Inspired by Choi Iteration 00

```
clear
```

Definitions

Plunger

```
pl_d_out    =    17.5;     % mm
pl_d_hole   =    1;     % mm
pl_height   =    15.5;         % mm
pl_d_in     =    12;     % mm
pl_A_out    =    pl_d_out^2/4*pi;     % mm^2
pl_A_hole   =    pl_d_hole^2/4*pi     % mm^2
```

```
pl_A_hole = 0.7854
```

```
pl_A_in     =    pl_d_in^2/4*pi;     % mm^2
pl_A_u      =    pl_A_out - pl_A_in;     % mm^2
pl_m        =    0.012;  % kg
pl_rom      =    0.003;  % m
```

Pipes

```
ip_d = 15; % mm
ip_A = ip_d^2/4*pi; % mm^2
op_d = 15; % mm
op_A = op_d^2/4*pi; % mm^2
V_psu       =   ip_A*250; % mm^3
V_psd       =   op_A*250; % mm^3

io_d = 10; % mm
io_A = io_d^2/4*pi; % mm^2
oo_d = 10; % mm
oo_A = oo_d^2/4*pi; % mm^2
```

Outlet

```
o_d_out     =   17.83;         % mm
o_d_in     =   10;     % mm
A_adj = 0.5^2/4*pi;%o_d_out^2/4*pi - pl_A_out % mm^2
oe_o_d = 1; % mm
oe_o_A = oe_o_d^2/4*pi; % % mm^2
```

Pintle Groove

```
pg_d        =   13.035;     % mm
PG_depth    =   30.2;     % mm
```

Pintle

```
pi_height    =   29.4;     % mm
```

```
pi_d_out    =   12.84;    % mm
pi_d_in        =   16.022;    % mm
```

Volume

```
v_closed    =   1722;    % mm^3
v_open        =   1037;    % mm^3
```

Init arrays

```
dt = 0.000001; % s
T = 0.02/dt; % s
% t = zeros(T); % s
% P_cr = zeros(T); % bar
% T_cr = zeros(T); % K
% P_u = zeros(T); % bar
% T_u = zeros(T); % K
% P_d = zeros(T); % bar
% T_d = zeros(T); % K
% P_psu = zeros(T); % K
% T_psu = zeros(T); % K
% P_psd = zeros(T); % K
% T_psd = zeros(T); % K
%
% x = zeros(T); % m
% v = zeros(T); % m/s
% a = zeros(T); % m/s^2
%
% V_cr = zeros(T); % mm^3
%
% pilot = zeros(T); % 1 = open, 0 = closed
%
% A_m = zeros(T); % mm^2
%
% m_dot_u_psu = zeros(T); % kg/s
% m_dot_psu_cr = zeros(T); % kg/s
% m_dot_cr_psd = zeros(T); % kg/s
% m_dot_psu_psd = zeros(T); % kg/s
% m_dot_psd_d = zeros(T); % kg/s
%
% m_dot_cr_net = zeros(T); % kg/s
% m_dot_psu_net = zeros(T); % kg/s
% m_dot_psd_net = zeros(T); % kg/s
%
% F_cr = zeros(T); % N
% F_d = zeros(T); % N
% F_u = zeros(T); % N
% F_f = zeros(T); % N
% F_s = zeros(T); % N
% F = zeros(T); % N
%
% m_cr = zeros(T);
% m_psu = zeros(T);
```

```
% m_psd = zeros(T);
```

Test Case 1

- Infinite Upstream Volume @ 400 bar 273 K
- Pipe Section after upstream @ 400 bar 273 K
- Infinite Downstream Volume @ 1 bar 273 K
- Pipe Section before downstream @ 1 bar 273 K
- Outlet external orifice D = 2 mm
- Pilot closed @ t(0)
- P_cr = 400 bar @ t(0)
- Plunger displacement x = 0 @ t(0)

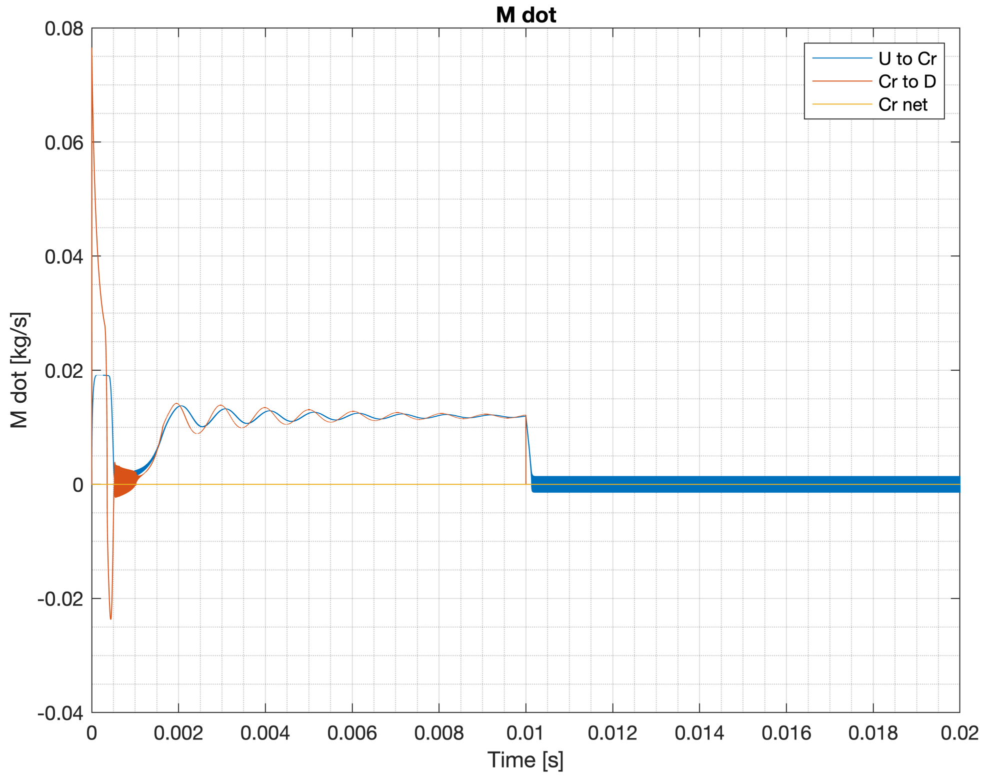
```
dt = 0.000001; % s
T = 0.02/dt; % s
gam = 1.4;
R = 296.8; % kJ/kgK
polythropic_index = gam ;

damper = 1000; % kg/s

t(1) = 0; % s
P_cr(1) = 400; % bar
T_cr(1) = 273; % K
P_u(1) = 400; % bar
T_u(1) = 273; % K
P_d(1) = 1; % bar
T_d(1) = 273; % K
P_psu(1) = 400; % K
T_psu(1) = 273; % K
P_psd(1) = 1; % K
T_psd(1) = 273; % K

x(1) = 0; % m
v(1) = 0; % m/s
a(1) = 0; % m/s^2

V_cr(1) = v_closed; % mm^3

pilot(1) = 0; % 1 = open, 0 = closed

A_m(1) = o_d_in * pi * x(1) * 10^-3; % mm^2

m_dot_u_psu(1) = 0; % kg/s
m_dot_psu_cr(1) = 0; % kg/s
m_dot_cr_psd(1) = 0; % kg/s
m_dot_psu_psd(1) = 0; % kg/s
m_dot_psd_d(1) = 0; % kg/s

m_dot_cr_net(1) = 0; % kg/s
m_dot_psu_net(1) = 0; % kg/s
```

```
m_dot_psd_net(1) = 0; % kg/s

F_cr(1) = B_to_Pa(P_cr(1)) * pl_A_out * 10^-6; % N
F_d(1) = B_to_Pa(P_psd(1)) * pl_A_in * 10^-6; % N
F_u(1) = B_to_Pa(P_psu(1)) * pl_A_u * 10^-6; % N
F_f(1) = - damper * v(1); % N
F_s(1) = 500; % N
F(1) = - F_cr(1) + F_d(1) + F_u(1) + F_f(1) - F_s(1); % N

m_cr(1) = 0.014 * B_to_Pa(P_cr(1)) * v_closed * 10^-9 / (T_cr(1) * R);
m_psu(1) = 0.014 * B_to_Pa(P_psu(1)) * V_psu * 10^-9 / (T_psu(1) * R);
m_psd(1) = 0.014 * B_to_Pa(P_psd(1)) * V_psd * 10^-9 / (T_psd(1) * R);

for i = 2:(T-1)
    t(i) = t(i-1) + dt; % s
    pilot(i) = i < (0.5*T); % 1 = open, 0 = closed

    P_u(i) = P_u(i-1); % bar
    T_u(i) = T_u(i-1); % K
    P_d(i) = P_d(i-1); % bar
    T_d(i) = T_d(i-1); % K

    % Calculate forces
    F_cr(i) = B_to_Pa(P_cr(i-1)) * pl_A_out * 10^-6; % N
    F_d(i) = B_to_Pa(P_psd(i-1)) * pl_A_in * 10^-6; % N
    F_u(i) = B_to_Pa(P_psu(i-1)) * pl_A_u * 10^-6; % N
    F_f(i) = - damper * v(i-1); % N
    F_s(i) = F_s(1); % N
    F(i) = - F_cr(i) + F_d(i) + F_u(i) + F_f(i) - F_s(i); % N

    % Calculate displacement from previous forces
    x(i) = x(i-1) + v(i-1)*dt + 0.5*a(i-1)*dt^2; % m
    v(i) = v(i-1) + a(i-1)*dt; % m/s
    a(i) = F(i) / pl_m; % m/s^2
    if x(i) < 0
        x(i) = 0; % m
        v(i) = 0; % m/s
        a(i) = 0; % m/s^2
    elseif x(i) > pl_rom
        x(i) = pl_rom; % m
        v(i) = 0; % m/s
        a(i) = 0; % m/s^2
    end

    % Calculate Main area with new displacement
    A_m(i) = o_d_in * pi * x(i) * 10^-3; % m^2

    % Calculate Critical volume after displacement
    V_cr(i) = (pl_rom - x(i)) * (v_closed - v_open) / pl_rom + v_open; % mm^3

    % Isentropic Compression
    P_cr(i) = P_cr(i-1) * (V_cr(i-1)/V_cr(i))^polythropic_index; % Bar
    T_cr(i) = T_cr(i-1) * (P_cr(i)/P_cr(i-1))^(1-1/polythropic_index); % K
```

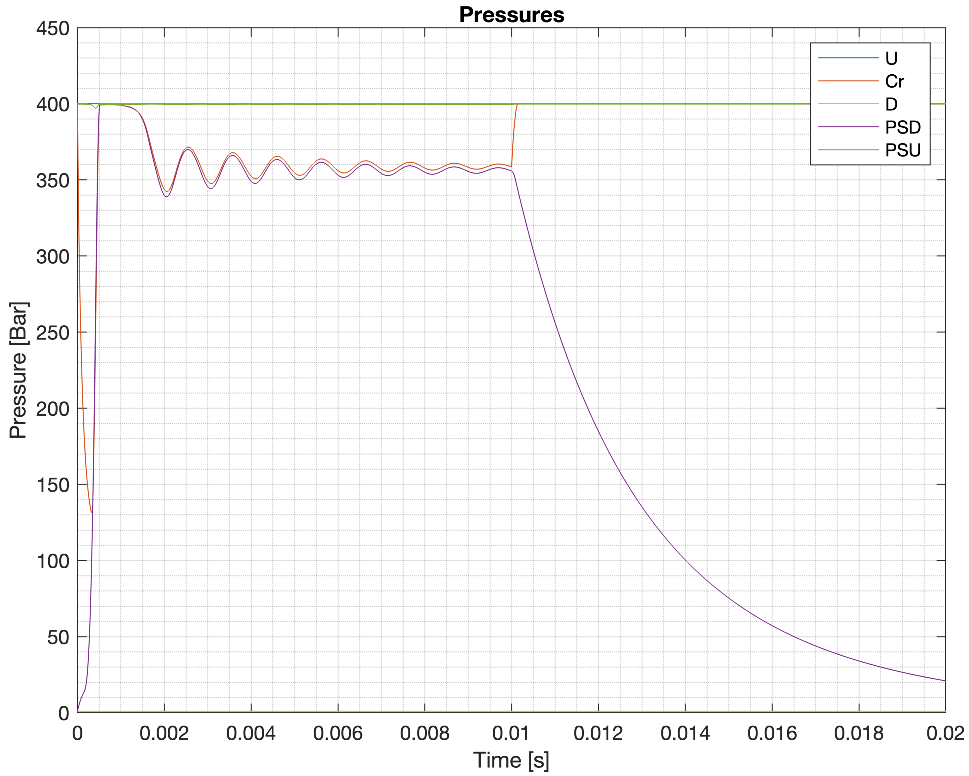
```
    % Critical volume / Actuation Chamber related
    m_dot_psu_cr(i) = mdot_orifice(...
        P_psu(i-1),P_cr(i) ,polythropic_index,A_adj    *10^-6,T_psu(i-1),R); % kg/s
    m_dot_cr_psd(i) = mdot_orifice(...
        P_cr(i), P_psd(i-1),polythropic_index,pl_A_hole*10^-6,T_cr(i), R) * (pilot(i)=

    [P_cr(i), T_cr(i), m_cr(i)] = tank_discharge_P_io(P_cr(i),T_cr(i),m_cr(i-1),...
         [T_psu(i-1),       T_cr(i-1)],...
         [m_dot_psu_cr(i),  - m_dot_cr_psd(i)] * dt,...
         polythropic_index); % bar, K

    m_dot_cr_net(i) = m_cr(i) - m_cr(i-1); % kg/s

    % Pipe Section Upstream related
    m_dot_psu_psd(i) = mdot_orifice(P_psu(i-1),P_psd(i-1),polythropic_index,A_m(i),T_p
    m_dot_u_psu(i) = mdot_orifice(P_u(i-1),  P_psu(i-1),polythropic_index,io_A    *10^

    [P_psu(i), T_psu(i), m_psu(i)] = tank_discharge_P_io(P_psu(i-1),T_psu(i-1),m_psu(i
         [T_u(i-1),        T_psu(i-1),          T_psu(i-1)],...
         [m_dot_u_psu(i),  - m_dot_psu_cr(i),   - m_dot_psu_psd(i)] * dt,...
         polythropic_index); % bar, K

    m_dot_psu_net(i) = m_psu(i) - m_psu(i-1); % kg/s

    % Pipe Section Upstream related
    m_dot_psd_d(i) = mdot_orifice(P_psd(i-1),P_d(i-1)  ,polythropic_index,oe_o_A    *1
    m_dot_psd_net(i) = m_dot_cr_psd(i) - m_dot_psd_d(i) + m_dot_psu_psd(i); % kg/s
    m_psd(i) = m_psd(i-1) + m_dot_psd_net(i) * dt; % kg
    [P_psd(i), T_psd(i)] = tank_discharge_P(P_psd(i-1),T_psd(i-1),m_psd(i-1),...
         - m_dot_psd_net(i) * dt,polythropic_index); % bar, K

    [P_psd(i), T_psd(i), m_psd(i)] = tank_discharge_P_io(P_psd(i-1),T_psd(i-1),m_psd(i
         [T_psd(i-1),       T_cr(i-1),         T_psu(i-1)],...
         [-m_dot_psd_d(i), m_dot_cr_psd(i),   m_dot_psu_psd(i)] * dt,...
         polythropic_index); % bar, K

    m_dot_psd_net(i) = m_psd(i) - m_psd(i-1); % kg/s
end
```

Results

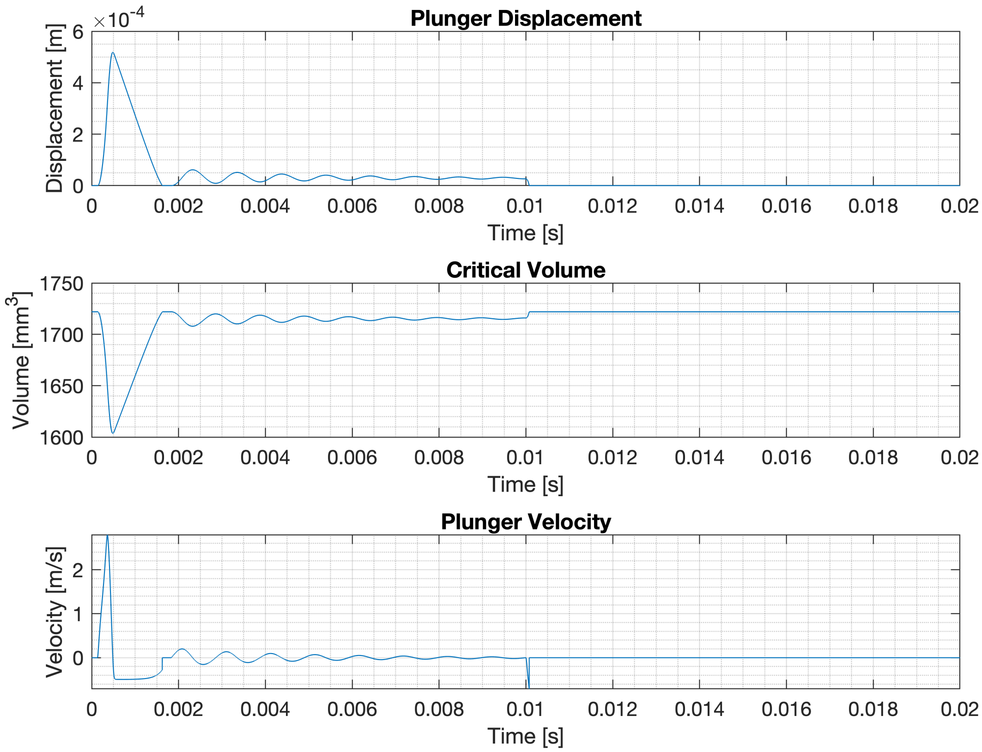
```
figure
plot(t,m_dot_psu_cr,t,m_dot_cr_psd,t,m_dot_cr_net)
grid on, grid minor, xlabel('Time [s]'), ylabel('M dot [kg/s]'), title('M dot')
legend('U to Cr', 'Cr to D', 'Cr net')
```



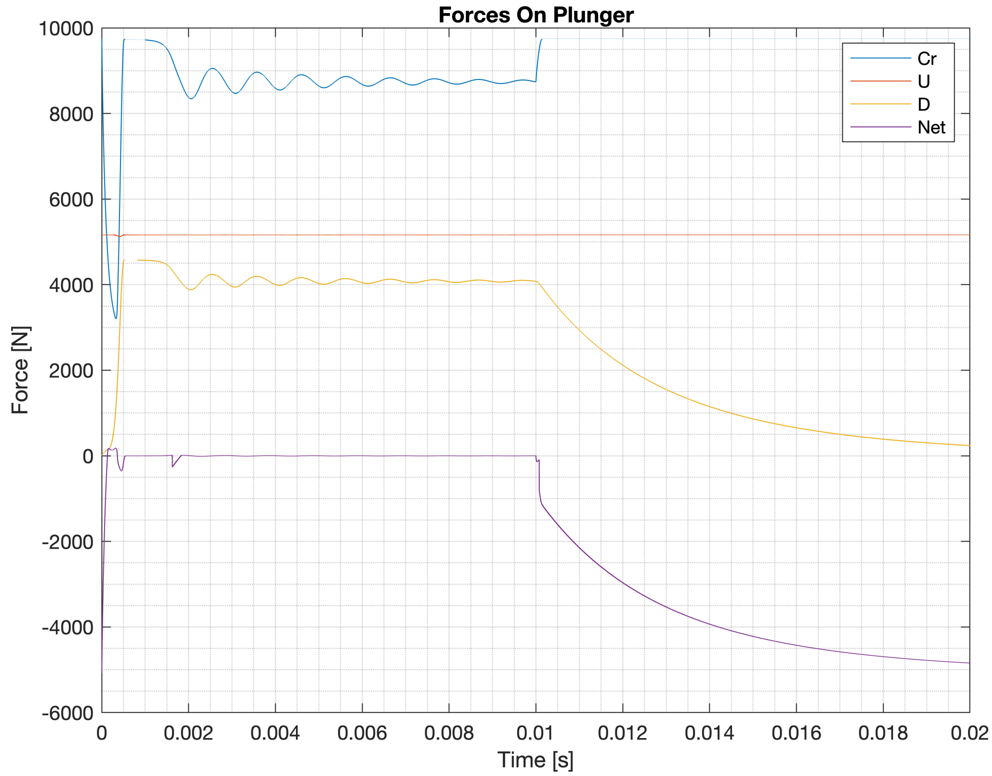

```
figure
plot(t,P_u,t,P_cr,t,P_d,t,P_psd,t,P_psu)
grid on, grid minor, xlabel('Time [s]'), ylabel('Pressure [Bar]'), title('Pressures')
legend('U','Cr','D','PSD','PSU')
```



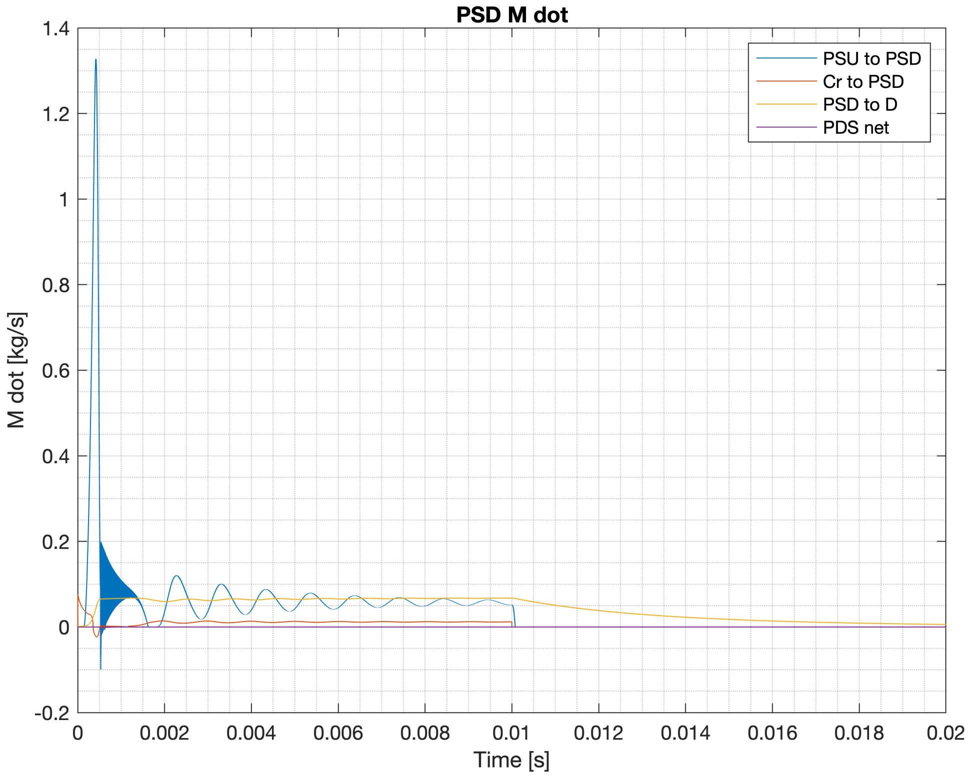

```
figure
subplot(3,1,1)
plot(t,x)
grid on, grid minor, xlabel('Time [s]'), ylabel('Displacement [m]'), title('Plunger Dis
subplot(3,1,2)
plot(t,V_cr)
grid on, grid minor, xlabel('Time [s]'), ylabel('Volume [mm^3]'), title('Critical Volum
subplot(3,1,3)
plot(t,v)
grid on, grid minor, xlabel('Time [s]'), ylabel('Velocity [m/s]'), title('Plunger Veloc
```



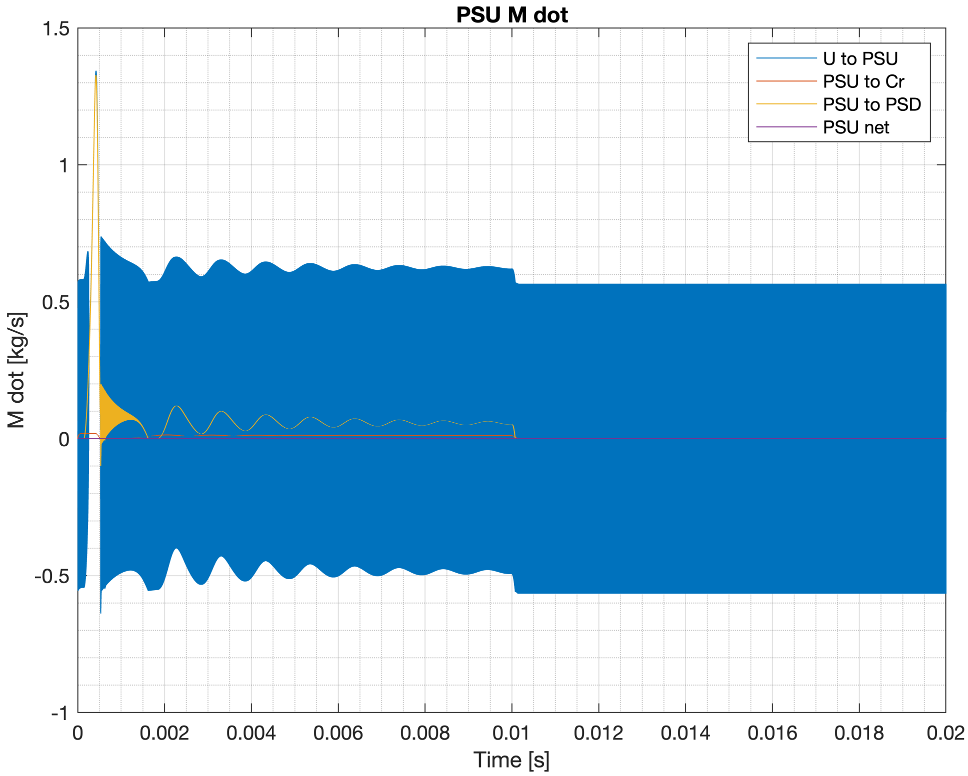

```
figure
plot(t,F_cr,t,F_u,t,F_d,t,F)
grid on, grid minor, xlabel('Time [s]'), ylabel('Force [N]'), title('Forces On Plunger
legend('Cr','U','D','Net')
```



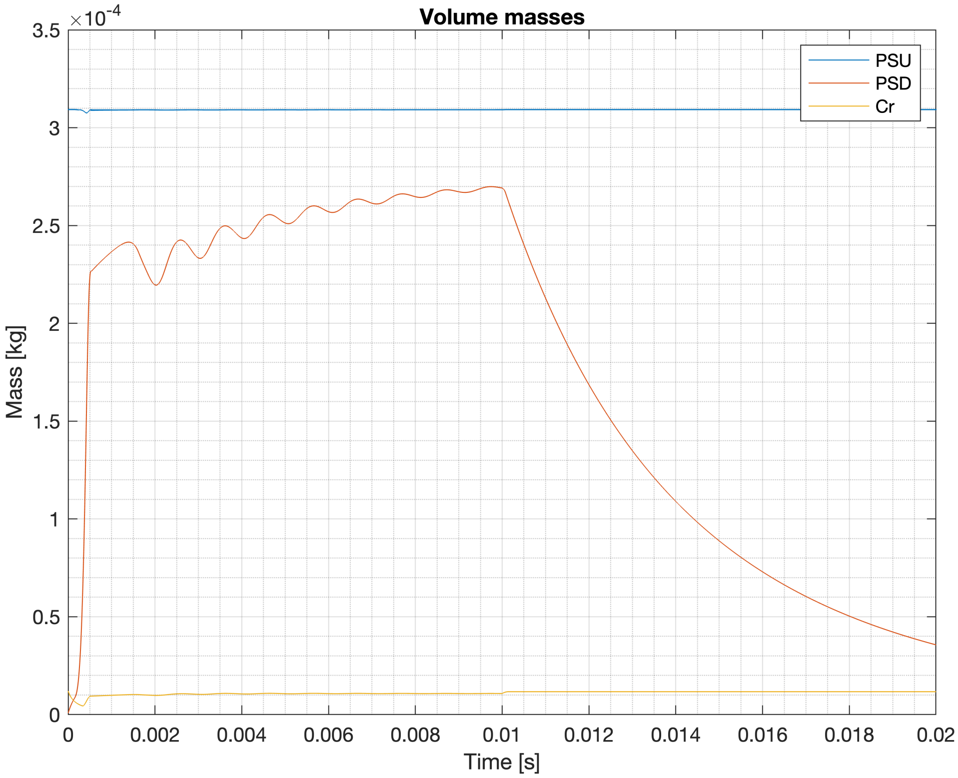

```
figure
plot(t,m_dot_psu_psd,t,m_dot_cr_psd,t,m_dot_psd_d,t,m_dot_psd_net)
grid on, grid minor, xlabel('Time [s]'), ylabel('M dot [kg/s]'), title('PSD M dot')
legend('PSU to PSD', 'Cr to PSD', 'PSD to D', 'PDS net')
```



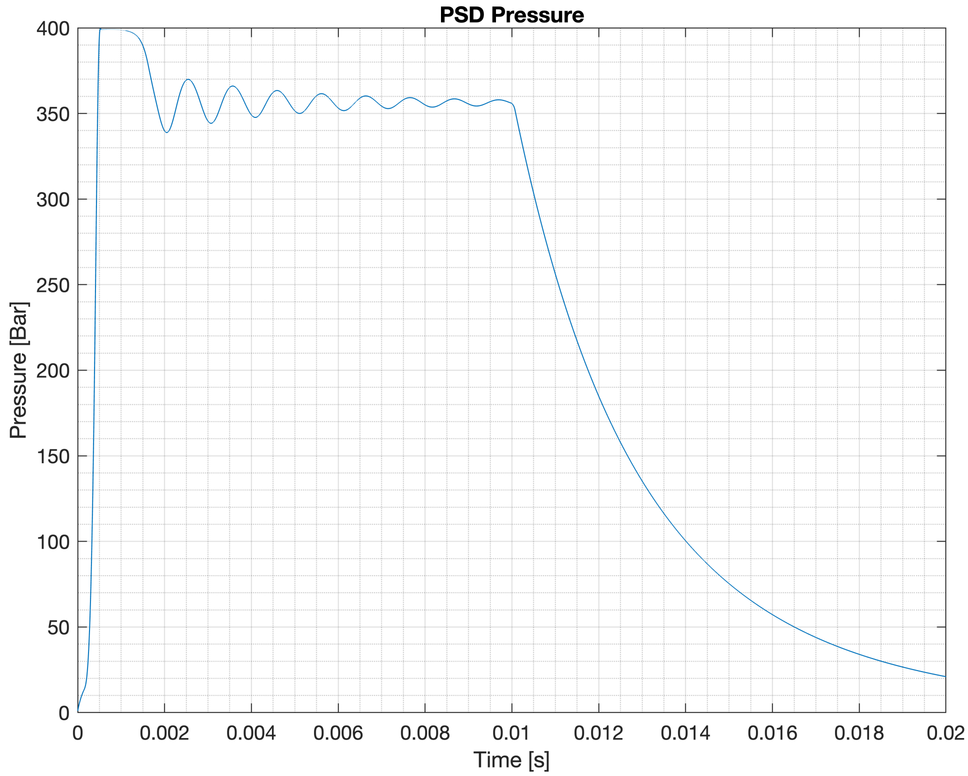

```
figure
plot(t,m_dot_u_psu,t,m_dot_psu_cr,t,m_dot_psu_psd,t,m_dot_psu_net)
grid on, grid minor, xlabel('Time [s]'), ylabel('M dot [kg/s]'), title('PSU M dot')
legend('U to PSU', 'PSU to Cr', 'PSU to PSD', 'PSU net')
```



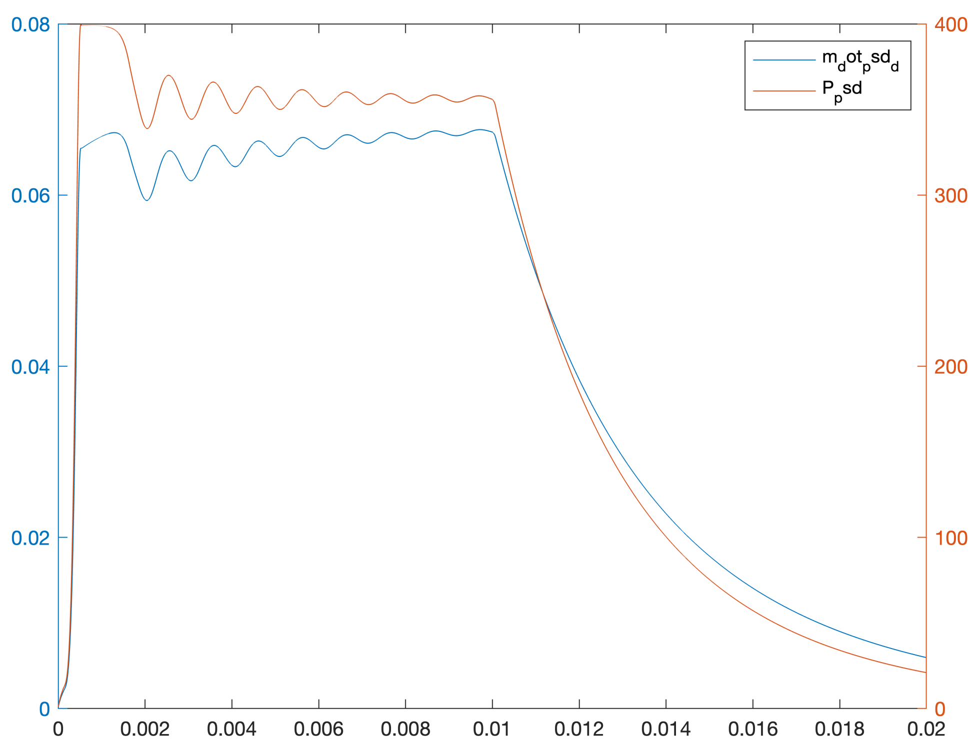

```
figure
plot(t,m_psu,t,m_psd,t,m_cr)
grid on, grid minor, xlabel('Time [s]'), ylabel('Mass [kg]'), title('Volume masses')
legend('PSU', 'PSD', 'Cr')
```



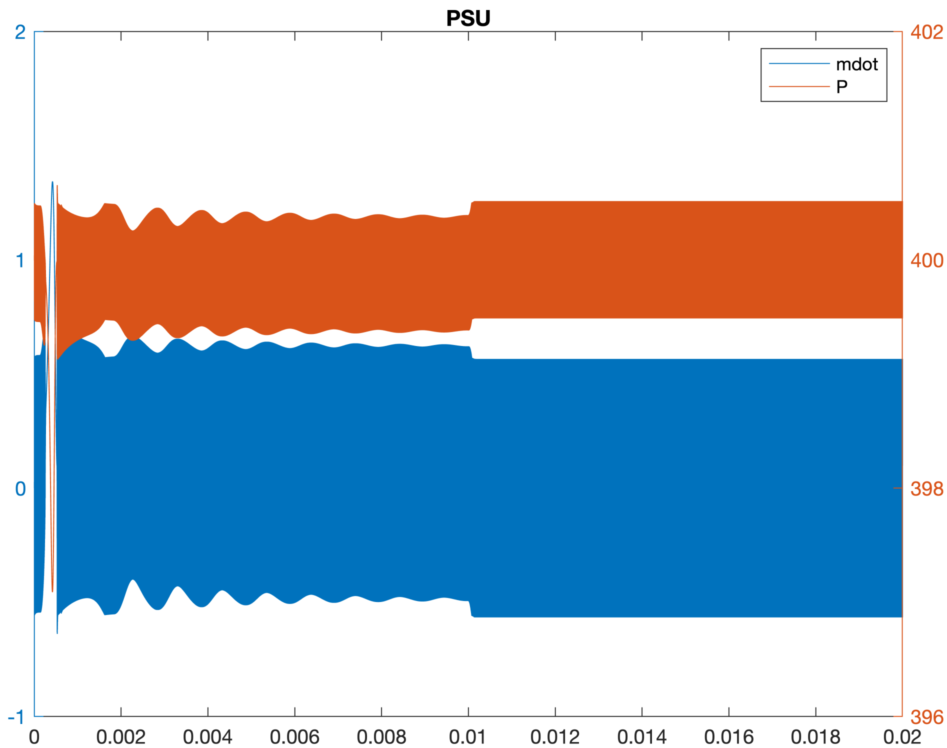

```
figure
plot(t,P_psd)
grid on, grid minor, xlabel('Time [s]'), ylabel('Pressure [Bar]'), title('PSD Pressure
```



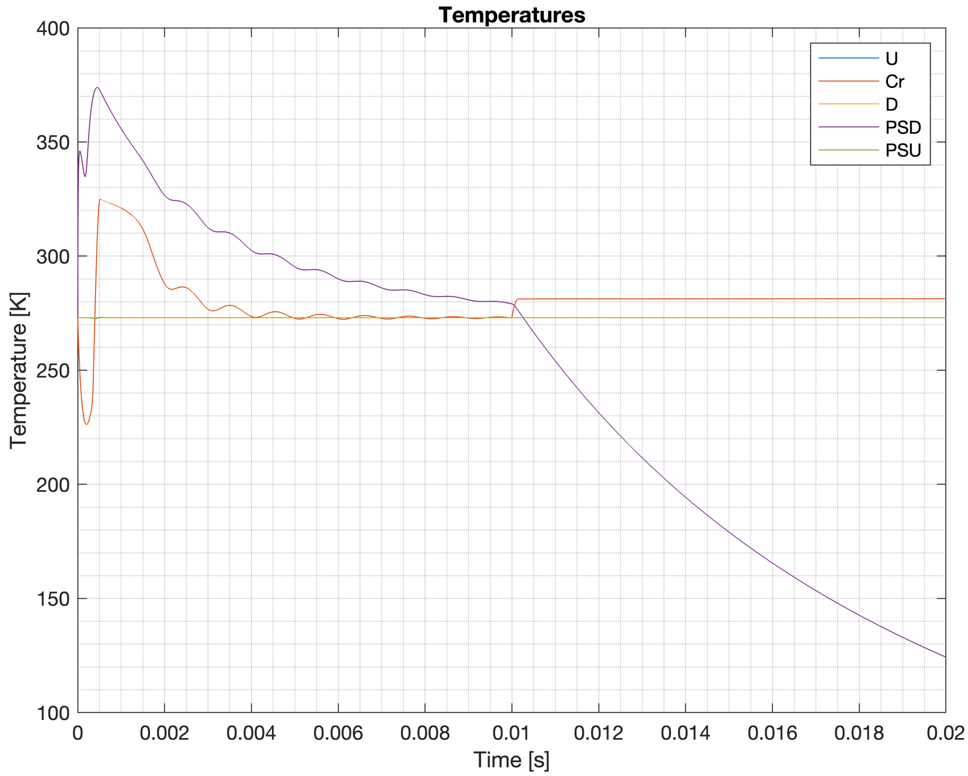

```
figure
plotyy(t,m_dot_psd_d,t,P_psd),legend('m_dot_psd_d','P_psd')
```



```
figure
plotyy(t,m_dot_u_psu,t,P_psu),legend('m_dot_psd_d','P_psd'),title('PSU'),legend('mdot'
```




```
figure
plot(t,T_u,t,T_cr,t,T_d,t,T_psd,t,T_psu)
grid on, grid minor, xlabel('Time [s]'), ylabel('Temperature [K]'), title('Temperature
legend('U','Cr','D','PSD','PSU')
```



Test Case 2

- Infinite Upstream Volume @ 400 bar 273 K
- Pipe Section after upstream @ 1 bar 273 K
- Infinite Downstream Volume @ 1 bar 273 K
- Pipe Section before downstream @ 1 bar 273 K
- Outlet external orifice D = 2 mm
- Pilot closed @ t(0)
- P_cr = 1 bar @ t(0)
- Plunger displacement x = 0 @ t(0)

```
dt = 0.000001; % s
T = 0.03/dt; % s
gam = 1.4;
R = 296.8; % kJ/kgK
polythropic_index = gam ;

damper = 1000; % kg/s

t(1) = 0; % s
P_cr(1) = 1; % bar
T_cr(1) = 273; % K
P_u(1) = 400; % bar
T_u(1) = 273; % K
P_d(1) = 1; % bar
```

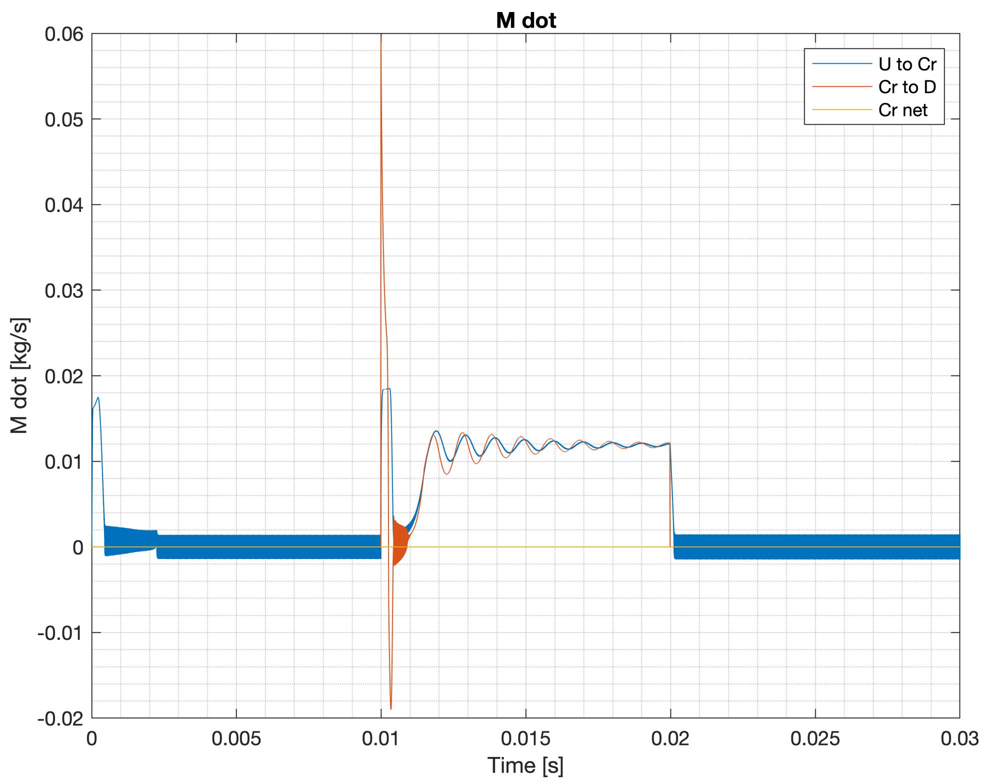
```
T_d(1) = 273; % K
P_psu(1) = 1; % K
T_psu(1) = 273; % K
P_psd(1) = 1; % K
T_psd(1) = 273; % K

x(1) = 0; % m
v(1) = 0; % m/s
a(1) = 0; % m/s^2

V_cr(1) = v_closed; % mm^3

pilot(1) = 0; % 1 = open, 0 = closed

A_m(1) = o_d_in * pi * x(1) * 10^-3; % mm^2

m_dot_u_psu(1) = 0; % kg/s
m_dot_psu_cr(1) = 0; % kg/s
m_dot_cr_psd(1) = 0; % kg/s
m_dot_psu_psd(1) = 0; % kg/s
m_dot_psd_d(1) = 0; % kg/s

m_dot_cr_net(1) = 0; % kg/s
m_dot_psu_net(1) = 0; % kg/s
m_dot_psd_net(1) = 0; % kg/s

F_cr(1) = B_to_Pa(P_cr(1)) * pl_A_out * 10^-6; % N
F_d(1) = B_to_Pa(P_psd(1)) * pl_A_in * 10^-6; % N
F_u(1) = B_to_Pa(P_psu(1)) * pl_A_u * 10^-6; % N
F_f(1) = - damper * v(1); % N
F_s(1) = 500; % N
F(1) = - F_cr(1) + F_d(1) + F_u(1) + F_f(1) - F_s(1); % N

m_cr(1) = 0.014 * B_to_Pa(P_cr(1)) * v_closed * 10^-9 / (T_cr(1) * R);
m_psu(1) = 0.014 * B_to_Pa(P_psu(1)) * V_psu * 10^-9 / (T_psu(1) * R);
m_psd(1) = 0.014 * B_to_Pa(P_psd(1)) * V_psd * 10^-9 / (T_psd(1) * R);

for i = 2:(T-1)
    t(i) = t(i-1) + dt; % s
    pilot(i) = (i > (0.333*T)) & (i < (0.666*T)); % 1 = open, 0 = closed

    P_u(i) = P_u(i-1); % bar
    T_u(i) = T_u(i-1); % K
    P_d(i) = P_d(i-1); % bar
    T_d(i) = T_d(i-1); % K

    % Calculate forces
    F_cr(i) = B_to_Pa(P_cr(i-1)) * pl_A_out * 10^-6; % N
    F_d(i) = B_to_Pa(P_psd(i-1)) * pl_A_in * 10^-6; % N
    F_u(i) = B_to_Pa(P_psu(i-1)) * pl_A_u * 10^-6; % N
    F_f(i) = - damper * v(i-1); % N
    F_s(i) = F_s(1); % N
    F(i) = - F_cr(i) + F_d(i) + F_u(i) + F_f(i) - F_s(i); % N
```

```matlab
    % Calculate displacement from previous forces
    x(i) = x(i-1) + v(i-1)*dt + 0.5*a(i-1)*dt^2; % m
    v(i) = v(i-1) + a(i-1)*dt; % m/s
    a(i) = F(i) / pl_m; % m/s^2
    if x(i) < 0
        x(i) = 0; % m
        v(i) = 0; % m/s
        a(i) = 0; % m/s^2
    elseif x(i) > pl_rom
        x(i) = pl_rom; % m
        v(i) = 0; % m/s
        a(i) = 0; % m/s^2
    end

    % Calculate Main area with new displacement
    A_m(i) = o_d_in * pi * x(i) * 10^-3; % m^2

    % Calculate Critical volume after displacement
    V_cr(i) = (pl_rom - x(i)) * (v_closed - v_open) / pl_rom + v_open; % mm^3

    % Isentropic Compression
    P_cr(i) = P_cr(i-1) * (V_cr(i-1)/V_cr(i))^polythropic_index; % Bar
    T_cr(i) = T_cr(i-1) * (P_cr(i)/P_cr(i-1))^(1-1/polythropic_index); % K

    % Critical volume / Actuation Chamber related
    m_dot_psu_cr(i) = mdot_orifice(...
        P_psu(i-1),P_cr(i) ,polythropic_index,A_adj    *10^-6,T_psu(i-1),R); % kg/s
    m_dot_cr_psd(i) = mdot_orifice(...
        P_cr(i), P_psd(i-1),polythropic_index,pl_A_hole*10^-6,T_cr(i), R) * (pilot(i)=

    [P_cr(i), T_cr(i), m_cr(i)] = tank_discharge_P_io(P_cr(i),T_cr(i),m_cr(i-1),...
         [T_psu(i-1),       T_cr(i-1)],...
         [m_dot_psu_cr(i),  - m_dot_cr_psd(i)] * dt,...
         polythropic_index); % bar, K

    m_dot_cr_net(i) = m_cr(i) - m_cr(i-1); % kg/s

    % Pipe Section Upstream related
    m_dot_psu_psd(i) = mdot_orifice(P_psu(i-1),P_psd(i-1),polythropic_index,A_m(i),T_ps
    m_dot_u_psu(i) = mdot_orifice(P_u(i-1),  P_psu(i-1),polythropic_index,io_A    *10^-

    [P_psu(i), T_psu(i), m_psu(i)] = tank_discharge_P_io(P_psu(i-1),T_psu(i-1),m_psu(i-
         [T_u(i-1),        T_psu(i-1),          T_psu(i-1)],...
         [m_dot_u_psu(i),  - m_dot_psu_cr(i),   - m_dot_psu_psd(i)] * dt,...
         polythropic_index); % bar, K

    m_dot_psu_net(i) = m_psu(i) - m_psu(i-1); % kg/s

    % Pipe Section Upstream related
    m_dot_psd_d(i) = mdot_orifice(P_psd(i-1),P_d(i-1)  ,polythropic_index,oe_o_A    *10
    m_dot_psd_net(i) = m_dot_cr_psd(i) - m_dot_psd_d(i) + m_dot_psu_psd(i); % kg/s
    m_psd(i) = m_psd(i-1) + m_dot_psd_net(i) * dt; % kg
    [P_psd(i), T_psd(i)] = tank_discharge_P(P_psd(i-1),T_psd(i-1),m_psd(i-1),...
         - m_dot_psd_net(i) * dt,polythropic_index); % bar, K
```

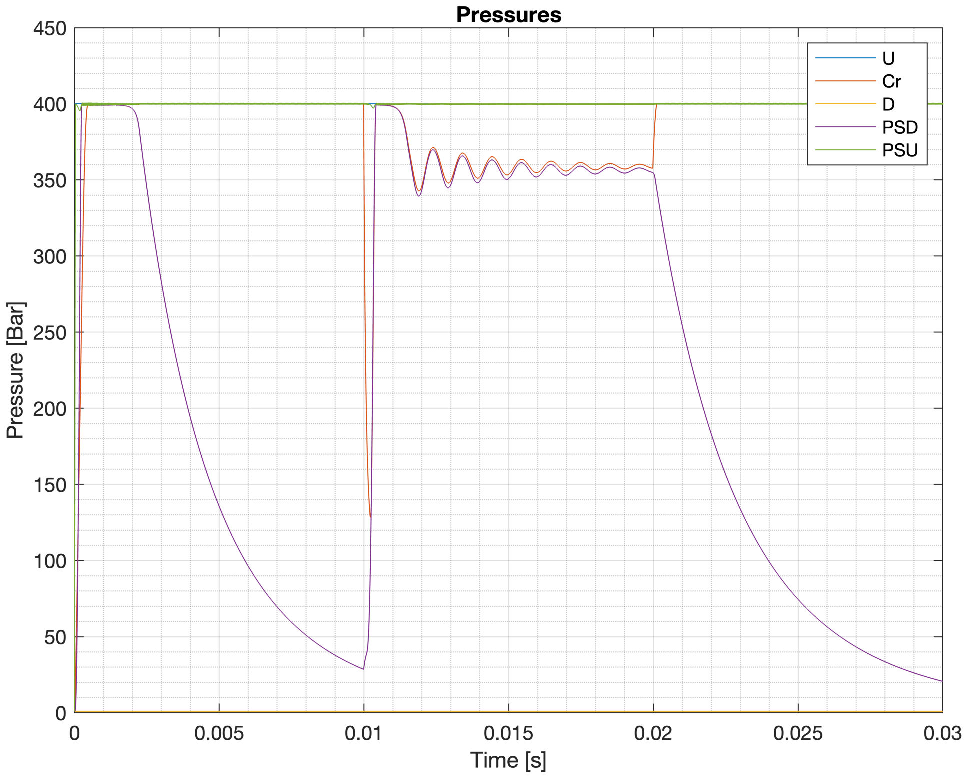
```
    [P_psd(i), T_psd(i), m_psd(i)] = tank_discharge_P_io(P_psd(i-1),T_psd(i-1),m_psd(i-
        [T_psd(i-1),        T_cr(i-1),         T_psu(i-1)],...
        [-m_dot_psd_d(i), m_dot_cr_psd(i),   m_dot_psu_psd(i)] * dt,...
        polythropic_index); % bar, K

    m_dot_psd_net(i) = m_psd(i) - m_psd(i-1); % kg/s
end
```

Results

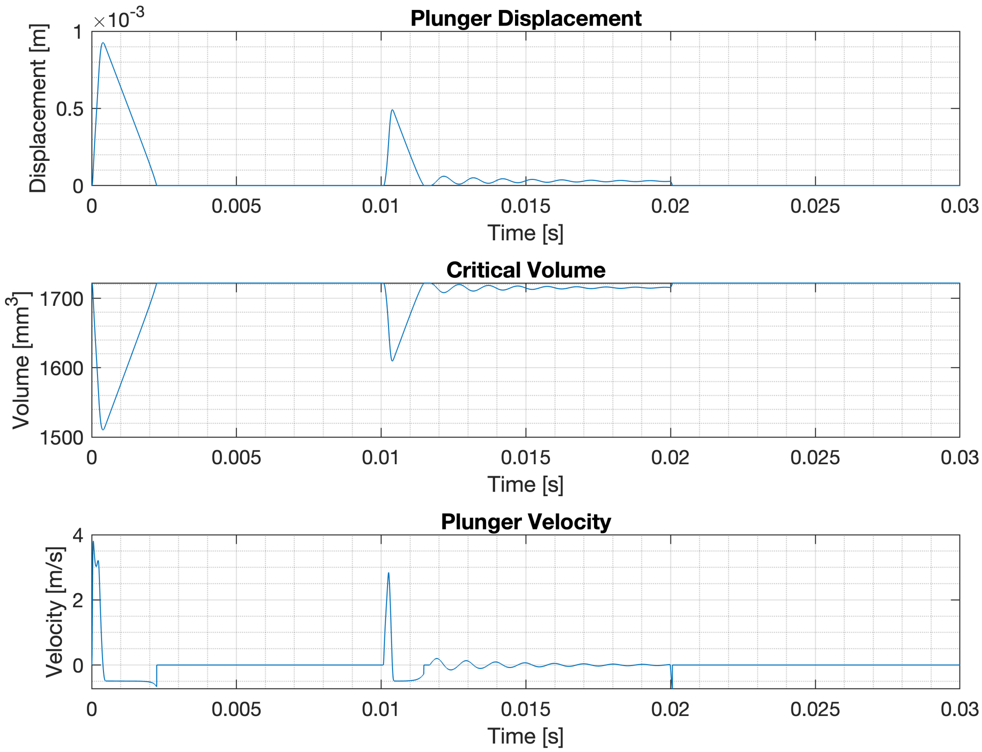
```
figure
plot(t,m_dot_psu_cr,t,m_dot_cr_psd,t,m_dot_cr_net)
grid on, grid minor, xlabel('Time [s]'), ylabel('M dot [kg/s]'), title('M dot')
legend('U to Cr', 'Cr to D', 'Cr net')
```



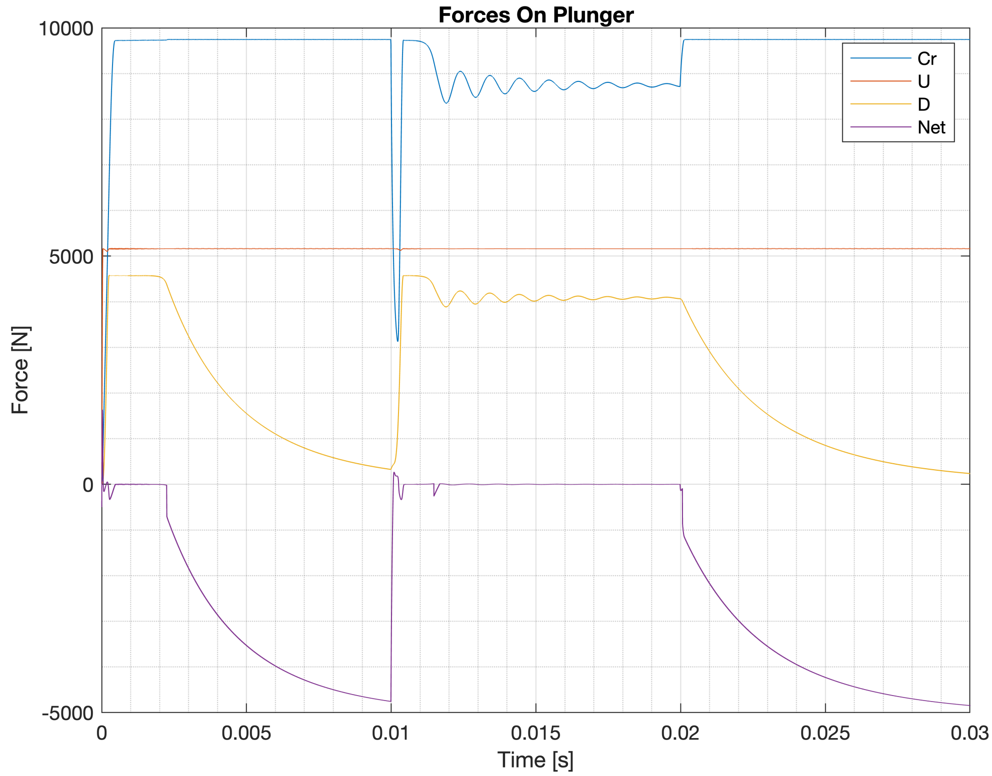

```
figure
plot(t,P_u,t,P_cr,t,P_d,t,P_psd,t,P_psu)
grid on, grid minor, xlabel('Time [s]'), ylabel('Pressure [Bar]'), title('Pressures')
legend('U','Cr','D','PSD','PSU')
```



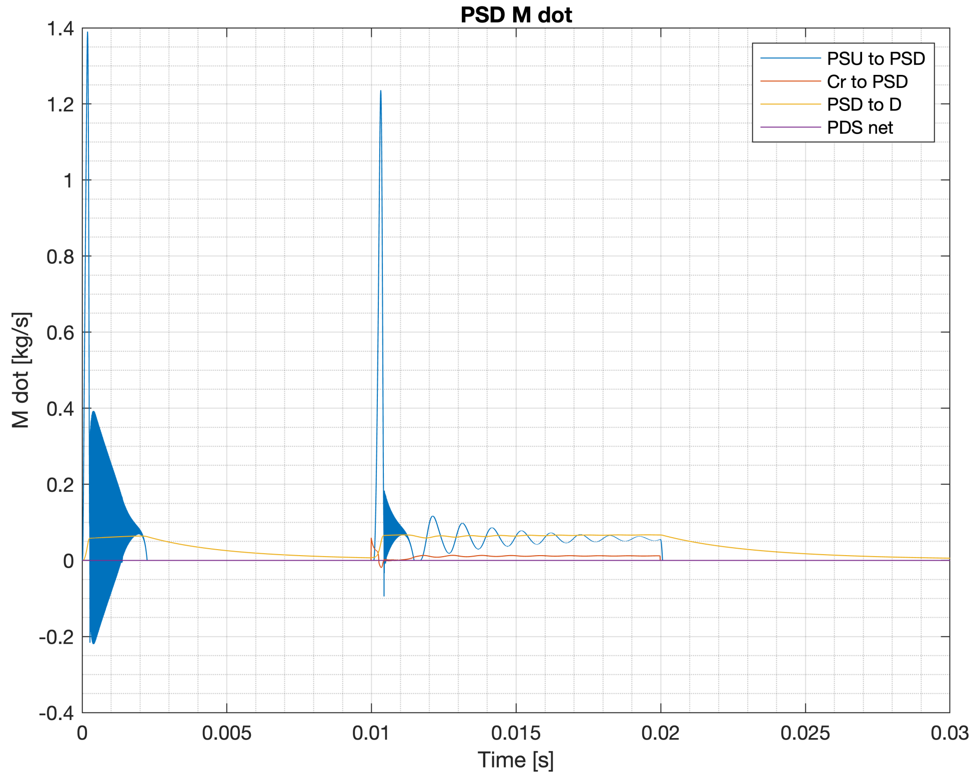

```
figure
subplot(3,1,1)
plot(t,x)
grid on, grid minor, xlabel('Time [s]'), ylabel('Displacement [m]'), title('Plunger Di
subplot(3,1,2)
plot(t,V_cr)
grid on, grid minor, xlabel('Time [s]'), ylabel('Volume [mm^3]'), title('Critical Volu
subplot(3,1,3)
plot(t,v)
grid on, grid minor, xlabel('Time [s]'), ylabel('Velocity [m/s]'), title('Plunger Velo
```



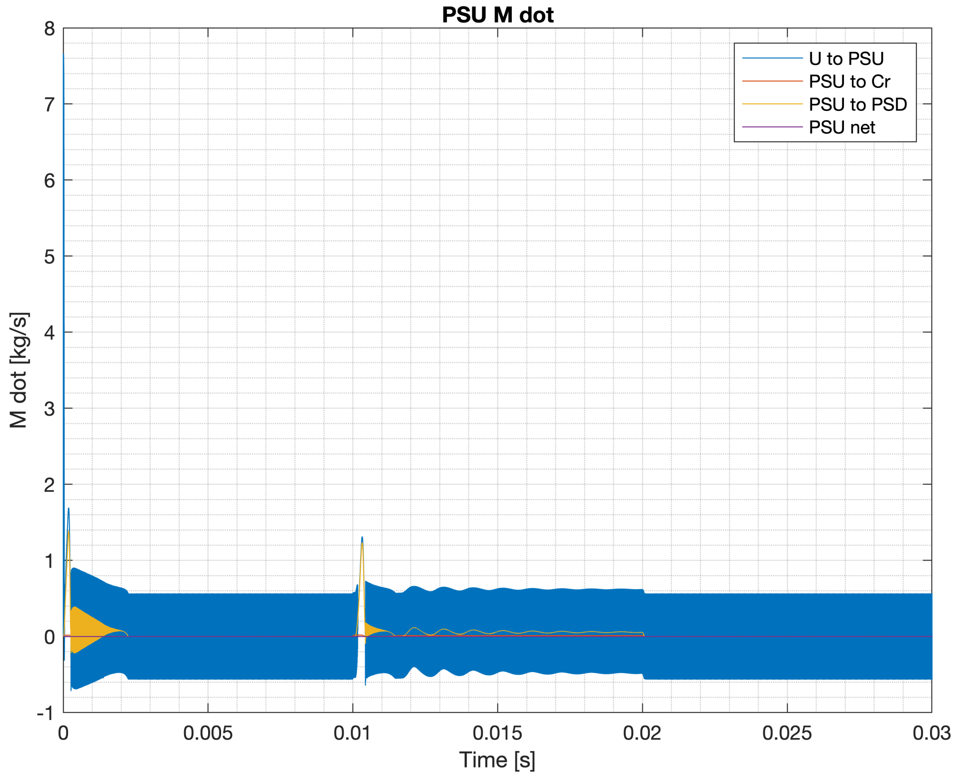

```
figure
plot(t,F_cr,t,F_u,t,F_d,t,F)
grid on, grid minor, xlabel('Time [s]'), ylabel('Force [N]'), title('Forces On Plunger
legend('Cr','U','D','Net')
```



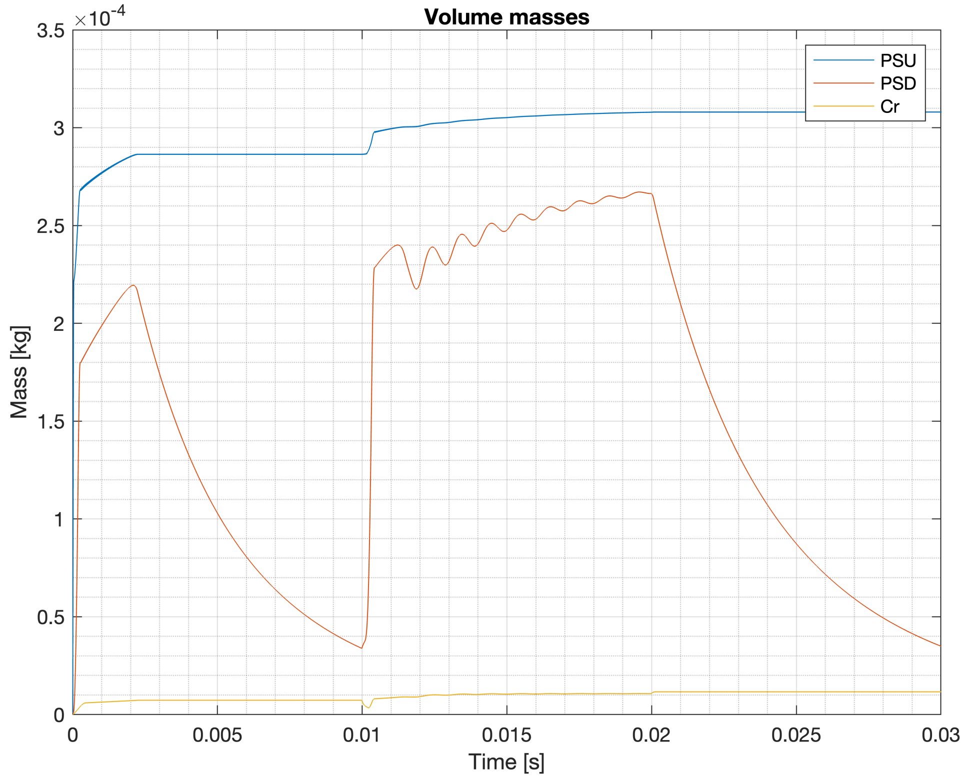

```
figure
plot(t,m_dot_psu_psd,t,m_dot_cr_psd,t,m_dot_psd_d,t,m_dot_psd_net)
grid on, grid minor, xlabel('Time [s]'), ylabel('M dot [kg/s]'), title('PSD M dot')
legend('PSU to PSD', 'Cr to PSD', 'PSD to D', 'PDS net')
```



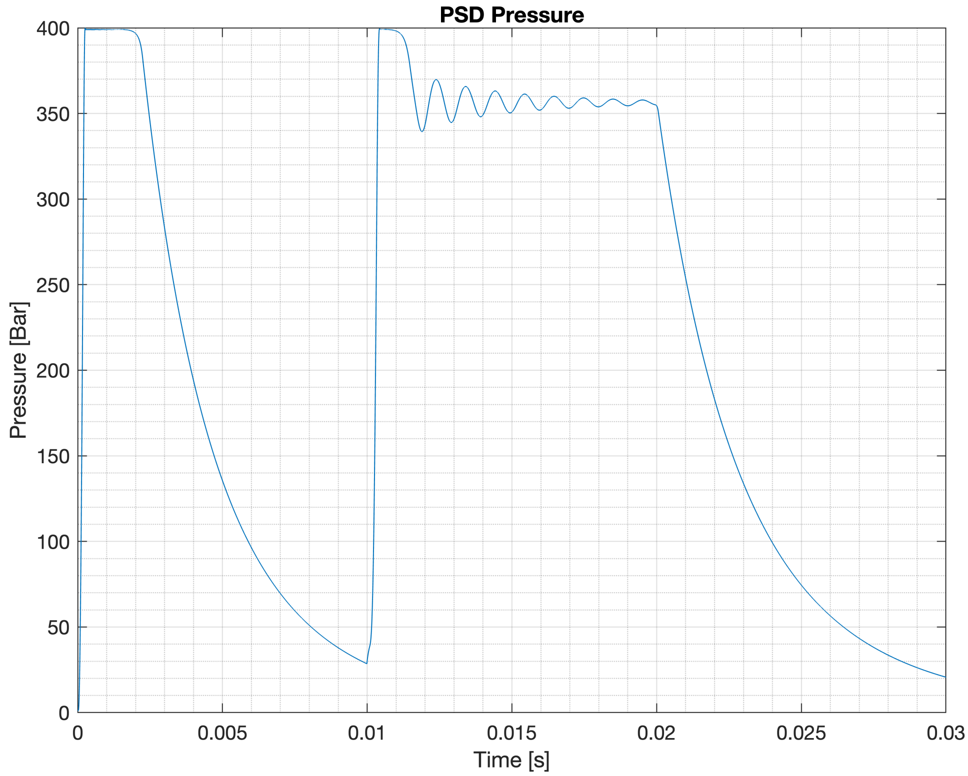

```
figure
plot(t,m_dot_u_psu,t,m_dot_psu_cr,t,m_dot_psu_psd,t,m_dot_psu_net)
grid on, grid minor, xlabel('Time [s]'), ylabel('M dot [kg/s]'), title('PSU M dot')
legend('U to PSU', 'PSU to Cr', 'PSU to PSD', 'PSU net')
```



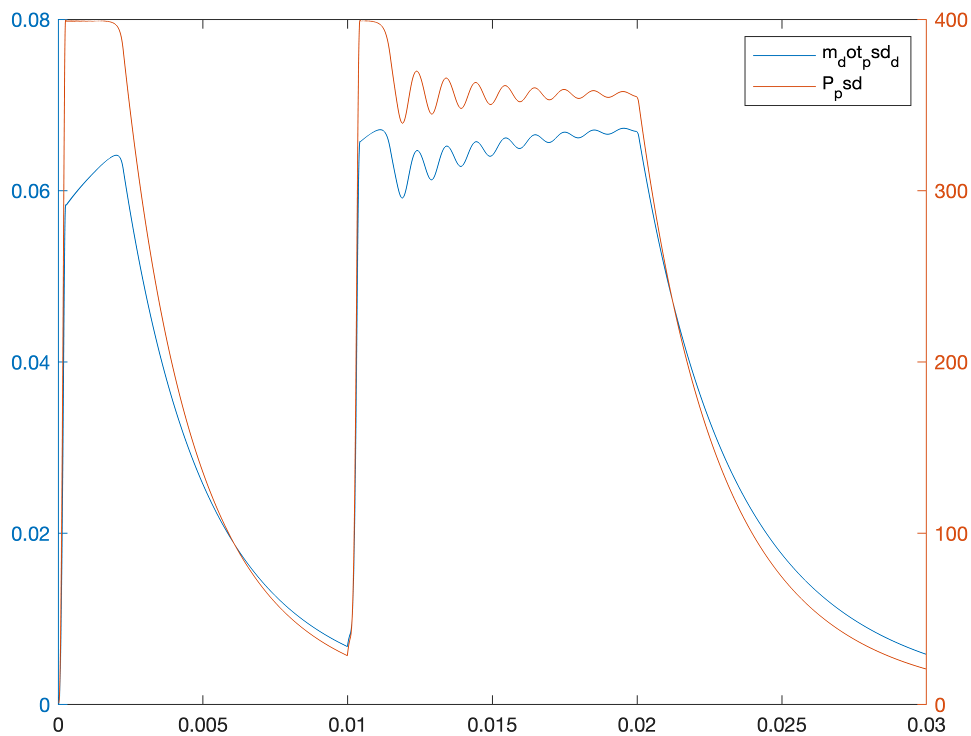

```
figure
plot(t,m_psu,t,m_psd,t,m_cr)
grid on, grid minor, xlabel('Time [s]'), ylabel('Mass [kg]'), title('Volume masses')
legend('PSU', 'PSD', 'Cr')
```



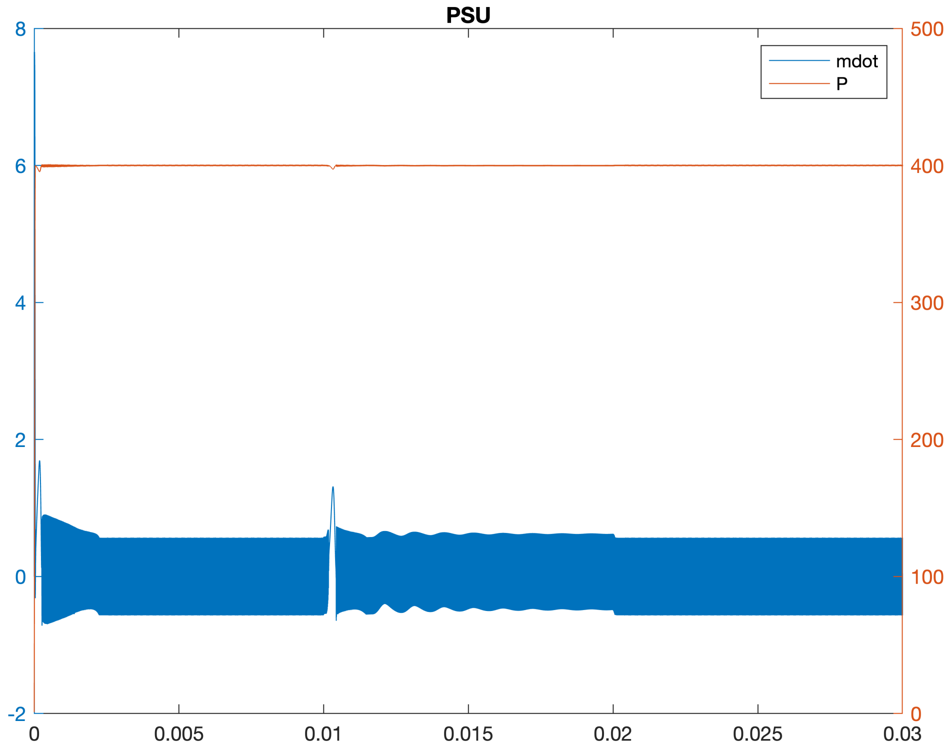

```
figure
plot(t,P_psd)
grid on, grid minor, xlabel('Time [s]'), ylabel('Pressure [Bar]'), title('PSD Pressure
```



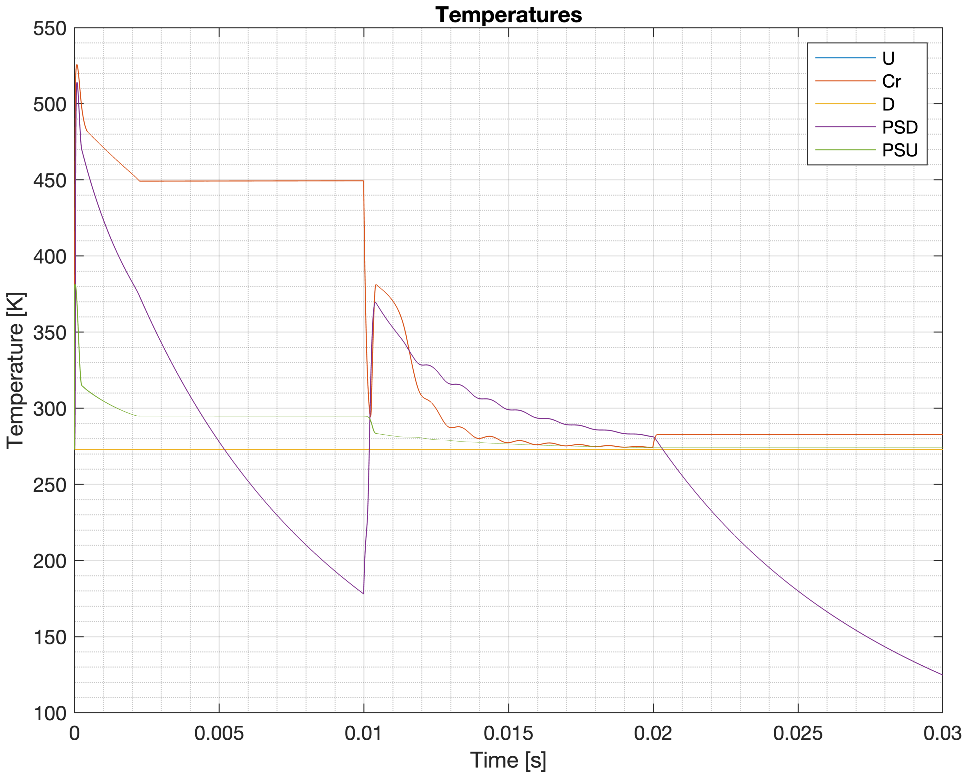

```
figure
plotyy(t,m_dot_psd_d,t,P_psd),legend('m_dot_psd_d','P_psd')
```



```
figure
plotyy(t,m_dot_u_psu,t,P_psu),legend('m_dot_psd_d','P_psd'),title('PSU'),legend('mdot'
```




```
figure
plot(t,T_u,t,T_cr,t,T_d,t,T_psd,t,T_psu)
grid on, grid minor, xlabel('Time [s]'), ylabel('Temperature [K]'), title('Temperature
legend('U','Cr','D','PSD','PSU')
```


Temperatures
U
Cr
D
PSD
PSU
Temperature [K]
Time [s]
550
500
450
400
350
300
250
200
150
100
0
0.005
0.01
0.015
0.02
0.025
0.03