

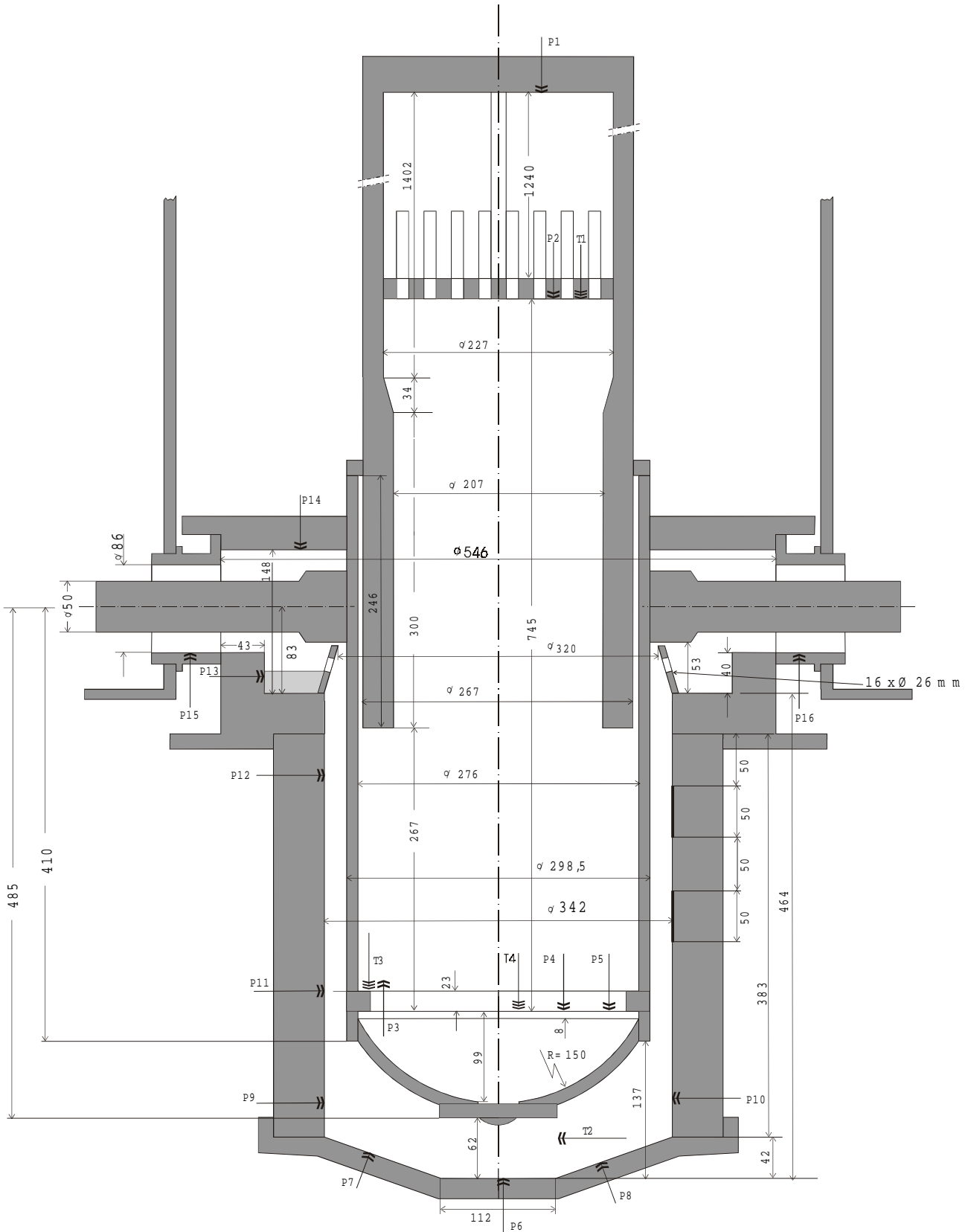
Utilisation de CASTEM pour des études de mécanique des fluides dans une enceinte de réacteur nucléaire

Application et validation sur les essais PHEBUS FPT0 et FPT1

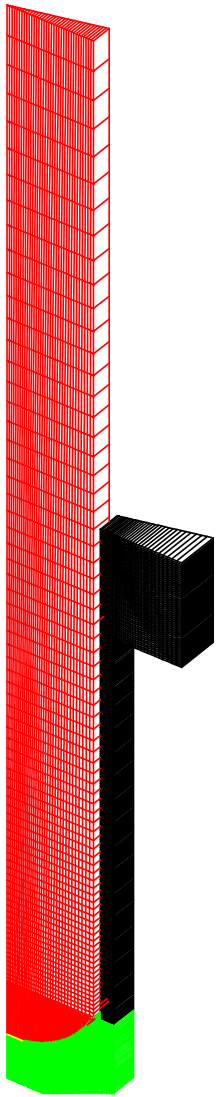
**E. Studer, IPSN
J.P. Magnaud, CEA**

**Caractérisation de l'écoulement vapeur dans la cavité du réacteur
en situation accidentelle**

**C. Caroli, ENEA - Italy
Work carried out by ENEA in collaboration with IPSN**



Vertical cut of the DISCO mock-up



Disco 3d mesh

Experiment	Initial RPV Pressure	Hole Diameter	Gas	Note
	MPa	mm		
B2	1.100	50	N₂	Experiment with pure gas
L05	0.600	50	N₂	Experiment with pure gas
D5	1.200	50	N₂	Gas + Water
D6	0.619	50	N₂	Gas + Water
D7	0.620	25	N₂	Gas + Water
H1	0.641	25	He	Gas + Water

Table 1: Main characteristics of the modeled Disco-C experiments

The 3-D model

Conservation equations: $\frac{\partial \underline{u}}{\partial t} + \frac{\partial \underline{f}_x}{\partial x} + \frac{\partial \underline{f}_y}{\partial y} + \frac{\partial \underline{f}_z}{\partial z} = 0$

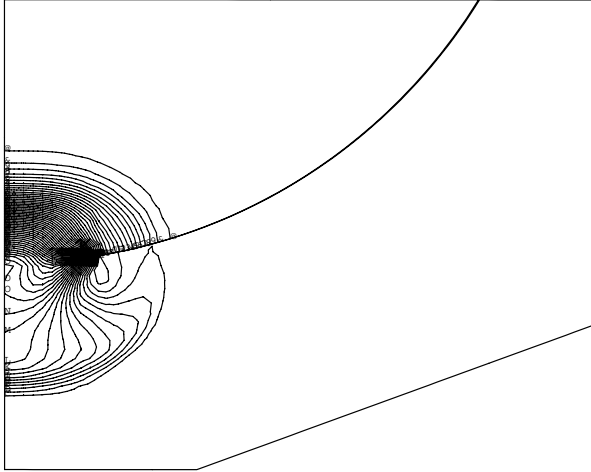
$$\underline{u} = \begin{pmatrix} \rho \\ \rho u \\ \rho v \\ \rho w \\ \rho e_t \end{pmatrix}, \quad \underline{f}_x = \begin{pmatrix} \rho u \\ \rho u^2 + p \\ \rho uv \\ \rho uw \\ \rho u h_t \end{pmatrix}, \quad \underline{f}_y = \begin{pmatrix} \rho v \\ \rho v u \\ \rho v^2 + p \\ \rho v w \\ \rho v h_t \end{pmatrix}, \quad \underline{f}_z = \begin{pmatrix} \rho w \\ \rho w u \\ \rho w v \\ \rho w^2 + p \\ \rho w h_t \end{pmatrix}$$

Jump conditions: $[\rho \cdot u_n] = 0, \quad [\rho \cdot u_n \cdot h_t] = 0, \quad [p + \rho \cdot u_n^2] = 0, \quad [\rho \cdot u_n \cdot u_{t1}] = 0, \quad [\rho \cdot u_n \cdot u_{t2}] = 0$

Model hypotheses:

Polytropic gas

Viscous and diffusion phenomena neglected



Disco D5 - P1/P2=12,d=50,N2 - t [s]= 6.14143E-05 P [Pa]

```

VAL - ISO
> 7.14E+04
< 1.20E+06
A 8.03E+04
D 1.33E+05
G 1.86E+05
J 2.39E+05
M 2.92E+05
P 3.45E+05
S 3.98E+05
V 4.51E+05
Y 5.03E+05
b 5.56E+05
e 6.09E+05
h 6.62E+05
k 7.15E+05
n 7.68E+05
q 8.21E+05
t 8.74E+05
w 9.27E+05
z 9.80E+05
2 1.03E+06
5 1.09E+06
8 1.14E+06
@ 1.19E+06

```

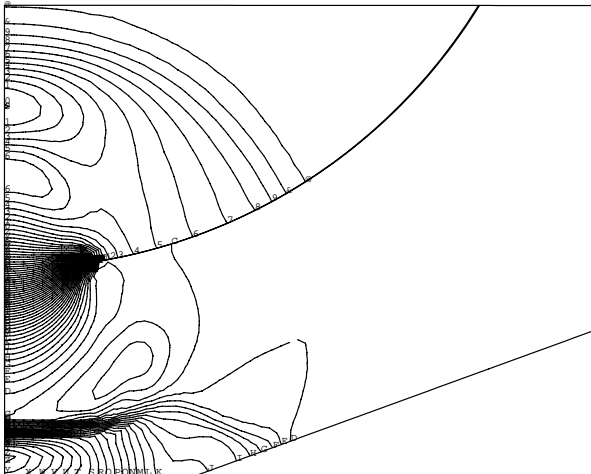


Disco D5 - P1/P2=12,d=50,N2 - t [s]= 1.22231E-04 P [Pa]

```

VAL - ISO
> 5.29E+04
< 1.20E+06
A 6.18E+04
D 1.16E+05
G 1.69E+05
J 2.23E+05
M 2.77E+05
P 3.31E+05
S 3.84E+05
V 4.38E+05
Y 4.92E+05
b 5.46E+05
e 6.00E+05
h 6.53E+05
k 7.07E+05
n 7.61E+05
q 8.15E+05
t 8.68E+05
w 9.22E+05
z 9.76E+05
2 1.03E+06
5 1.08E+06
8 1.14E+06
@ 1.19E+06

```

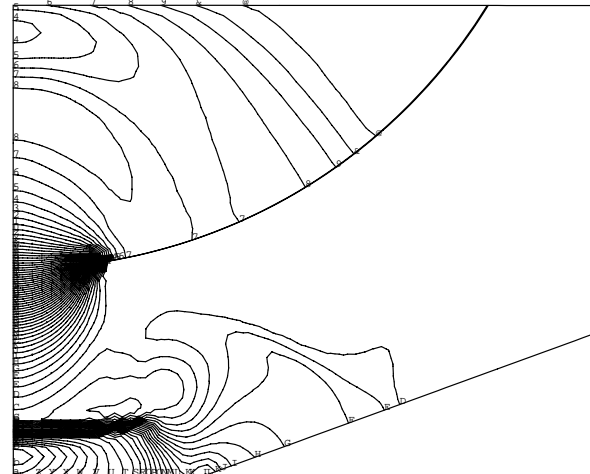


Disco D5 - P1/P2=12,d=50,N2 - t [s]= 1.85073E-04 P [Pa]

```

VAL - ISO
> 5.13E+04
< 1.20E+06
A 6.03E+04
D 1.14E+05
G 1.68E+05
J 2.22E+05
M 2.76E+05
P 3.30E+05
S 3.83E+05
V 4.37E+05
Y 4.91E+05
b 5.45E+05
e 5.99E+05
h 6.53E+05
k 7.06E+05
n 7.60E+05
q 8.14E+05
t 8.68E+05
w 9.22E+05
z 9.76E+05
2 1.03E+06
5 1.08E+06
8 1.14E+06
@ 1.19E+06

```

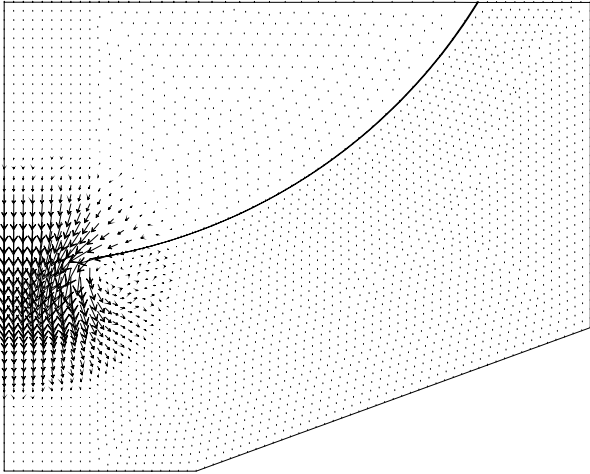


Disco D5 - P1/P2=12,d=50,N2 - t [s]= 2.44964E-04 P [Pa]

```

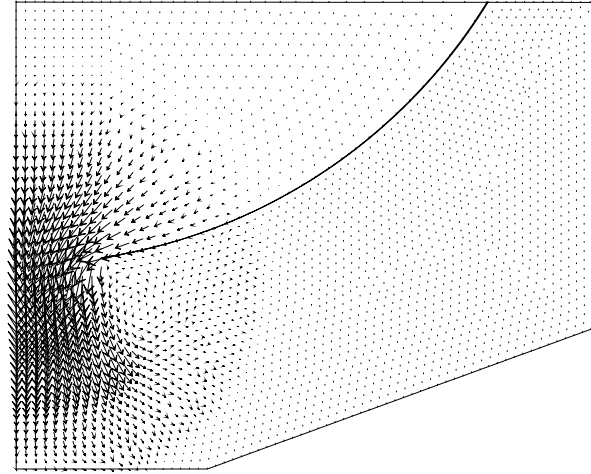
VAL - ISO
> 4.78E+04
< 1.20E+06
A 5.68E+04
D 1.11E+05
G 1.65E+05
J 2.19E+05
M 2.73E+05
P 3.27E+05
S 3.81E+05
V 4.35E+05
Y 4.89E+05
b 5.43E+05
e 5.97E+05
h 6.51E+05
k 7.05E+05
n 7.59E+05
q 8.13E+05
t 8.67E+05
w 9.21E+05
z 9.75E+05
2 1.03E+06
5 1.08E+06
8 1.14E+06
@ 1.19E+06

```



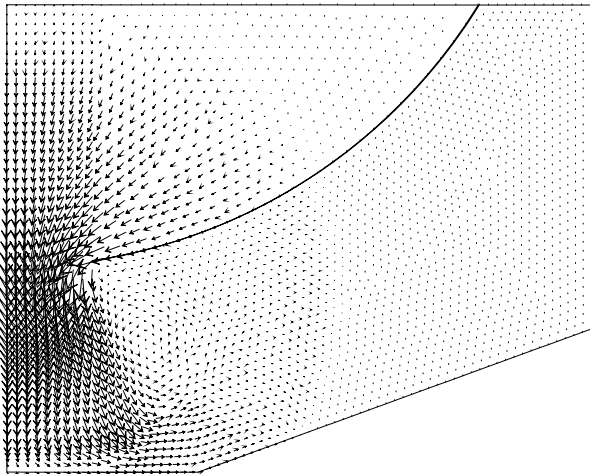
COMPOSANTES
VECTEURS
UX UY UZ

Disco D5 - P1/P2=12,d=50,N2 - t [s]= 6.14143E-05 RhoU [kg/m2/s]



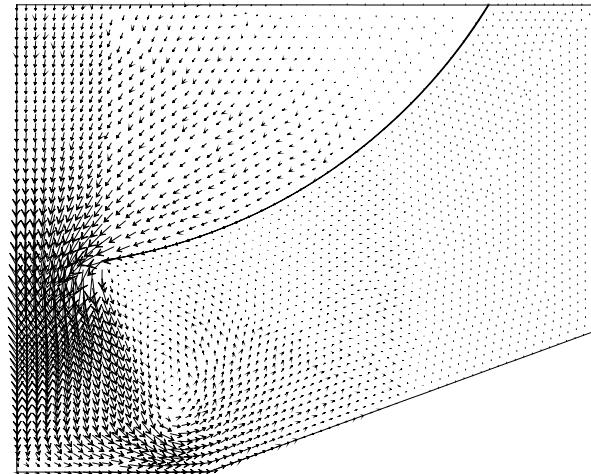
COMPOSANTES
VECTEURS
UX UY UZ

Disco D5 - P1/P2=12,d=50,N2 - t [s]= 1.22231E-04 RhoU [kg/m2/s]



COMPOSANTES
VECTEURS
UX UY UZ

Disco D5 - P1/P2=12,d=50,N2 - t [s]= 1.85073E-04 RhoU [kg/m2/s]



COMPOSANTES
VECTEURS
UX UY UZ

Disco D5 - P1/P2=12,d=50,N2 - t [s]= 2.44964E-04 RhoU [kg/m2/s]



VAL - ISO
 > 2.21E+04
 < 1.12E+06
 A 3.07E+04
 D 8.23E+04
 G 1.34E+05
 J 1.86E+05
 M 2.37E+05
 P 2.89E+05
 S 3.40E+05
 V 3.92E+05
 Y 4.44E+05
 b 4.95E+05
 e 5.47E+05
 h 5.99E+05
 k 6.50E+05
 n 7.02E+05
 q 7.53E+05
 t 8.05E+05
 w 8.57E+05
 z 9.08E+05
 2 9.60E+05
 5 1.01E+06
 8 1.06E+06
 @ 1.11E+06

Disco D5 - P1/P2=12,d=50,N2 - t [s]= 1.00000E-02 P [Pa]



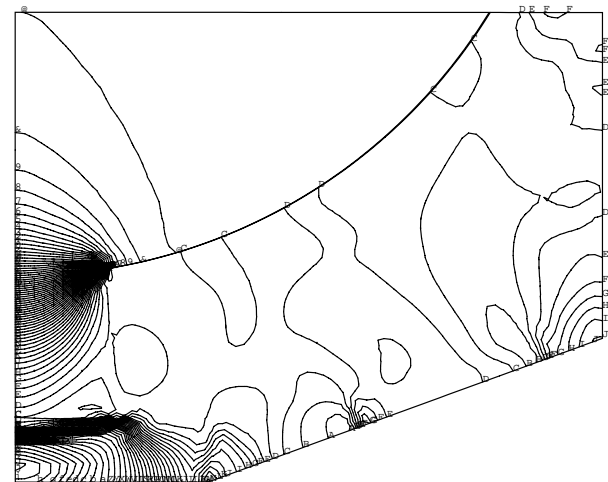
VAL - ISO
 > 1.71E+04
 < 1.07E+06
 A 2.54E+04
 D 7.49E+04
 G 1.24E+05
 J 1.74E+05
 M 2.24E+05
 P 2.73E+05
 S 3.23E+05
 V 3.72E+05
 Y 4.22E+05
 b 4.71E+05
 e 5.21E+05
 h 5.70E+05
 k 6.20E+05
 n 6.69E+05
 q 7.19E+05
 t 7.69E+05
 w 8.18E+05
 z 8.68E+05
 2 9.17E+05
 5 9.67E+05
 8 1.02E+06
 @ 1.07E+06

Disco D5 - P1/P2=12,d=50,N2 - t [s]= 2.00000E-02 P [Pa]



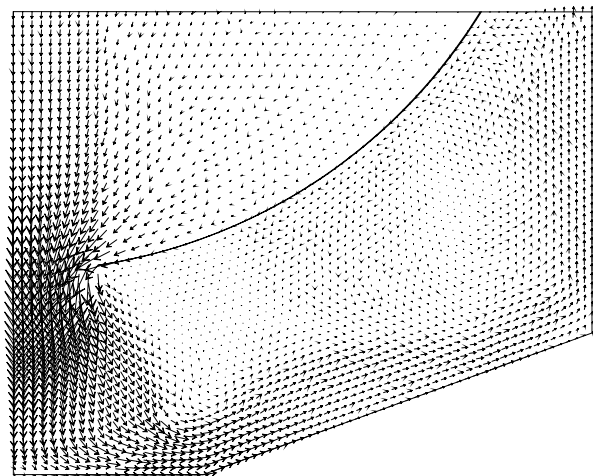
VAL - ISO
 > 2.91E+04
 < 9.09E+05
 A 3.59E+04
 D 7.72E+04
 G 1.18E+05
 J 1.60E+05
 M 2.01E+05
 P 2.42E+05
 S 2.84E+05
 V 3.25E+05
 Y 3.66E+05
 b 4.07E+05
 e 4.49E+05
 h 4.90E+05
 k 5.31E+05
 n 5.72E+05
 q 6.14E+05
 t 6.55E+05
 w 6.96E+05
 z 7.37E+05
 2 7.79E+05
 5 8.20E+05
 8 8.61E+05
 @ 9.03E+05

Disco D5 - P1/P2=12,d=50,N2 - t [s]= 5.00000E-02 P [Pa]



VAL - ISO
 > 3.05E+04
 < 7.10E+05
 A 3.58E+04
 D 6.77E+04
 G 9.95E+04
 J 1.31E+05
 M 1.63E+05
 P 1.95E+05
 S 2.27E+05
 V 2.59E+05
 Y 2.91E+05
 b 3.22E+05
 e 3.54E+05
 h 3.86E+05
 k 4.18E+05
 n 4.50E+05
 q 4.82E+05
 t 5.13E+05
 w 5.45E+05
 z 5.77E+05
 2 6.09E+05
 5 6.41E+05
 8 6.73E+05
 @ 7.05E+05

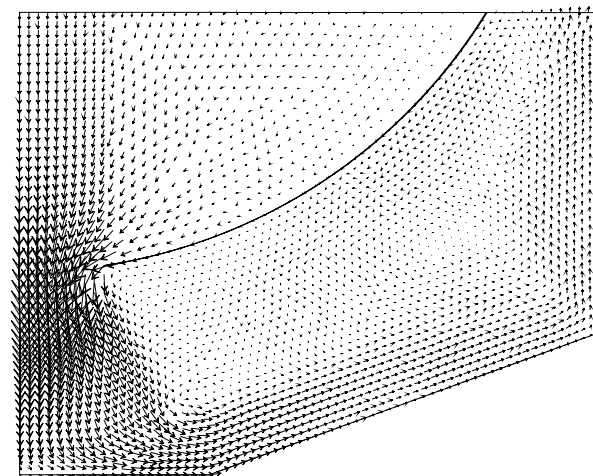
Disco D5 - P1/P2=12,d=50,N2 - t [s]= 1.00000E-01 P [Pa]



COMPOSANTES
VECTEURS

UX UY UZ

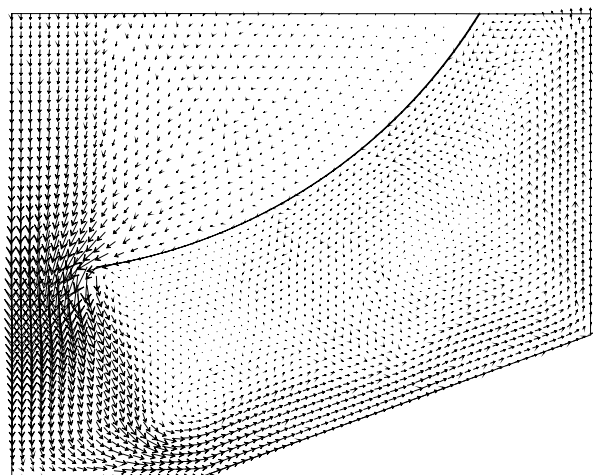
Disco D5 - P1/P2=12,d=50,N2 - t [s]= 1.00000E-02 RhoU [kg/m2/s]



COMPOSANTES
VECTEURS

UX UY UZ

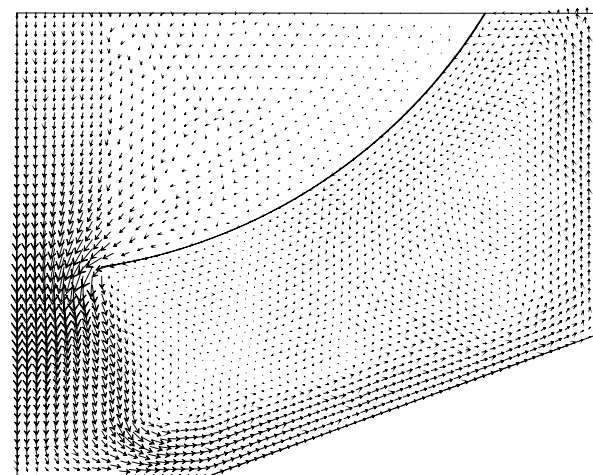
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COMPOSANTES
VECTEURS

UX UY UZ

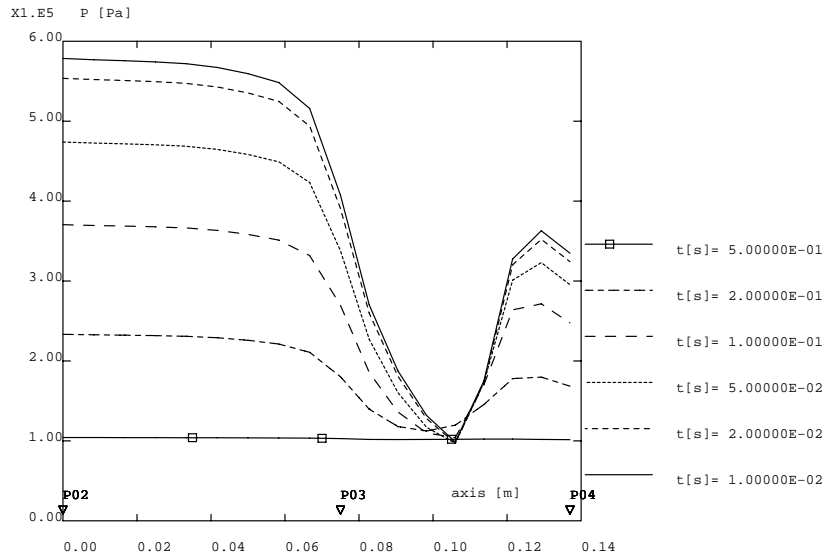
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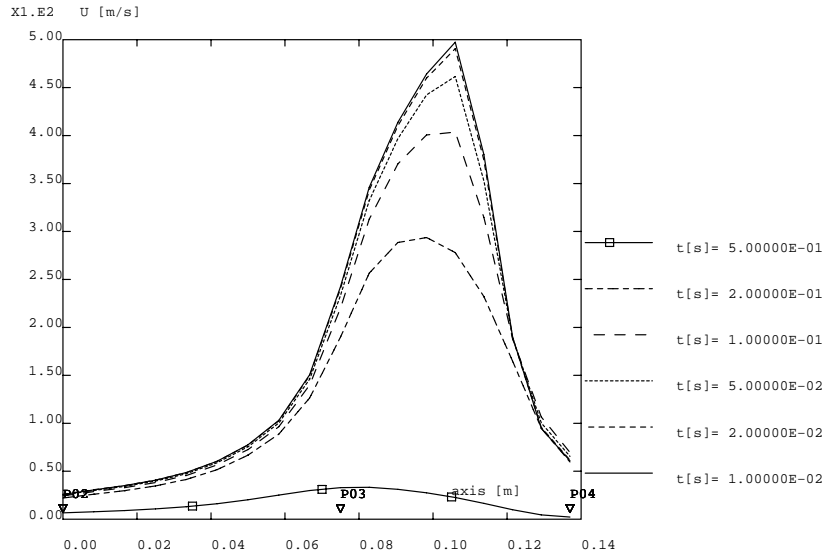
COMPOSANTES
VECTEURS

UX UY UZ

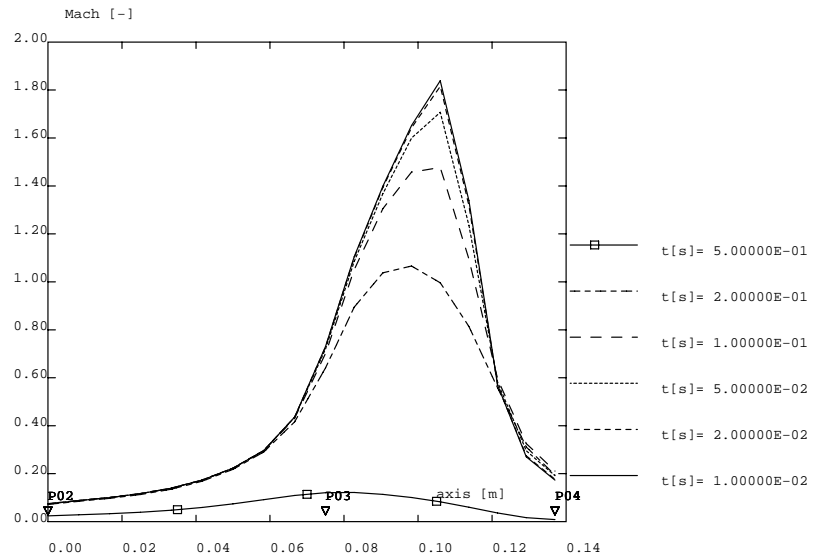
Disco D5 - P1/P2=12,d=50,N2 - t [s]= 1.00000E-01 RhoU [kg/m2/s]



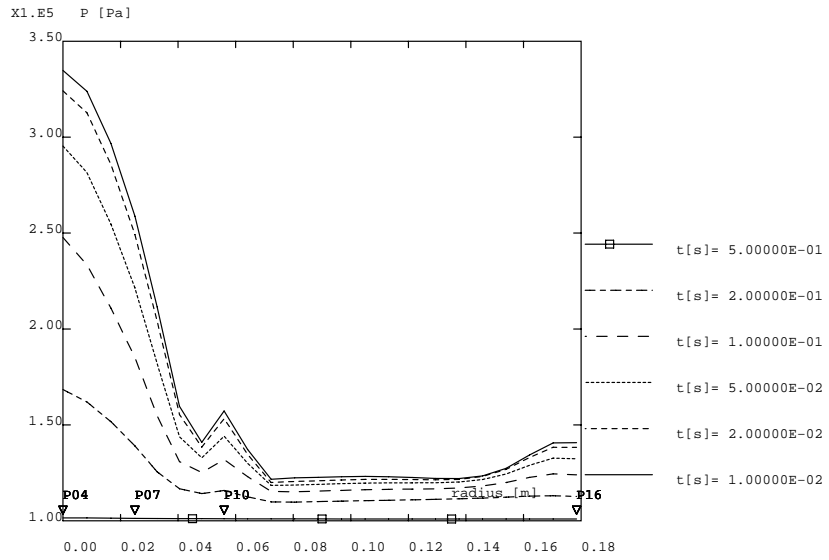
Disco D6 - Pressure along the axis



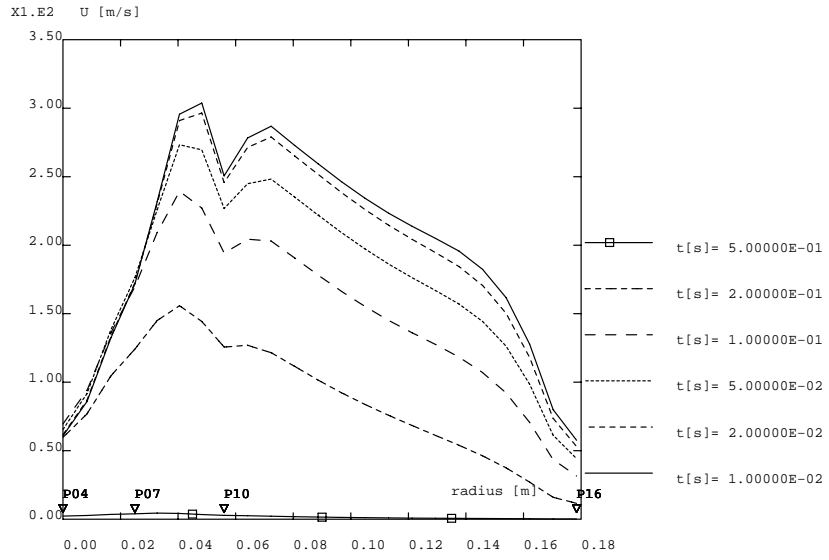
Disco D6 - Velocity along the axis



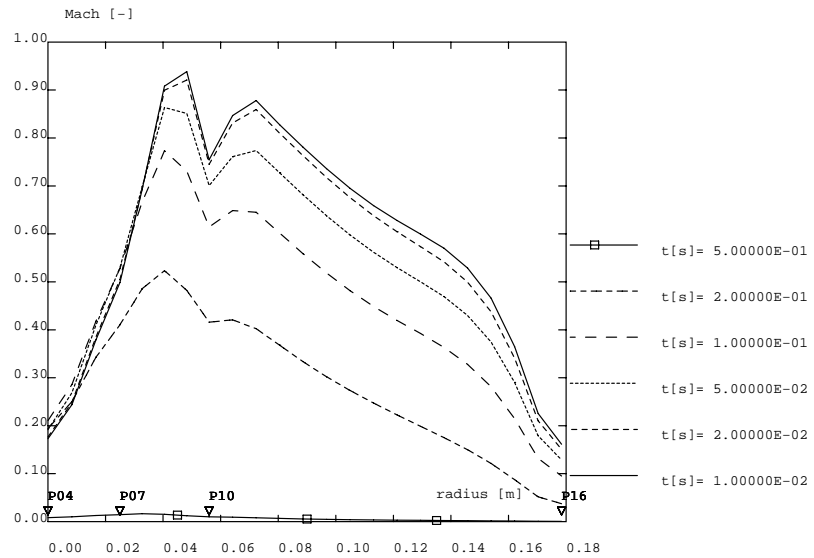
Disco D6 - Mach along the axis



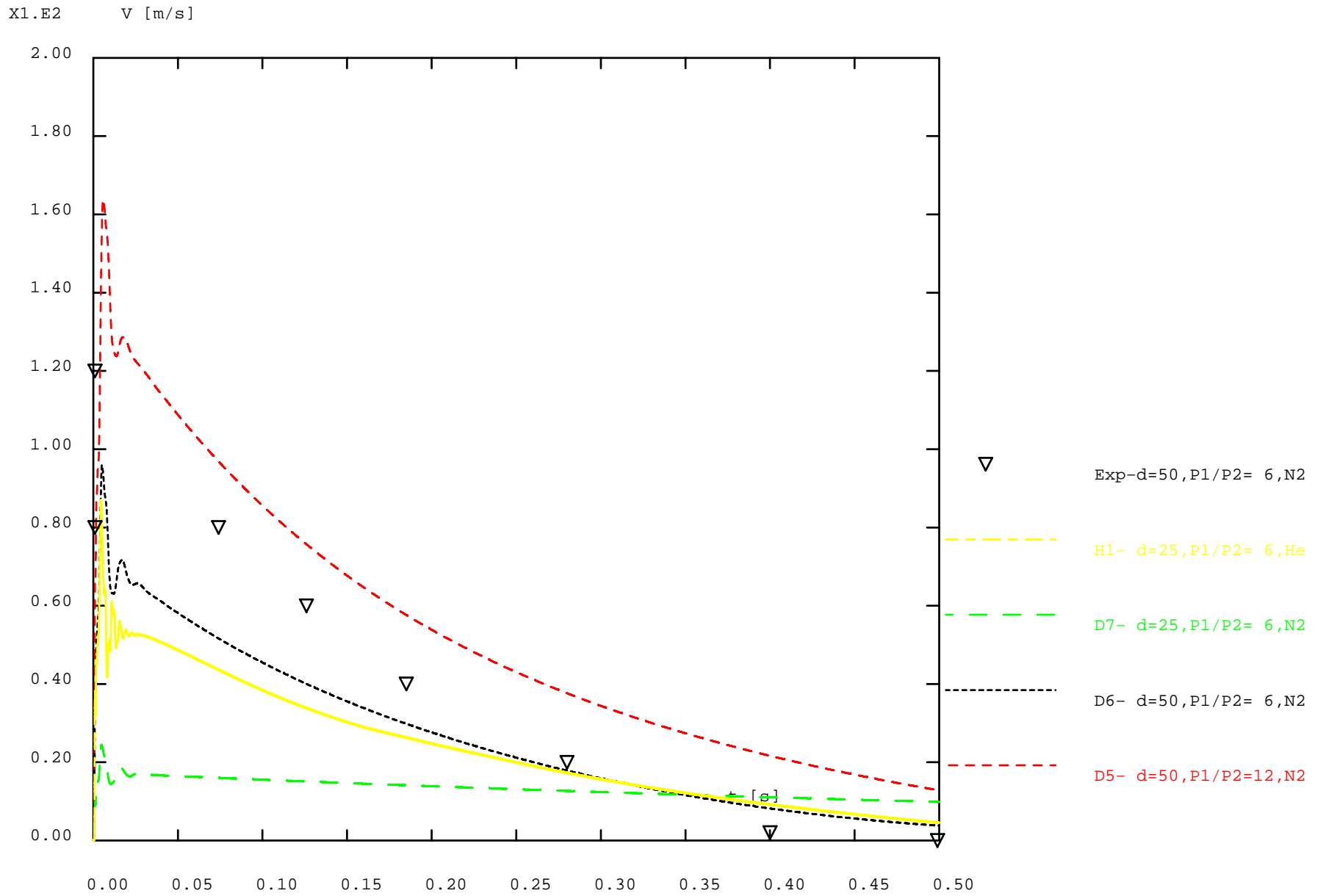
Disco D6 - Pressure in the cavity floor



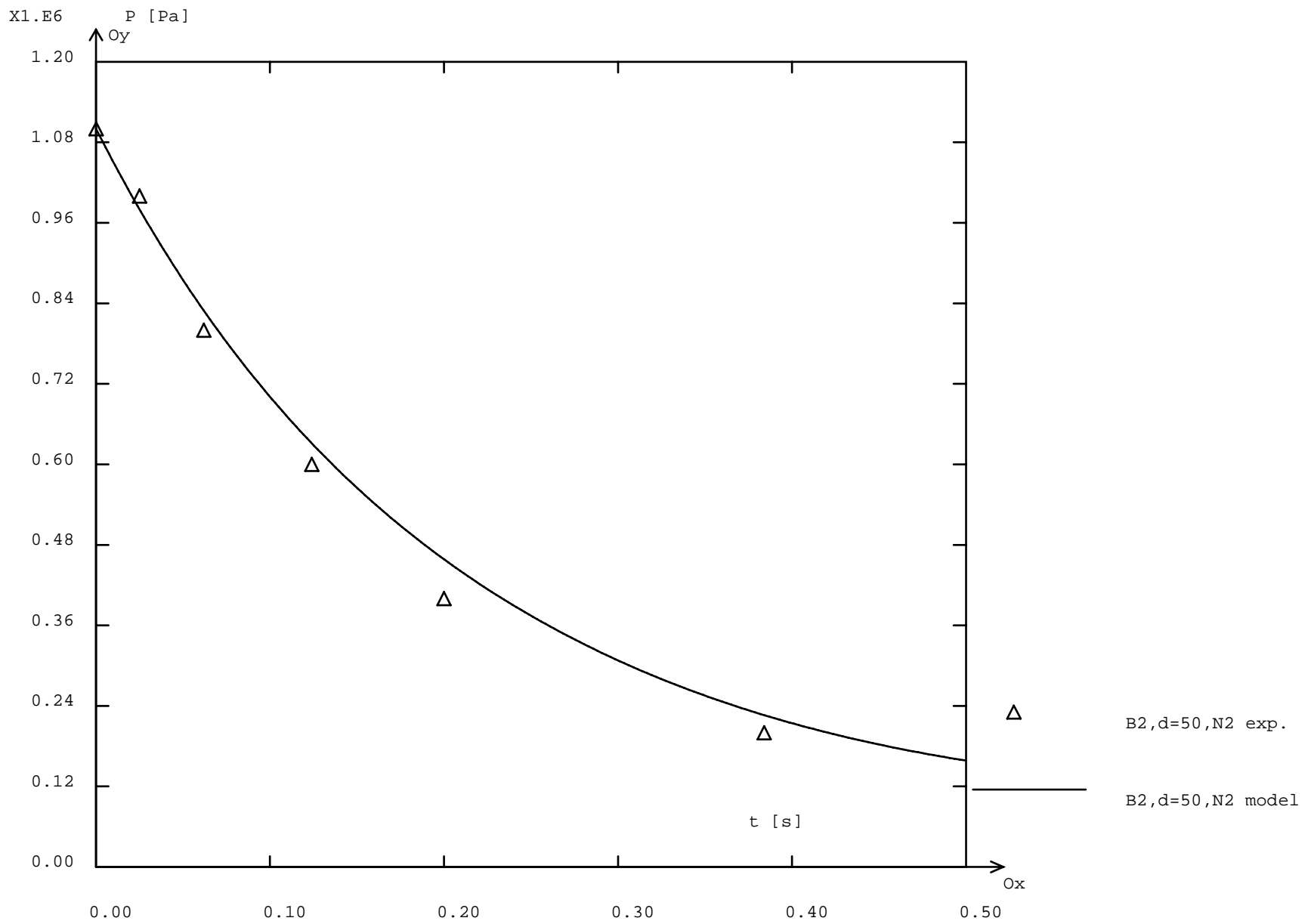
Disco D6 - Velocity in the Cavity floor



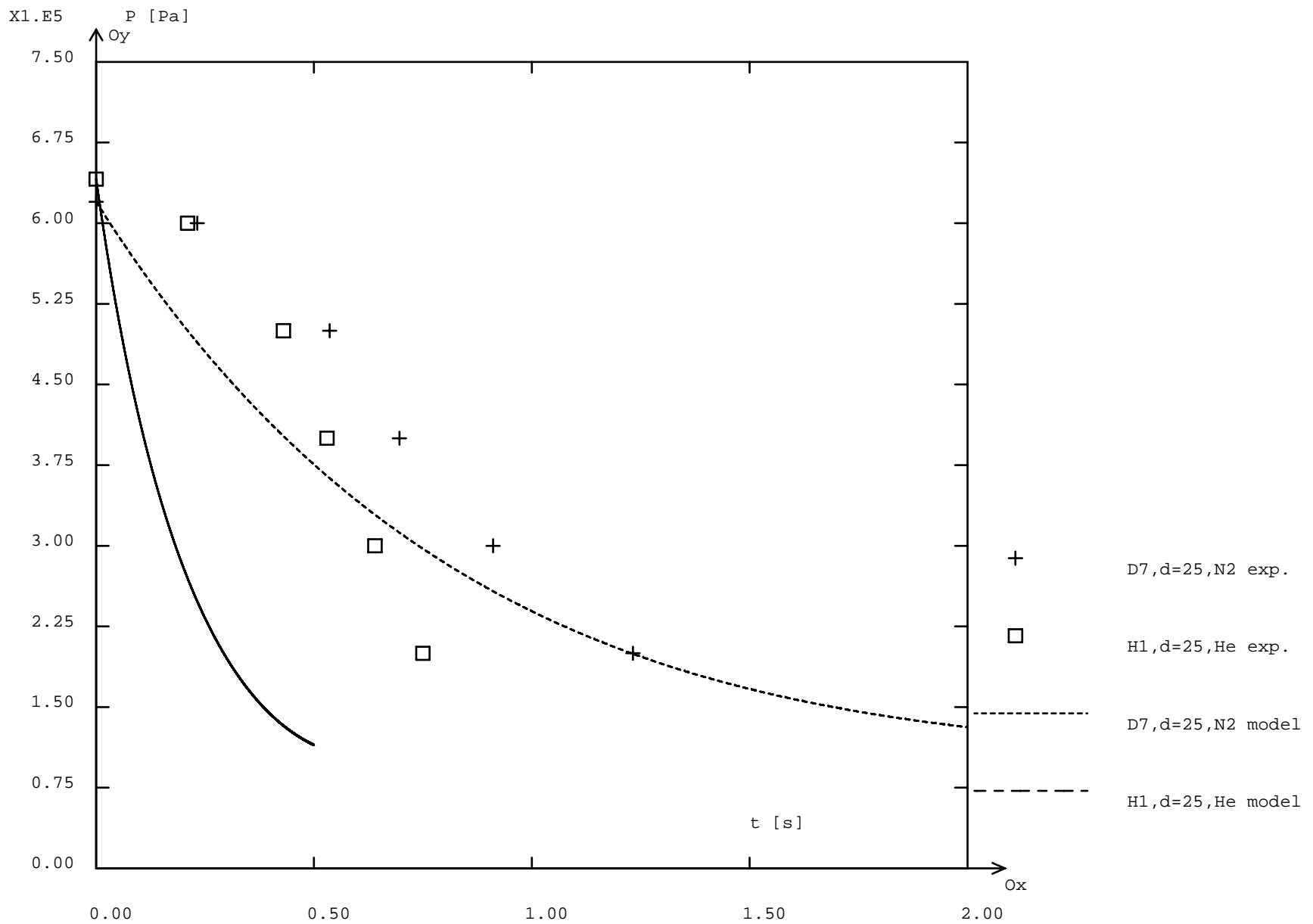
Disco D6 - Mach in the cavity floor



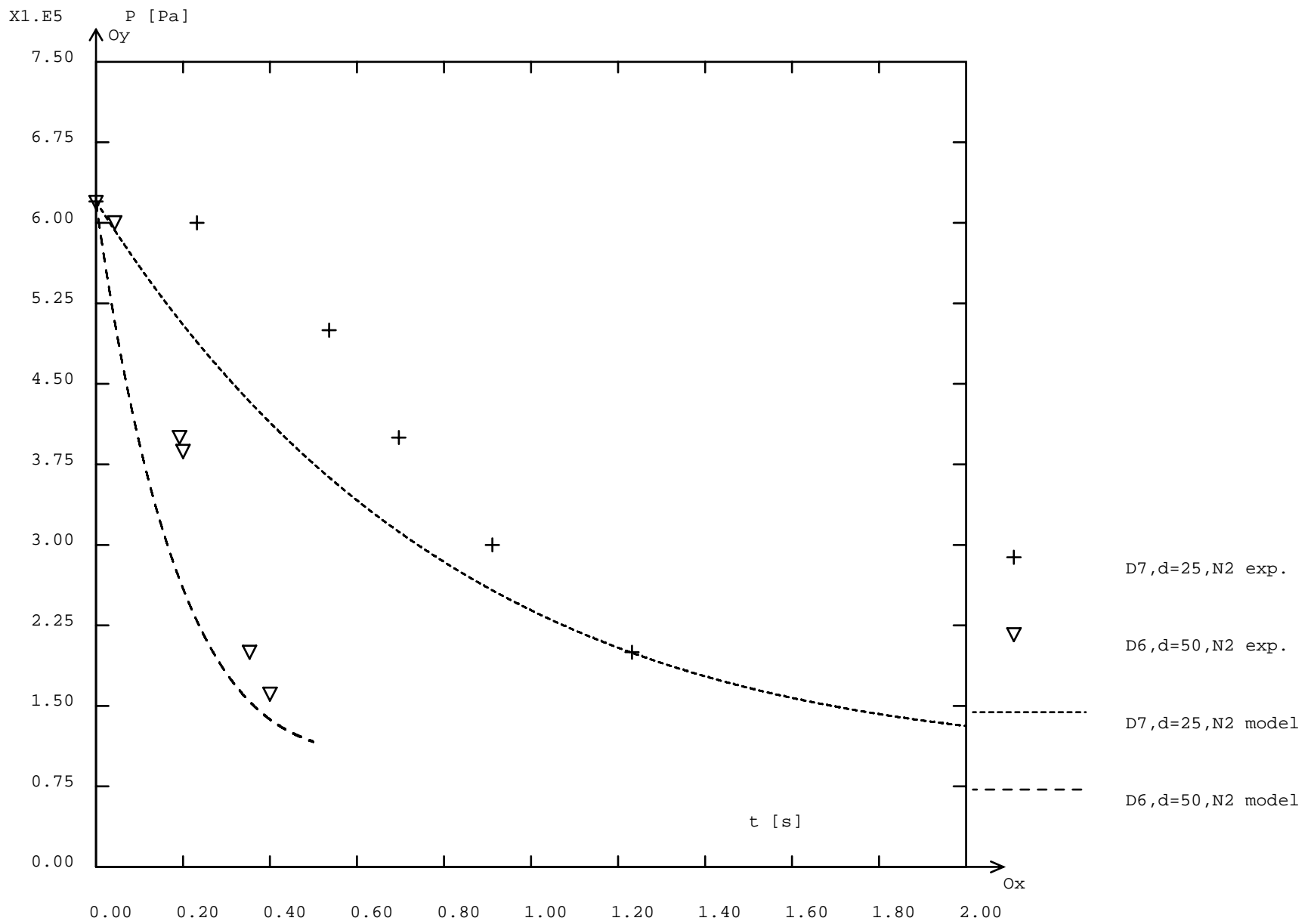
Velocity in the annular space v.s. time



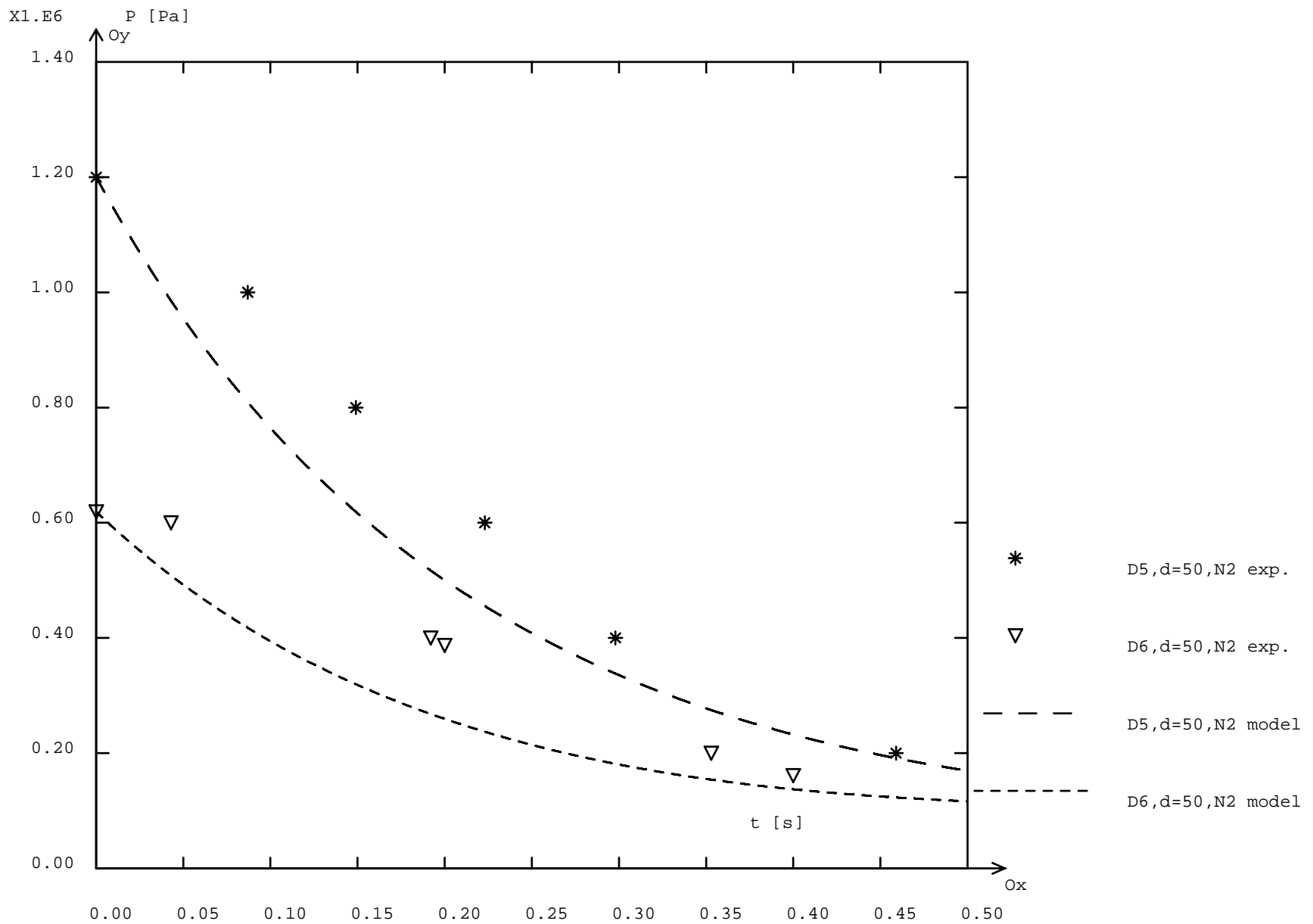
Disco experiment B2 (Pure Gas) - RPV pressure histories



Disco experiment - RPV pressure histories for different gas



Disco experiment - RPV pressure histories for different hole sizes



Disco experiment- RPV pressure histories for different initial pressure

Conclusions

- Global validity of the modeling approach followed (inviscid compressible flow of perfect gases)
- Need to consider a two-phase flow model to correctly describe some aspects of the flow (blow down and annular space velocities behavior)
- Gas flow characterized by a fast transient at the beginning of the blow down followed by quasi-steady state (depressurization time constant much larger than the flow field time constant)
- Blow through time much more dependent on the failure size and on the gas specie than on the initial pressure drop.
- Gas velocities at the RPV failure supersonic over a large time interval no matter the considered case.
- Gas flow in the cavity essentially confined in a thin layer parallel to the cavity floor. A recirculation observed but with a limited velocity level.