressure load and a numerical integration has to be performed to determine the maximum.

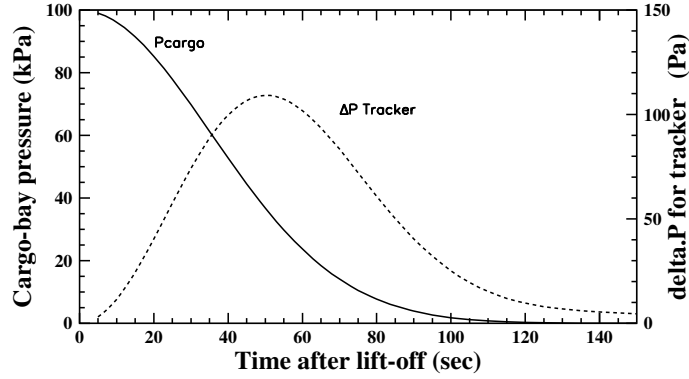


Figure 9: Pressure evolution for the whole tracker during launch

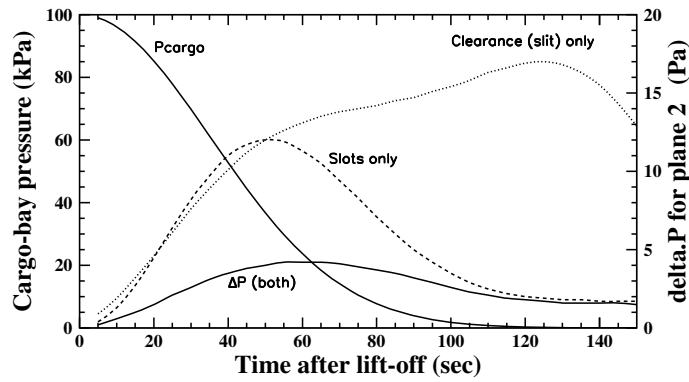


Figure 10: Pressure evolution for for plane 2 or 4 during launch

## 4.2 Numerical simulations (launch)

Equations were integrated step by step for a gaussian pressure profile with characteristic time of  $\tau=50 \text{ sec}$ , assuming air an ideal gaz at room temperature with constant dynamic viscosity. Head loss coefficients were parametrized as  $\zeta = \zeta_0 + \zeta_1/Re$ , according to our measurements or calculations. Detailed computer outputs can be seen at section 10.

A) For the whole tracker volume, the pressure load reaches 110 Pa. Evolution can be seen on fig. 9.

B) Three case are shown on fig. 10 for the pressure load on plane 2 (or 4) corresponding to 3 combinations of apertures. *i)* Cable slots only with  $\Delta P_{max} = 12[\text{Pa}]$ , *ii)* Clearance only with  $\Delta P_{max} = 17[\text{Pa}]$  with dominant laminar effects, *iii)* With both types of aperture we get  $\Delta P_{max} = 4.2[\text{Pa}]$ . These values are overestimated since the flow through *occupied slots* is neglected.

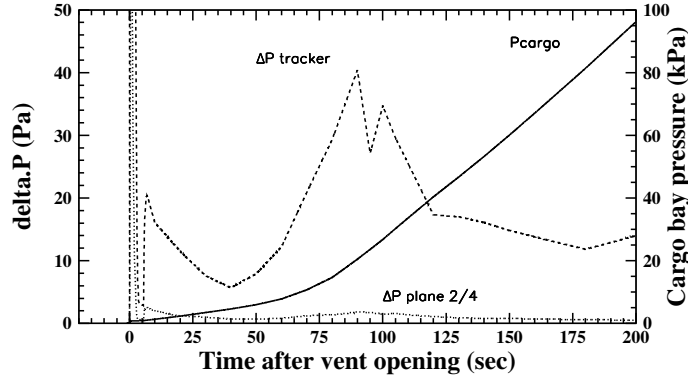


Figure 11: Repressurization evolution and pressure loads for re-entry

## 5 Repressurization (re-entry)

We used the repressurization profile provided by T. Martin (LMCO,*private communication*). It is analogous to those provided in the NSTS-21000-IDD-ISS document, but with a non-zero pressure ( $0.0175 \text{ PSI} = 120 \text{ Pa}$ ) before the *vent opening*. As for the launch case, we assume an ideal gaz with room temperature properties. Calculations were performed in two steps:

A) We computed the pressure load considering the whole volume of the tracker and using the largest head loss coefficient of the 4 light traps ( $15 + 480/Re$ ).

B) For the load on inner planes, the inner pressure evolution was obtained by subtracting the pressure load obtained in A) to the external pressure using the lowest value of the coefficient ( $10 + 400/Re$ ). The pressure load was then computed considering the open cable slots and the clearance.

Computer outputs can be seen in section 10. Figure 11 shows the whole repressurization evolution. Except for the very beginning, the pressure load stays below 50 Pa for the external parts and below 3 Pa for the inner planes.

The situation at the very beginning is shown on figures 12 and 13. The sudden increase of the external (cargo bay) pressure (640 Pa in less than half second) reflects almost totally (530 Pa) as a bump in the pressure load. This effect is attenuated on the inner planes where it is less than 80 Pa.

## 6 Conclusion

We computed the pressure loads on tracker structures for launch and re-entry:

- During launch, the pressure load on the outer planes, shells and conical flanges reaches 110 Pa. On inner planes it stays below 4.2 Pa. An additionnal safety factor of  $\simeq 3$  will take into account the possible peaks in the depressurization rate shown in figure 8.
- During re-entry, the pressure loads are lower, except at the very beginning. The pressure bump at vent opening (640 Pa), if real, reflects almost totally (530 Pa) on the external tracker structures. It is attenuated and below 80 Pa on the inner planes.

I would like to thank S. Bergamaschi of DPNC who build prototype and models, M. Perraudin and F. Lanier of the *Ecole d'Ingénieurs de Genève* for fruitfull discussions and measurements.

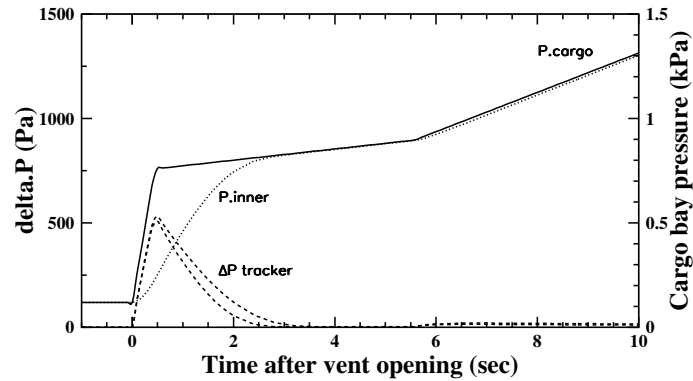


Figure 12: Details of pressure on whole tracker at the very beginning

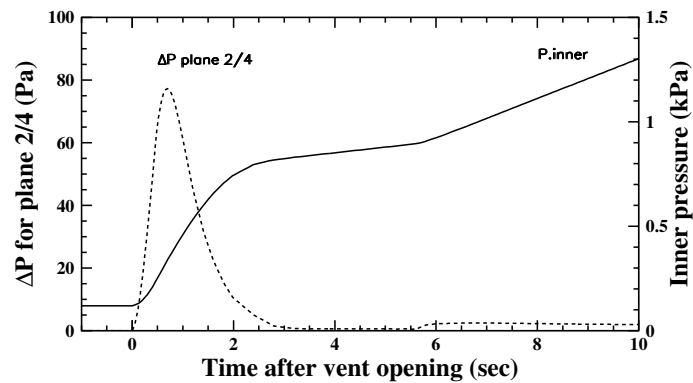


Figure 13: Details of pressure on inner planes at the very beginning

## 7 Litterature

- I. E. IDELCIK, *Memento des pertes de charges*, French translation from Russian. Eyrolles editions Paris. May exist in English with the title: *Handbook of hydraulic resistance*.
- VDI-Wärmeatlas, 4.Auflage 1984, chapters La, Lb & Lc (Druckverlust) *in German*
- Spacecraft Launch Depressurization Loads, A. Sanz-Andres et al. Journal of Spacecraft and Rockets, Vol 34, number 6, nov-dec 1997

## 8 Computer outputs

Knudsen number is the ratio of mean free path of air molecules over the hydraulic diameter of the apertures. Values less than  $10^{-2}$  indicate *viscous regime* (continuum). *Molecular regime* occurs at 0.3.

```

=====
      Depressurization whole tracker
=====
Give Tau[s], Vol[m3], S1,S2,S3 [mm2]
      50.      1.14  8000. 0 0/ Whole Tracker volume 4 traps
for S(1), enter Zeta, Zp, Dh[mm]:
      15.  480.  14. / measured head loss
To, Nb_steps/sec, NdP ? 0.1  50000 100
  T  steps  Pout   del.P  Knud   Re   vel frac
  5. 278216 99005.0   3.1  0.00  497.5  0.6 100.%
 10. 250000 96079.0  11.5  0.00  965.7  1.1 100.%
 15. 250000 91393.1  24.5  0.00 1378.2  1.7 100.%
 20. 250000 85214.4  40.4  0.00 1713.7  2.3 100.%
 25. 250000 77880.1  57.5  0.00 1958.2  2.8 100.%
 30. 250000 69767.7  74.2  0.00 2105.8  3.4 100.%
 35. 250000 61262.7  88.6  0.00 2158.1  4.0 100.%
 40. 250000 52729.3  99.7  0.00 2123.8  4.5 100.%
 45. 250000 44485.8 106.6  0.00 2016.7  5.1 100.%
 50. 250000 36788.0 109.1  0.00 1854.1  5.7 100.%
 55. 250000 29819.7 107.3  0.00 1654.2  6.3 100.%
 60. 250000 23692.8 101.8  0.00 1434.7  6.8 100.%
 65. 250000 18452.0  93.5  0.00 1211.3  7.4 100.%
 70. 250000 14085.9  83.3  0.00  996.6  8.0 100.%
 75. 250000 10539.9  72.1  0.00  799.7  8.5 100.%
 80. 250000  7730.5  60.9  0.00  626.2  9.1 100.%
 85. 250000  5557.6  50.2  0.00  478.8  9.7 100.%
 90. 250000  3916.4  40.5  0.00  357.6 10.2 100.%
 95. 250000  2705.2  32.2  0.00  261.0 10.8 100.%
100. 250000  1831.6  25.2  0.00  186.2 11.3 100.%
105. 250000  1215.5  19.6  0.00  129.9 11.9 100.%
110. 250000   790.7  15.3  0.00   88.6 12.4 100.%
115. 250000   504.2  12.0  0.00   59.1 13.0 100.%
120. 250000   315.1   9.7  0.00   38.6 13.4 100.%
125. 250000   193.0   8.0  0.00   24.7 13.9 100.%
130. 250000   115.9   6.9  0.00   15.4 14.2 100.%
135. 250000    68.2   6.1  0.01    9.5 14.4 100.%
140. 250000    39.4   5.5  0.01    5.7 14.3 100.%
145. 250000    22.3   5.0  0.02    3.4 14.0 100.%
150. 250000    12.3   4.6  0.03    2.0 13.2 100.%

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=====
DEPRESS.   PLANE 2   OPEN CABLE SLOTS ALONE
=====
Give Tau[s], Vol[m3], S1,S2,S3 [mm2]
    50.    .262   1944. 0 0/ 4 cable-slots alone
for S(1), enter Zeta, Zp, Dh[mm]:
    1.8  150  12.5 / pessimistic (meas)
To, Nb_steps/sec, NdP ? 0.1 5000 100
  T  steps  Pout   del.P  Knud  Re   vel frac
  5. 1089942 99005.0   0.4  0.00  421.2  0.5 100.%
 10. 386383 96079.0   1.3  0.00  817.6  1.1 100.%
 15. 238107 91393.1   2.7  0.00 1166.6  1.6 100.%
 20. 172347 85214.4   4.5  0.00 1450.3  2.2 100.%
 25. 134996 77880.1   6.4  0.00 1656.9  2.7 100.%
 30. 110853 69767.7   8.2  0.00 1781.2  3.2 100.%
 35.  93930 61262.7   9.7  0.00 1824.8  3.8 100.%
 40.  81380 52729.2  11.0  0.00 1795.1  4.3 100.%
 45.  71672 44485.8  11.7  0.00 1703.9  4.9 100.%
 50.  63908 36788.0  12.0  0.00 1565.7  5.4 100.%
 55.  57519 29819.8  11.9  0.00 1396.1  5.9 100.%
 60.  52130 23692.9  11.3  0.00 1210.2  6.5 100.%
 65.  47472 18452.0  10.5  0.00 1021.1  7.0 100.%
 70.  43346 14085.9   9.4  0.00  839.5  7.5 100.%
 75.  39598 10540.0   8.3  0.00  673.1  8.1 100.%
 80.  36097  7730.5   7.1  0.00  526.7  8.6 100.%
 85.  32731  5557.7   6.0  0.00  402.3  9.2 100.%
 90.  29402  3916.4   5.0  0.00  300.2  9.7 100.%
 95.  26095  2705.2   4.2  0.00  218.9 10.2 100.%
100.  25000  1831.6   3.5  0.00  156.0 10.8 100.%
105.  25000  1215.5   2.9  0.00  108.7 11.3 100.%
110.  25000   790.7   2.5  0.00   74.1 11.8 100.%
115.  25000   504.2   2.2  0.00   49.4 12.4 100.%
120.  25000   315.1   2.0  0.00   32.2 12.9 100.%
125.  25000   193.0   1.9  0.00   20.6 13.4 100.%
130.  25000   115.9   1.8  0.00   12.8 13.8 100.%
135.  25000    68.2   1.8  0.01    7.8 14.2 100.%
140.  25000    39.4   1.7  0.01    4.7 14.5 100.%
145.  25000    22.3   1.7  0.02    2.8 14.6 100.%
150.  25000    12.3   1.7  0.04    1.6 14.4 100.%
=====

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=====
DEPRESS.   PLANE 2  CLEARANCE (SLIT) ALONE
=====
Give Tau[s], Vol[m3], S1,S2,S3 [mm2]
    50.    .262    4600. 0 0/   Clearance alone (slit)
for S(1), enter Zeta, Zp, Dh[mm]:
    4.1  677.  2. / Calculated Head loss
To, Nb_steps/sec, NdP ? 0.1 50000 100
  T  steps  Pout   del.P  Knud   Re    vel frac
  5. 250325 99005.0   0.9  0.00   28.5  0.2 100.%
 10. 250000 96078.9   1.9  0.00   55.3  0.5 100.%
 15. 250000 91393.1   3.2  0.00   78.9  0.7 100.%
 20. 250000 85214.4   4.6  0.00   98.1  0.9 100.%
 25. 250000 77880.1   6.1  0.00  112.0  1.1 100.%
 30. 250000 69767.6   7.6  0.00  120.4  1.4 100.%
 35. 250000 61262.7   8.9  0.00  123.4  1.6 100.%
 40. 250000 52729.3  10.1  0.00  121.4  1.8 100.%
 45. 250000 44485.8  11.2  0.00  115.2  2.0 100.%
 50. 250000 36788.0  12.0  0.00  105.9  2.3 100.%
 55. 250000 29819.7  12.6  0.00   94.4  2.5 100.%
 60. 250000 23692.8  13.1  0.00   81.8  2.7 100.%
 65. 250000 18452.0  13.5  0.00   69.0  3.0 100.%
 70. 250000 14085.8  13.8  0.00   56.7  3.2 100.%
 75. 250000 10539.9  14.0  0.00   45.5  3.4 100.%
 80. 250000  7730.5  14.2  0.00   35.6  3.6 100.%
 85. 250000  5557.6  14.5  0.00   27.2  3.9 100.%
 90. 250000  3916.4  14.7  0.00   20.3  4.1 100.%
 95. 250000  2705.2  15.1  0.00   14.8  4.3 100.%
100. 250000  1831.6  15.4  0.00   10.5  4.5 100.%
105. 250000  1215.5  15.8  0.00    7.3  4.7 100.%
110. 250000   790.7  16.3  0.00    5.0  4.9 100.%
115. 250000   504.2  16.6  0.01    3.3  5.1 100.%
120. 250000   315.1  16.9  0.01    2.2  5.2 100.%
125. 250000   193.0  17.0  0.02    1.4  5.2 100.%
130. 250000   115.9  16.8  0.03    0.9  5.2 100.%
135. 250000    68.2  16.3  0.04    0.5  5.1 100.%
140. 250000    39.4  15.5  0.06    0.3  4.8 100.%
145. 250000    22.3  14.3  0.09    0.2  4.4 100.%
150. 250000    12.3  12.9  0.13    0.1  4.0 100.%
=====

```

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=====
DEPRESS. PLANE 2 BOTH CABLE SLOTS AND CLEARANCE (SLIT)
=====
Give Tau[s], Vol[m3], S1,S2,S3 [mm2]
50. .262 1944 4600 0/ 4 cable slots + clearance
for S(1), enter Zeta, Zp, Dh[mm]:
1.8 150 12.5 / pessimistic (meas)
for S(2), enter Zeta, Zp, Dh[mm]:
4.1 677. 2. / Calculated Head loss
To, Nb_steps/sec, NdP ? 0.1 50000 100
<-- Open Cable Slots --><-- Clearance (slit)-->
T steps Pout del.P Knud Re vel frac Knud Re vel frac
5.1487262 99005.0 0.2 0.00 306.5 0.4 73.% 0.00 7.8 0.1 27.%
10. 780483 96078.9 0.6 0.00 527.7 0.7 65.% 0.00 19.6 0.2 35.%
15. 587198 91393.1 1.0 0.00 701.4 1.0 60.% 0.00 31.5 0.3 40.%
20. 478916 85214.4 1.5 0.00 834.7 1.2 58.% 0.00 41.6 0.4 42.%
25. 403597 77880.1 2.1 0.00 928.6 1.5 56.% 0.00 49.3 0.5 44.%
30. 345767 69767.6 2.6 0.00 984.2 1.8 55.% 0.00 53.9 0.6 45.%
35. 298815 61262.7 3.1 0.00 1003.5 2.1 55.% 0.00 55.5 0.7 45.%
40. 260356 52729.3 3.5 0.00 990.3 2.4 55.% 0.00 54.4 0.8 45.%
45. 250000 44485.8 3.8 0.00 949.6 2.7 56.% 0.00 51.0 0.9 44.%
50. 250000 36788.0 4.0 0.00 887.3 3.1 57.% 0.00 45.9 1.0 43.%
55. 250000 29819.7 4.2 0.00 809.5 3.4 58.% 0.00 39.7 1.1 42.%
60. 250000 23692.8 4.2 0.00 722.1 3.9 60.% 0.00 33.0 1.1 40.%
65. 250000 18452.0 4.2 0.00 630.4 4.3 62.% 0.00 26.4 1.1 38.%
70. 250000 14085.9 4.1 0.00 538.8 4.8 64.% 0.00 20.3 1.1 36.%
75. 250000 10539.9 3.9 0.00 450.8 5.4 67.% 0.00 15.0 1.1 33.%
80. 250000 7730.5 3.7 0.00 368.8 6.0 70.% 0.00 10.7 1.1 30.%
85. 250000 5557.6 3.5 0.00 294.7 6.7 73.% 0.00 7.3 1.0 27.%
90. 250000 3916.4 3.2 0.00 229.7 7.4 77.% 0.00 4.8 1.0 23.%
95. 250000 2705.2 2.9 0.00 174.4 8.2 80.% 0.00 3.0 0.9 20.%
100. 250000 1831.6 2.6 0.00 128.8 8.9 83.% 0.00 1.8 0.8 17.%
105. 250000 1215.5 2.3 0.00 92.4 9.6 85.% 0.00 1.1 0.7 15.%
110. 250000 790.7 2.1 0.00 64.5 10.3 87.% 0.00 0.6 0.6 13.%
115. 250000 504.2 1.9 0.00 43.8 11.0 89.% 0.01 0.4 0.6 11.%
120. 250000 315.1 1.8 0.00 28.9 11.6 90.% 0.01 0.2 0.6 10.%
125. 250000 193.0 1.7 0.00 18.6 12.1 91.% 0.02 0.1 0.5 9.%
130. 250000 115.9 1.6 0.00 11.7 12.6 91.% 0.03 0.1 0.5 9.%
135. 250000 68.2 1.6 0.01 7.2 13.0 92.% 0.05 0.0 0.5 8.%
140. 250000 39.4 1.6 0.01 4.3 13.3 92.% 0.08 0.0 0.5 8.%
145. 250000 22.3 1.6 0.02 2.5 13.5 92.% 0.14 0.0 0.5 8.%
150. 250000 12.3 1.5 0.04 1.5 13.3 92.% 0.24 0.0 0.5 8.%
=====

```

```

=====
REPRESS. WHOLE TRACKER (T.Martin pressure profile)
=====
Give Case, Vol[m3], S1,S2,S3 [mm2]:
    1 1.14 8000 0 0/Tracker full volume 4 traps
for S(1), enter Zeta, Zp, Dh[mm]:
    15. 480. 14. /Measurement (pessim)
To, Nb_steps/sec, NdP ? 0 45000 500
  T  steps  P_out  delP  Knud  Re  vel
0.0 45000  120.0
0.1  4501  261.9 135.6  0.00 136.0 79.3 100.%
0.2  4500  403.7 262.8  0.00 233.9 97.1 100.%
0.3  4500  545.6 382.4  0.00 327.5 104.5 100.%
0.4  4500  687.5 494.6  0.00 419.2 107.7 100.%
0.5  4500  759.8 531.0  0.00 461.8 105.7 100.%
0.6  4500  762.5 497.3  0.00 455.4 100.2 100.%
0.7  4499  765.2 464.1  0.00 447.9  95.0 100.%
0.8  4501  767.9 431.6  0.00 439.2  90.0 100.%
0.9  4499  770.5 399.8  0.00 429.5  85.1 100.%
1.0  4500  773.2 368.8  0.00 418.6  80.4 100.%
1.2  9001  778.6 309.7  0.00 393.9  71.4 100.%
1.4  8999  784.0 254.7  0.00 365.5  63.0 100.%
1.6  9001  789.4 204.6  0.00 333.8  54.9 100.%
1.8  8999  794.8 159.7  0.00 299.3  47.3 100.%
2.0  9001  800.1 120.4  0.00 262.7  40.1 100.%
2.4 18000  810.9  59.9  0.00 186.2  27.0 100.%
2.8 17999  821.7  23.4  0.00 113.2  15.8 100.%
3.2 18001  832.4   7.5  0.00  59.3   8.1 100.%
3.6 17999  843.2   3.6  0.00  38.0   5.1 100.%
4.0 18000  854.0   3.1  0.00  34.4   4.6 100.%
4.4 18001  864.7   3.0  0.00  34.1   4.5 100.%
4.8 18000  875.5   3.0  0.00  34.0   4.4 100.%
5.0  8999  880.9   2.9  0.00  34.0   4.4 100.%
5.2  9000  886.2   2.9  0.00  34.0   4.3 100.%
5.3  4501  888.9   2.9  0.00  34.0   4.3 100.%
5.4  4500  891.6   2.9  0.00  34.0   4.3 100.%
5.5  4499  894.3   2.9  0.00  34.0   4.3 100.%
5.6  4500  898.7   4.5  0.00  45.1   5.7 100.%
5.7  4500  908.1   9.2  0.00  70.4   8.8 100.%
5.8  4501  917.5  12.4  0.00  84.4  10.5 100.%
6.0  8999  936.4  16.4  0.00 100.3  12.2 100.%
6.5 22500  983.5  20.1  0.00 115.4  13.4 100.%
7.0 22500 1030.5  20.4  0.00 119.5  13.2 100.%
8.0 45000 1124.7  19.0  0.00 120.7  12.2 100.%
9.0 45000 1218.9  17.5  0.00 120.5  11.3 100.%
10.0 45000 1313.1  16.1  0.00 120.2  10.4 100.%
20.0 450001 2311.0  11.5  0.00 136.3   6.7 100.%
30.0 450000 3456.3   7.6  0.00 135.9   4.5 100.%
40.0 450000 4601.5   5.7  0.00 135.8   3.3 100.%
50.0 450000 5954.0   7.9  0.00 186.7   3.5 100.%
60.0 450000 7785.5  12.2  0.00 271.7   3.9 100.%
70.0 450000 10706.2  20.9  0.00 424.6   4.5 100.%

```

80.0	449999	14636.6	29.3	0.00	594.5	4.6	100.0%
90.0	450000	20492.0	40.4	0.00	832.3	4.6	100.0%
95.0	225000	23602.4	27.1	0.00	729.8	3.5	100.0%
100.	225000	26758.6	34.7	0.00	882.6	3.7	100.0%
105.	225000	30228.9	29.6	0.00	865.4	3.2	100.0%
110.	225000	33633.7	25.5	0.00	848.2	2.9	100.0%
120.	450000	40385.6	17.3	0.00	763.2	2.1	100.0%
130.	450000	46704.3	17.0	0.00	814.0	2.0	100.0%
140.	450000	53262.8	16.1	0.00	847.8	1.8	100.0%
150.	450000	60071.1	14.8	0.00	864.8	1.6	100.0%
160.	450001	67079.6	13.8	0.00	881.7	1.5	100.0%
180.	900000	81349.7	11.8	0.00	898.7	1.2	100.0%
200.	900000	96257.1	14.0	0.00	1068.1	1.3	100.0%

```
=====
REPRESS. PLANE 2/4 (T.Martin pressure profile damped by external aperture)
=====
```

```
Give Case, Vol[m3], S1,S2,S3 [mm2] (+file Case=0)
```

```
0 .262 1944. 4600. 0 / 4 slots + clearance
```

```
RTR_LP_10_400.pin / Higer case of intermediate pressure
```

```
for S(1), enter Zeta, Zp, Dh[mm]:
```

```
1.8 150 12.5 / Meas H.L. coeff (pessim)
```

```
for S(2), enter Zeta, Zp, Dh[mm]:
```

```
4.1 677 2. / Calc H.L. coeff
```

```
To, Nb_steps/sec, NdP ? -.1 45000 100
```

```
<-- Open Cable Slots --> <-- Clearance (slit)-->
```

T	steps	P_ext	delP	Knud	Re	vel	frac	Knud	Re	vel	frac
0.0	45000	120.0									
0.1	9001	127.6	5.5	0.00	33.9	34.4	89.%	0.03	0.3	1.7	11.%
0.2	4500	145.5	16.9	0.00	81.2	75.1	86.%	0.02	0.9	5.2	14.%
0.3	4500	172.6	31.8	0.00	132.9	107.4	82.%	0.02	1.9	9.8	18.%
0.4	4500	208.7	48.8	0.00	189.9	130.5	79.%	0.02	3.5	14.9	21.%
0.5	4500	252.3	65.4	0.00	249.3	143.8	76.%	0.02	5.5	19.7	24.%
0.6	4500	296.2	74.7	0.00	295.1	144.4	73.%	0.01	7.3	22.3	27.%
0.7	4499	339.1	77.2	0.00	326.7	137.7	72.%	0.01	8.7	22.8	28.%
0.8	4501	380.9	74.7	0.00	345.4	127.4	71.%	0.01	9.5	22.0	29.%
0.9	4499	421.3	68.7	0.00	352.3	115.3	71.%	0.01	9.9	20.2	29.%
1.0	4500	460.3	61.1	0.00	349.8	103.1	71.%	0.01	9.7	17.9	29.%
1.2	9001	533.4	45.2	0.00	325.9	80.8	72.%	0.01	8.6	13.4	28.%
1.4	8999	599.2	32.1	0.00	289.9	63.0	74.%	0.01	7.1	9.6	26.%
1.6	9001	656.6	22.5	0.00	250.7	49.2	75.%	0.01	5.5	6.8	25.%
1.8	8999	705.1	15.5	0.00	211.8	38.5	78.%	0.00	4.2	4.7	22.%
2.0	9001	744.3	10.4	0.00	173.2	29.7	80.%	0.00	3.0	3.2	20.%
2.4	18000	795.5	5.0	0.00	114.6	18.3	84.%	0.00	1.5	1.5	16.%
2.8	17999	818.1	1.5	0.00	52.6	8.1	88.%	0.00	0.5	0.5	12.%
3.2	18001	830.0	0.7	0.00	28.7	4.4	90.%	0.00	0.2	0.2	10.%
3.6	17999	840.9	0.6	0.00	25.9	3.9	90.%	0.00	0.2	0.2	10.%
4.0	18000	851.7	0.6	0.00	25.9	3.9	90.%	0.00	0.2	0.2	10.%
4.4	18001	862.5	0.6	0.00	25.9	3.8	90.%	0.00	0.2	0.2	10.%
4.8	18000	873.3	0.6	0.00	25.9	3.8	90.%	0.00	0.2	0.2	10.%
5.0	8999	878.7	0.6	0.00	25.9	3.7	90.%	0.00	0.2	0.2	10.%
5.2	9000	884.0	0.5	0.00	25.0	3.6	90.%	0.00	0.2	0.2	10.%
5.3	4501	886.7	0.6	0.00	25.9	3.7	90.%	0.00	0.2	0.2	10.%
5.4	4500	889.4	0.6	0.00	25.9	3.7	90.%	0.00	0.2	0.2	10.%
5.5	4499	892.1	0.5	0.00	25.9	3.7	90.%	0.00	0.2	0.2	10.%
5.6	4500	895.0	0.6	0.00	27.7	3.9	90.%	0.00	0.2	0.2	10.%
5.7	4500	900.2	1.2	0.00	48.2	6.8	88.%	0.00	0.4	0.4	12.%
5.8	4501	907.1	1.8	0.00	63.2	8.8	87.%	0.00	0.6	0.5	13.%
6.0	8999	923.2	2.2	0.00	73.7	10.1	86.%	0.00	0.8	0.7	14.%
6.5	22500	968.8	2.5	0.00	83.2	10.9	86.%	0.00	0.9	0.8	14.%
7.0	22500	1016.1	2.5	0.00	86.6	10.8	85.%	0.00	1.0	0.8	15.%
8.0	45000	1111.5	2.3	0.00	86.6	9.9	85.%	0.00	1.0	0.7	15.%
9.0	45000	1206.8	2.1	0.00	86.6	9.1	85.%	0.00	1.0	0.7	15.%
10.0	45000	1301.9	2.0	0.00	86.5	8.4	85.%	0.00	1.0	0.6	15.%
20.0	450001	2303.0	1.2	0.00	90.7	5.0	85.%	0.00	1.1	0.4	15.%
30.0	450000	3451.0	1.0	0.00	103.2	3.8	84.%	0.00	1.3	0.3	16.%

40.0	450000	4597.5	0.7	0.00	103.2	2.8	84.%	0.00	1.3	0.2	16.%
50.0	450000	5948.5	0.7	0.00	119.5	2.5	83.%	0.00	1.6	0.2	17.%
60.0	450000	7777.2	0.8	0.00	157.2	2.6	81.%	0.00	2.5	0.3	19.%
70.0	450000	10692.1	1.2	0.00	236.0	2.8	76.%	0.00	5.0	0.4	24.%
80.0	449999	14616.8	1.4	0.00	303.9	2.6	73.%	0.00	7.7	0.4	27.%
90.0	450000	20464.8	1.8	0.00	423.1	2.6	68.%	0.00	13.5	0.5	32.%
95.0	225000	23584.2	1.7	0.00	445.9	2.4	67.%	0.00	14.7	0.5	33.%
100.	225000	26735.3	1.5	0.00	449.4	2.1	67.%	0.00	14.9	0.4	33.%
105.	225000	30209.0	1.6	0.00	486.6	2.0	66.%	0.00	17.1	0.4	34.%
110.	233447	33616.5	1.4	0.00	478.6	1.8	66.%	0.00	16.6	0.4	34.%
120.	542641	40374.0	1.1	0.00	475.8	1.5	66.%	0.00	16.5	0.3	34.%
130.	660214	46692.9	0.9	0.00	450.5	1.2	67.%	0.00	15.0	0.3	33.%
140.	743950	53252.0	0.8	0.00	464.4	1.1	67.%	0.00	15.8	0.2	33.%
150.	827910	60061.1	0.8	0.00	478.6	1.0	66.%	0.00	16.6	0.2	34.%
160.	915577	67070.3	0.7	0.00	490.0	0.9	66.%	0.00	17.3	0.2	34.%
180	2118709	81341.8	0.6	0.00	497.3	0.8	65.%	0.00	17.7	0.2	35.%
200	2480873	96247.7	0.5	0.00	514.6	0.7	65.%	0.00	18.8	0.2	35.%