Report on Anaesthesia

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Part I

Anaesthesia

Chapter 1

MaplesonModelP

1.1 MaplesonModelP_abg.tex

MTT command:

```
mtt MaplesonModelP abg tex
```

The acausal bond graph of system **MaplesonModelP** is displayed in Figure 1.1 (on page 10) and its label file is listed in Section 1.1.1 (on page 9). The subsystems are listed in Section 1.1.2 (on page 17).

This is a Bond Graph interpretation of Mapleson's model P of the pharmokokinetics of anaesthetic drug delivery. It is discussed in detail in Chapter 9 of "Metamodelling".

It badly needs conversion to hierarchical form.

1.1.1 Summary information

System MaplesonModelP::Pharmokinetic model from section 9.6 of"Metamodelling"
Detailed model with pools

Note that the bond graph has been redrawn to replace active bonds with AF components. This would be much neater using a heirachical model.

The following commands make the figures.

Fig 9.17 mtt MaplesonModelP abg view Figs 9.18-19 mtt MaplesonModelP odeso view 'T=[0:0.1:6]' Fig 9.20 mtt MaplesonModelP lmfr view 'W=logspace(-2,2,100)' Fig 9.21 mtt MaplesonModelP lpfr view 'W=logspace(-2,2,100)'

Interface information:

This component has no ALIAS declarations

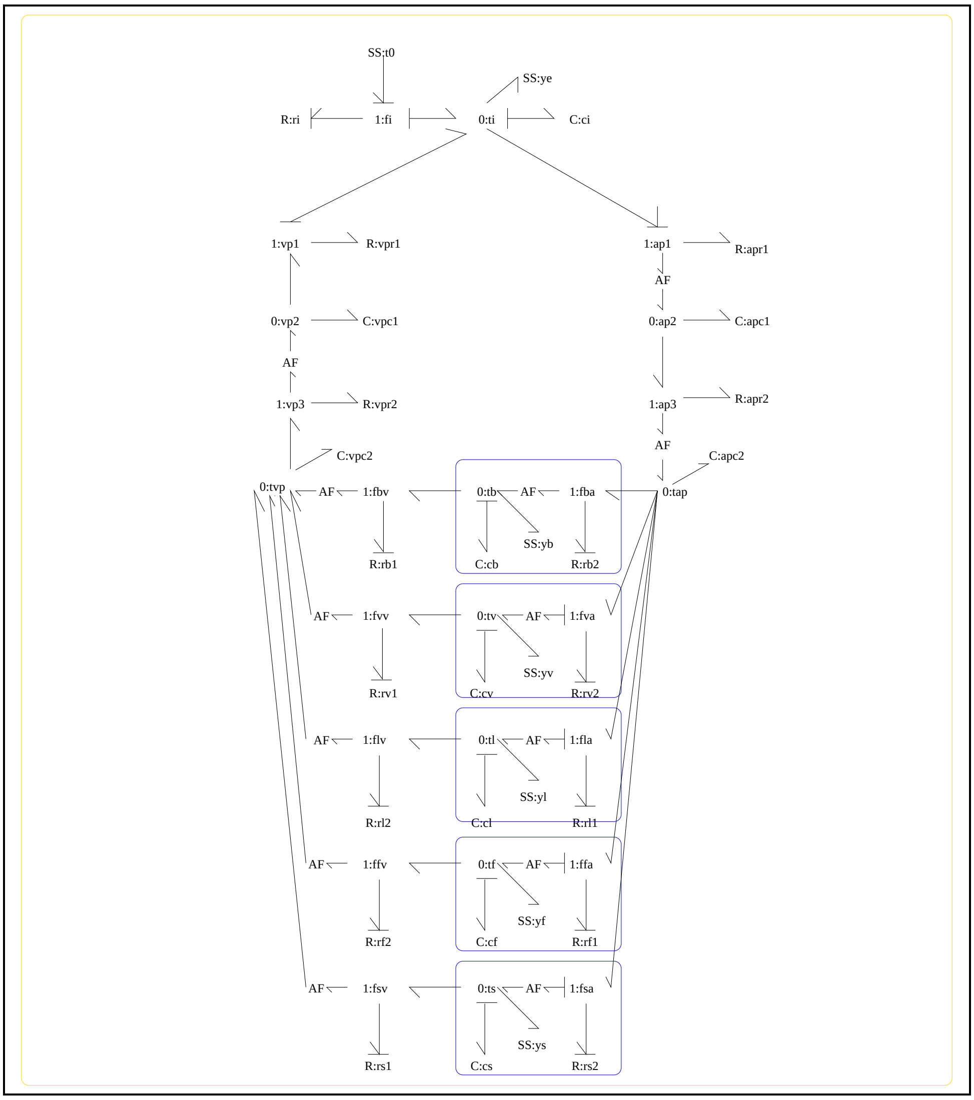

Figure 1.1: System **MaplesonModelP**: acausal bond graph

Variable declarations:

apools

breathing_interval

heart_interval

k_ap

k_b

k_f

k_i

k_l

k_s

k_v

k_vp

kb

kf

kl

ks

kv

lambdab

lambdablood

lambdaf

lambdal

lambdalung

lambdav

stroke_volume

t_1

t_2

t_b

t_f

t_i

t_l

t_s

t_v

v_i

vap

varterial

vb

vbp

vf

vfp

vgas

vl

vlp

vlung

vplung

vpools

vsp

vv

vvenous

vvp

Units declarations:

This component has no UNITs declarations

The label file: MaplesonModelP_lbl.txt

```
#SUMMARY MaplesonModelP: Pharmokinetic model from section 9.6 of"Metamod
#DESCRIPTION Detailed model with pools
#DESCRIPTION
#DESCRIPTION Note that the bond graph has been redrawn to replace active
#DESCRIPTION AF components.
#DESCRIPTION This would be much neater using a heirachical model.
#DESCRIPTION
#DESCRIPTION The following commands make the figures.
#DESCRIPTION
#DESCRIPTION Fig 9.17 mtt MaplesonModelP abg view
#DESCRIPTION Figs 9.18-19 mtt MaplesonModelP odeso view 'T=[0:0.1:6]'
#DESCRIPTION Fig 9.20 mtt MaplesonModelP lmfr view 'W=logspace(-2,2,100)
#DESCRIPTION Fig 9.21 mtt MaplesonModelP lpfr view 'W=logspace(-2,2,100)


# ###############################################################
# ## Version control history
# ###############################################################
# ## $Id: MaplesonModelP_lbl.txt,v 1.1 2000/12/28 17:04:39 peterg Exp $
# ## $Log: MaplesonModelP_lbl.txt,v $
# ## Revision 1.1  2000/12/28 17:04:39  peterg
# ## To RCS
# ##
# ## Revision 1.1  1996/08/30  18:37:56  peter
# ## Initial revision
# ##
# ###############################################################

#VAR apools
#VAR breathing_interval
#VAR heart_interval
#VAR k_ap
#VAR k_b
#VAR k_f
#VAR k_i
```

```
#VAR k_l
#VAR k_s
#VAR k_v
#VAR k_vp
#VAR kb
#VAR kf
#VAR kl
#VAR ks
#VAR kv
#VAR lambdab
#VAR lambdablood
#VAR lambdaf
#VAR lambdal
#VAR lambdalung
#VAR lambdav
#VAR stroke_volume
#VAR t_1
#VAR t_2
#VAR t_b
#VAR t_f
#VAR t_i
#VAR t_l
#VAR t_s
#VAR t_v
#VAR v_i
#VAR vap
#VAR varterial
#VAR vb
#VAR vbp
#VAR vf
#VAR vfp
#VAR vgas
#VAR vl
#VAR vlp
#VAR vlung
#VAR vplung
#VAR vpools
#VAR vsp
#VAR vv
#VAR vvenous
#VAR vvp
```

```
### Common tension junctions ###
ti
tb
tv
tl
tf
ts
tap
tvp

##Common flow junctions - inspiration ###
fi

##Common flow junctions - arteries ###
fba
fva
fla
ffa
fsa

##Common flow junctions - veins ###
fbv
fvv
flv
ffv
fsv

## More junctions
ap3
vp3
ap2
vp2
ap1
vp1

### Resistances ###
rb1 lin flow,r_b
rv1 lin flow,r_v
rl1 lin flow,r_l
rf1 lin flow,r_f
```

```
rs1 lin flow,r_s

rb2 lin flow,r_b
rv2 lin flow,r_v
rl2 lin flow,r_l
rf2 lin flow,r_f
rs2 lin flow,r_s

ri lin flow,r_i

## Capacities ###
cb lin effort,c_b
cv lin effort,c_v
cl lin effort,c_l
cf lin effort,c_f
cs lin effort,c_s
ci lin effort,c_i


### Input ###
t0 SS  external,internal

### Outputs ###
yb SS  external,0
yv SS  external,0
yl SS  external,0
yf SS  external,0
ys SS  external,0
ye SS  external,0

### Arterial pool
# ap1 apool1
# ap2 apool2
# ap3 apool3

apc1 lin effort,c_ap
apc2 lin effort,c_ap

apr1 lin flow,r_ap
apr2 lin flow,r_ap
```

```
### Venous pool
# vp1 vpool1
# vp2 vpool2
# vp3 vpool3

vpc1 lin effort,c_vp
vpc2 lin effort,c_vp
vpr1 lin flow,r_vp
vpr2 lin flow,r_vp
```

1.1.2 Subsystems

No subsystems.

1.2 MaplesonModelP_struc.tex

MTT command:

```
mtt MaplesonModelP struc tex
```

List of inputs for system MaplesonModelP			
	Component	System	Repetition
1	t0	MaplesonModelP__t0	1

List of outputs for system MaplesonModelP			
	Component	System	Repetition
1	yb	MaplesonModelP__yb	1
2	yv	MaplesonModelP__yv	1
3	yl	MaplesonModelP__yl	1
4	yf	MaplesonModelP__yf	1
5	ys	MaplesonModelP__ys	1
6	ye	MaplesonModelP__ye	1

List of states for system MaplesonModelP			
	Component	System	Repetition
1	cb	MaplesonModelP_cb	1
2	cv	MaplesonModelP_cv	1
3	cl	MaplesonModelP_cl	1
4	cf	MaplesonModelP_cf	1
5	cs	MaplesonModelP_cs	1
6	ci	MaplesonModelP_ci	1
7	apc1	MaplesonModelP_apc1	1
8	apc2	MaplesonModelP_apc2	1
9	vpc1	MaplesonModelP_vpc1	1
10	vpc2	MaplesonModelP_vpc2	1

1.3 MaplesonModelP_ode.tex

MTT command:

```
mtt MaplesonModelP ode tex
```

$$
\begin{aligned}
\dot{x}_1 &= \frac{(-c_{ap}x_1 + c_b x_8)}{(c_{ap}c_b r_b)} \\
\dot{x}_2 &= \frac{(-c_{ap}x_2 + c_v x_8)}{(c_{ap}c_v r_v)} \\
\dot{x}_3 &= \frac{(-c_{ap}x_3 + c_l x_8)}{(c_{ap}c_l r_l)} \\
\dot{x}_4 &= \frac{(-c_{ap}x_4 + c_f x_8)}{(c_{ap}c_f r_f)} \\
\dot{x}_5 &= \frac{(-c_{ap}x_5 + c_s x_8)}{(c_{ap}c_s r_s)} \\
\dot{x}_6 &= \frac{(c_i c_{vp} u_1 r_{ap} r_{vp} + c_i x_9 r_{ap} r_i - c_{vp} x_6 r_{ap} r_i - c_{vp} x_6 r_{ap} r_{vp} - c_{vp} x_6 r_i r_{vp})}{(c_i c_{vp} r_{ap} r_i r_{vp})} \\
\dot{x}_7 &= \frac{(c_{ap}x_6 - c_i x_7)}{(c_{ap}c_i r_{ap})} \\
\dot{x}_8 &= \frac{(x_7 r_b r_f r_l r_s r_v - x_8 r_{ap} r_b r_f r_l r_s - x_8 r_{ap} r_b r_f r_l r_v - x_8 r_{ap} r_b r_f r_s r_v - x_8 r_{ap} r_b r_l r_s r_v - x_8 r_{ap} r_f r_l r_s r_v)}{(c_{ap} r_{ap} r_b r_f r_l r_s r_v)} \\
\dot{x}_9 &= \frac{(c_i x_{10} - c_i x_9 + c_{vp} x_6)}{(c_i c_{vp} r_{vp})} \\
\dot{x}_{10} &= \frac{(-c_b c_f c_l c_s c_v x_{10} r_b r_f r_l r_s r_v + c_b c_f c_l c_s c_{vp} x_2 r_b r_f r_l r_s r_{vp} + c_b c_f c_l c_v c_{vp} x_5 r_b r_f r_l r_v r_{vp} + c_b c_f c_s c_v c_{vp} x_3 r_b r_f \ldots}{(c_b c_f c_l c_s c_v c_{vp} r_b r_f r_l r_s r_v r_{vp})}
\end{aligned}
\tag{1.1}
$$

$$
\begin{aligned}
y_1 &= \frac{x_1}{c_b} \\
y_2 &= \frac{x_2}{c_v} \\
y_3 &= \frac{x_3}{c_l} \\
y_4 &= \frac{x_4}{c_f} \\
y_5 &= \frac{x_5}{c_s} \\
y_6 &= \frac{x_6}{c_i}
\end{aligned}
\tag{1.2}
$$

1.4 MaplesonModelP_sm.tex

MTT command:

```
mtt MaplesonModelP sm tex
```

$$A_{11} = \frac{(-1)}{(c_b r_b)} \tag{1.3}$$

$$A_{18} = \frac{1}{(c_{ap} r_b)} \tag{1.4}$$

$$A_{22} = \frac{(-1)}{(c_v r_v)} \tag{1.5}$$

$$A_{28} = \frac{1}{(c_{ap} r_v)} \tag{1.6}$$

$$A_{33} = \frac{(-1)}{(c_l r_l)} \tag{1.7}$$

$$A_{38} = \frac{1}{(c_{ap} r_l)} \tag{1.8}$$

$$A_{44} = \frac{(-1)}{(c_f r_f)} \tag{1.9}$$

$$A_{48} = \frac{1}{(c_{ap} r_f)} \tag{1.10}$$

$$A_{55} = \frac{(-1)}{(c_s r_s)} \tag{1.11}$$

$$A_{58} = \frac{1}{(c_{ap} r_s)} \tag{1.12}$$

$$A_{66} = \frac{(-(r_{ap}r_i + r_{ap}r_{vp} + r_i r_{vp}))}{(c_i r_{ap} r_i r_{vp})} \tag{1.13}$$

$$A_{69} = \frac{1}{(c_{vp} r_{vp})} \tag{1.14}$$

$$A_{76} = \frac{1}{(c_i r_{ap})} \tag{1.15}$$

$$A_{77} = \frac{(-1)}{(c_{ap} r_{ap})} \tag{1.16}$$

$$A_{87} = \frac{1}{(c_{ap} r_{ap})} \tag{1.17}$$

$$A_{88} = \frac{\left(-\left(r_b r_f r_l r_s + r_b r_f r_l r_v + r_b r_f r_s r_v + r_b r_l r_s r_v + r_f r_l r_s r_v\right)\right)}{\left(c_{ap} r_b r_f r_l r_s r_v\right)} \tag{1.18}$$

$$A_{96} = \frac{1}{(c_i r_{vp})} \tag{1.19}$$

$$A_{99} = \frac{(-1)}{(c_{vp} r_{vp})} \tag{1.20}$$

$$A_{910} = \frac{1}{(c_{vp} r_{vp})} \tag{1.21}$$

$$A_{101} = \frac{1}{(c_b r_b)} \tag{1.22}$$

$$A_{102} = \frac{1}{(c_v r_v)} \tag{1.23}$$

$$A_{103} = \frac{1}{(c_l r_l)} \tag{1.24}$$

$$A_{104} = \frac{1}{(c_f r_f)} \tag{1.25}$$

$$A_{105} = \frac{1}{(c_s r_s)} \tag{1.26}$$

$$A_{1010} = \frac{(-1)}{(c_{vp} r_{vp})} \tag{1.27}$$

$$B = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ \frac{1}{r_i} \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \tag{1.28}$$

$$C_{11} = \frac{1}{c_b} \tag{1.29}$$

$$C_{22} = \frac{1}{c_v} \tag{1.30}$$

$$C_{33} = \frac{1}{c_l} \tag{1.31}$$

$$C_{44} = \frac{1}{c_f} \tag{1.32}$$

$$C_{55} = \frac{1}{c_s} \tag{1.33}$$

$$C_{66} = \frac{1}{c_i} \tag{1.34}$$

$$D = \begin{pmatrix} 0 \end{pmatrix} \tag{1.35}$$

1.5 MaplesonModelP_lmfr.ps

MTT command:

```
mtt MaplesonModelP lmfr ps
```

This representation is given as Figure 1.2 (on page 23).

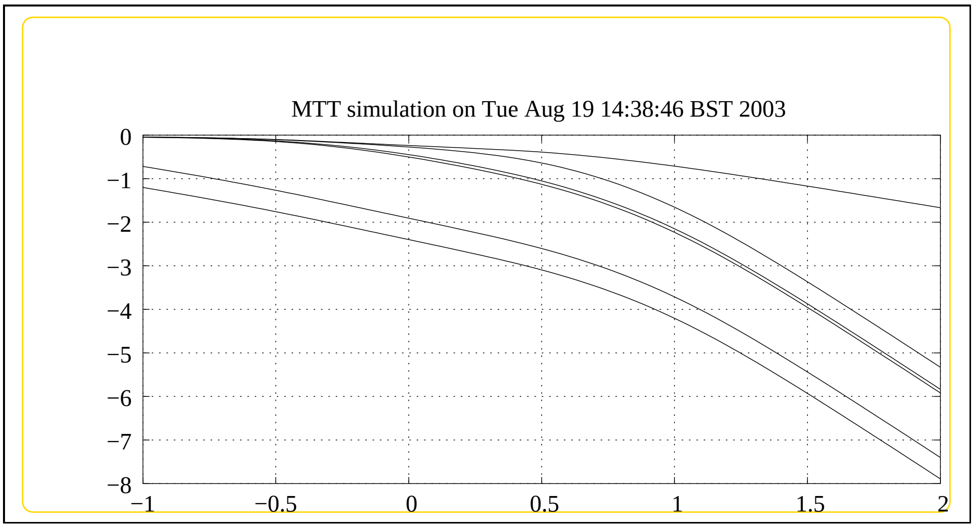

Figure 1.2: System **MaplesonModelP**, representation lmfr (-noargs)

1.6 MaplesonModelP_simpar.txt

MTT command:

```
mtt MaplesonModelP simpar txt
```

```
# -*-octave-*- Put Emacs into octave-mode
# Simulation parameters for system MaplesonModelP (MaplesonModelP_
# Generated by MTT on Fri Nov 10 11:37:00 GMT 2000.
###############################################################
## Version control history
###############################################################
## $Id: MaplesonModelP_simpar.txt,v 1.1 2000/12/28 17:04:39 peterg
## $Log: MaplesonModelP_simpar.txt,v $
## Revision 1.1  2000/12/28 17:04:39  peterg
## To RCS
##
###############################################################


FIRST        = 0.0;       # First time in simulation output
DT           = 0.1;       # Print interval
LAST         = 10.0;      # Last time in simulation
STEPFACTOR  = 10;          # Integration steps per print interval
WMIN         = -1;        # Minimum frequency = 10^WMIN
WMAX         = 2;         # Maximum frequency = 10^WMAX
WSTEPS       = 100;       # Number of frequency steps
INPUT        = 1;         # Index of the input
```

1.7 MaplesonModelP_numpar.txt

MTT command:

```
mtt MaplesonModelP numpar txt
```

```
# Numerical parameter file (MaplesonModelP_numpar.txt)
# Generated by MTT at Mon Aug 11 14:45:13 BST 1997

# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
# %% Version control history
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
# %% $Id: MaplesonModelP_numpar.txt,v 1.1 2000/12/28 17:04:39 pete
# %% $Log: MaplesonModelP_numpar.txt,v $
# %% Revision 1.1  2000/12/28 17:04:39  peterg
```

```
# %% To RCS
# %%
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

# Parameters

# Modified 17/11/93 to correspond to Mapleson's 1973 paper.
# Like model O except that blood has its own pools distinct form the tis


Heart_interval = 1.0/60.0;
Breathing_interval = 4*Heart_interval;
Stroke_volume = 0.108;
lambdaBlood = 0.46;
vArterial = 1.4;
vVenous = 4.0;

# %%%%%%%%%%%%%%%%%% Inspiration %%%%%%%%%%%%%%%%%%%%%%%%%%%
v_i = 0.4;
r_i = Breathing_interval/v_i;

# %%%%%%%%%%%%%%%%%% Lung %%%%%%%%%%%%%%%%%%%%%%%%%%%
vLung = 0.6;
vPLung =  0;
vGas = 2.5;
lambdaLung = 0.46;

c_i = lambdaLung*(vLung + vPLung) + vGas;
t_i = r_i*c_i;
# %%%%%%%%%%%%%%%%%% Brain %%%%%%%%%%%%%%%%%%%%%%%%%%%
kB = 0.000086;

vB = 0.0007;
vBP = 0.0;

lambdaB = 0.46;

c_b = lambdaB*vB + lambdaBlood*vBP;
r_b = Heart_interval/(kB*lambdaBlood*Stroke_volume);
t_b = r_b*c_b;
```

```
# %%%%%%%%%%%%%%%%%% Viscera %%%%%%%%%%%%%%%%%%%%%%%%%%%
kV = 0.63;

vV = 6.2;
lambdaV = 0.46;
vVP = 0;

c_v = lambdaV*vV + lambdaBlood*vVP;
r_v = Heart_interval/(kV*lambdaBlood*Stroke_volume);
t_v = r_v*c_v;

# %%%%%%%%%%%%%%%%%% Lean %%%%%%%%%%%%%%%%%%%%%%%%%%%
kL = 0.131;

vL = 39.2;
lambdaL = 0.46;
vLP = 0;

c_l = lambdaL*vL + lambdaBlood*vLP;
r_l = Heart_interval/(kL*lambdaBlood*Stroke_volume);
t_l = r_l*c_l;

# %%%%%%%%%%%%%%%%%% Fat %%%%%%%%%%%%%%%%%%%%%%%%%%%
kF = 0.04;

vF = 12.2;
lambdaF = 1.40;
vFP = 0;

c_f = lambdaF*vF + lambdaBlood*(vFP);
r_f = Heart_interval/(kF*lambdaBlood*Stroke_volume);
t_f = r_f*c_f;

# %%%%%%%%%%%%%%%%%% Shunt %%%%%%%%%%%%%%%%%%%%%%%%%%%
kS = 0.199;

vSP = 0.126*vVenous;

c_s = lambdaBlood*(vSP);
r_s = Heart_interval/(kS*lambdaBlood*Stroke_volume);
t_s = r_s*c_s;
```

```
# %%%%%%%%%%%%%%%%%% Time constants %%%%%%%%%%%%%%%%%%%%%%%%%%%
t_1 = t_b*t_v*t_l*t_f*t_s;
t_2 = t_1*t_i;


# %%%%%%%%%%%%%%%%%% Convert from rs to ks %%%%%%%%%%%%%%%%%%%%

k_b = 1/r_b;
k_v = 1/r_v;
k_l = 1/r_l;
k_f = 1/r_f;
k_s = 1/r_s;
k_i = 1/r_i;

# %%%%%%%%%%%%%%%%%% Arterial pools %%%%%%%%%%%%%%%%%%%%%%%%%%%
# Two pool version
aPools = 2;

vAP = vArterial;

c_ap = lambdaBlood*(vAP)/aPools;
r_ap  = Heart_interval/(lambdaBlood*Stroke_volume);

# %%%%%%%%%%%%%%%%%% Venous pools %%%%%%%%%%%%%%%%%%%%%%%%%%%
# Two pool version
vPools = 2;

vVP = vVenous - vSP;

c_vp = lambdaBlood*(vVP)/vPools;
r_vp  = Heart_interval/(lambdaBlood*Stroke_volume);

k_ap = 1/r_ap;
k_vp = 1/r_vp;
```

1.8 MaplesonModelP_input.txt

MTT command:

```
mtt MaplesonModelP input txt
```

```
## -*-octave-*- Put Emacs into octave-mode ##

##
## System MaplesonModelP, representation input, language txt;
## File MaplesonModelP_input.txt;
## Generated by MTT on Fri Nov 10 10:45:52 GMT 2000;


MaplesonModelP__t0 = 0.75*760*(t<2); #75% atmospheric pressure for
```

1.9 MaplesonModelP_odeso.ps

MTT command:

```
mtt MaplesonModelP odeso ps
```

This representation is given as Figure 1.3 (on page 28).

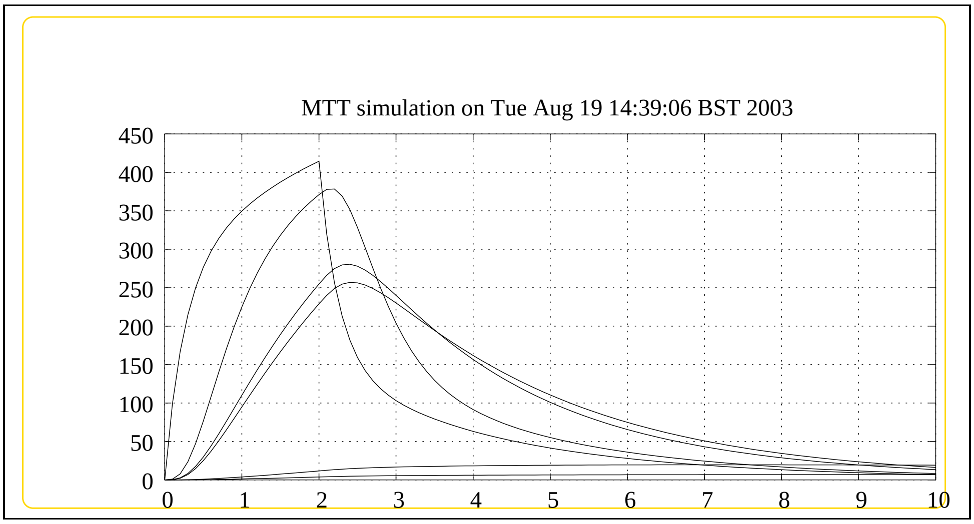

Figure 1.3: System **MaplesonModelP**, representation odeso (-noargs)

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