10.0 Appendices

Appendix A

MATLAB®/Simulink® Simulation Models

I: MATLAB SDOF MODELS FOR INITIAL CONTROLLER EVALUATION

1. Models for Passive On and Off Damper Control and No Damper

```
%mrsp1d2.m
% 1-D Approx. of Spencer's 3 Floor Model - Addition of B.W.
%
%clear all
%
global A B E ua alpha0 alpha1 c01 c02 c11 c12 k0 k1 gamma beta Ad nd eta alpha c0 c1 umax
%
%load elcs00e.dat
%load testin.txt
%
%tim=elcs00e(:,1)/5;
%tim=testin(:,1);
%xacc=(elcs00e(:,2)/386.4)*9.81;
%xacc=(testin(:,2)/386.4)*9.81;
%
xacc=(xacc/386.4)*9.81;
ua=[tim xacc];
%
figure(1)
plot(tim,xacc/9.81),title('Base Input')
xlabel('Time-sec'),ylabel('gs'),grid
%
%m=294.9;
%ks=5.16e5;
%cs=125;
g=9.81;
m=113.4;
ks=330087;
omega=sqrt(ks/m);
zeta=0.03;
cs=13.16;
%
A=[0 1 0 0;-ks/m -cs/m 0 0];
B=[0 1/m]';
E=[0 -1]';
%
%umax=2.25;
%umax=0.0;
umax=input('Enter the voltage -> ')
volt=umax;
%volt=0;
%
alpha0=140*100;
alpha1=695*100;
c01=21*100;
c02=3.5*100;
c11=283*100;
c12=2.95*100;
k0=46.9*100;
k1=5*100;
gamma=363*(100^2);
beta=363*(100^2);
Ad=301;
nd=2;
eta=190;
%
alpha=alpha0+alpha1*volt;
c0=c01+c02*volt;
c1=c11+c12*volt;
%
tinc=0.01;
tend=1.498;
timn=0:tinc:tend
%
```

```
x0=zeros(4,1);
tol=1e-3;
trace=0;
t0=0;
tfinal=tend;
%[t,x]=ode45('mr1dode2',t0,tfinal,x0,tol,trace);
[t,x]=ode45('mr1dode2',[t0 tfinal],x0);
%
figure(2)
plot(t,x(:,1)*100),title('Floor Displacement')
xlabel('Time-sec'),ylabel('cm'),grid
%
nt=length(t);
for p=1:nt
   u(p)=m1du2(x(p,:));
end
racc=(-ks/m)*x(:,1)-(cs/m)*x(:,2)+(u'/m);
%
figure(3)
plot(t,racc/9.81),title('Floor gs')
xlabel('Time-sec'),ylabel('gs'),grid
%
acc=racc/g;
rdisp=x(:,1)*100;
max(abs(x(:,1)))*100
max(abs(racc/9.81))

%mr1dode2.m
function xprime=mr1dode2(t,x)
%
global A B E ua alpha0 alpha1 c01 c02 c11 c12 k0 k1 gamma beta Ad nd eta alpha c0 c1
%
t;
xin=table1(ua,t);
u=m1du2(x);
g=yg1d2(x);
%
xprime=[A*x+B*u+E*xin;(1/(c0+c1))*(k0*(x(1)-x(3))+c0*x(2)-alpha*x(4));-gamma*abs(g-
x(2))*x(4)*abs(x(4))^(nd-1)-beta*(g-x(2))*abs(x(4))^nd+Ad*(g-x(2))];

%m1du2.m
%
function uout=m1du2(x)
%
global A B E ua alpha0 alpha1 c01 c02 c11 c12 k0 k1 gamma beta Ad nd eta alpha c0 c1
%
g=yg1d2(x);
uc=alpha*x(4)-k0*(x(1)-x(3))-c0*(x(2)-g)-k0*x(1);
%uc=-c1*g-k1*x(1);
uout=uc;

%yg1d2.m
%
function g=yg1d2(x)
%
global A B E ua alpha0 alpha1 c01 c02 c11 c12 k0 k1 gamma beta Ad nd eta alpha c0 c1
%
g=(1/(c0+c1))*(k0*(x(1)-x(3))+c0*x(2)-alpha*x(4));
```

2. Models for Control Based on Lyapunov Stability Theory

```
%mrsp1d3.m
% 1-D Approx. of Spencer's 3 Floor Model - Addition of B.W. w/Spencer Lyaponov
%
%clear all
%
global A B E ua alpha0 alpha1 c01 c02 c11 c12 k0 k1 gamma beta Ad nd eta umax P eta
%
%load elcs00e.dat
```

```
%load testin.txt
%
%tim=elcs00e(:,1)/5;
%xacc=(elcs00e(:,2)/386.4)*9.81;
%tim=testin(:,1);
%xacc=(testin(:,2)/386.4)*9.81;
%
xacc=(xacc/386.4)*9.81;
ua=[tim xacc];
%
figure(1)
plot(tim,xacc/9.81),title('Base Input')
xlabel('Time-sec'),ylabel('gs'),grid
%
%m=294.9;
%ks=5.16e5;
%cs=125;
g=9.81;
%m=294.84;
%ks=53936;
m=113.4;
ks=330087;
omega=sqrt(ks/m);
zeta=0.1316;
cs=2*zeta*omega*m;
%
A=[0 1 0 0 0;-ks/m -cs/m 0 0 0];
B=[0 1/m]';
E=[0 -1]';
%
umax=2.25;
volt=umax;
%
alpha0=140*100;
alpha1=695*100;
c01=21*100;
c02=3.5*100;
c11=283*100;
c12=2.95*100;
k0=46.9*100;
k1=5*100;
gamma=363*(100^2);
beta=363*(100^2);
Ad=301;
nd=2;
eta=190;
%
% P Determination
At=[0 1;-ks/m -cs/m];
Qp=[1e-6 0;0 10];
P=lyap(At,Qp);
%
tinc=0.01;
%tend=2.25;
tend=1.499;
timn=0:tinc:tend;
%
x0=zeros(5,1);
tol=1e-3;
trace=0;
t0=0;
tfinal=tend;
%[t,x]=ode45('mr1dode3',t0,tfinal,x0,tol,trace);
[t,x]=ode45('mr1dode3',[t0 tfinal],x0);
%
figure(2)
plot(t,x(:,1)*100),title('Floor Displacement')
xlabel('Time-sec'),ylabel('cm'),grid
%
nt=length(t);
for p=1:nt
```

```
   u(p)=m1du3(x(p,:));
end
racc=(-ks/m)*x(:,1)-(cs/m)*x(:,2)+(u'/m);
%
figure(3)
plot(t,racc/9.81),title('Floor gs')
xlabel('Time-sec'),ylabel('gs'),grid
%
figure(4)
plot(t,x(:,5)),title('Control Voltage')
xlabel('Time-sec'),ylabel('gs'),grid
acc=racc/g;
rdisp=x(:,1)*100;
max(abs(x(:,1)))*100
max(abs(racc/9.81))

%mr1dode3.m
function xprime=mr1dode3(t,x)
%
global A B E ua alpha0 alpha1 c01 c02 c11 c12 k0 k1 gamma beta Ad nd eta P umax
%
t;
xin=table1(ua,t);
vc=usplya(x);
u=m1du3(x);
g=yg1d3(x);
%
xprime=[A*x+B*u+E*xin;(1/((c01+c11)+(c02+c12)*x(5)))*(k0*(x(1)-x(3))+(c01+c02*x(5))*x(2)-
(alpha0+alpha1*x(5))*x(4));-gamma*abs(g-x(2))*x(4)*abs(x(4))^(nd-1)-beta*(g-
x(2))*abs(x(4))^nd+Ad*(g-x(2));-eta*(x(5)-vc)];

%m1du3.m
%
function uout=m1du3(x)
%
global A B E ua alpha0 alpha1 c01 c02 c11 c12 k0 k1 gamma beta Ad nd eta P umax
%
g=yg1d3(x);
uc=(alpha0+alpha1*x(5))*x(4)-k0*(x(1)-x(3))-(c01+c02*x(5))*(x(2)-g)-k0*x(1);
%uc=-(c11+c12*x(5))*g-k1*x(1);
uout=uc;

%usplya.m
%
function vout=usplya(x)
%
global A B E ua alpha0 alpha1 c01 c02 c11 c12 k0 k1 gamma beta Ad nd eta umax P eta
%
fb=m1du3(x);
z=[x(1) x(2)]';
test=-z'*P*B*fb;
if test>0
   v=umax;
else
   v=0;
end
vout=v;

%yg1d3.m
%
function g=yg1d3(x)
%
global A B E ua alpha0 alpha1 c01 c02 c11 c12 k0 k1 gamma beta Ad nd eta P umax
%
g=(1/((c01+c11)+(c02+c12)*x(5)))*(k0*(x(1)-x(3))+(c01+c02*x(5))*x(2)-
(alpha0+alpha1*x(5))*x(4));
```

3. Models for Decentralized Bang-Bang Control

```
%mrsp1d4.m
% 1-D Approx. of Spencer's 3 Floor Model - Addition of B.W. w/Spencer Decentralized Bang-
Bang Control
%
%clear all
%
global A B E ua alpha0 alpha1 c01 c02 c11 c12 k0 k1 gamma beta Ad nd eta umax P eta uv
gam
%
%load elcsint.dat
%load testin.txt
%
%tim=elcsint(:,1)/5;
%tim=testin(:,1);
%xvin=elcsint(:,3)/100;
%xvin=testin(:,3)/100;
%xacc=elcsint(:,4)/100;
%xacc=testin(:,4)/100;
%
xacc=(xacc/386.4)*9.81;
xvin=xvin*.0254;
uv=[tim xvin];
ua=[tim xacc];
%
figure(1)
plot(tim,xacc/9.81),title('Base Input')
xlabel('Time-sec'),ylabel('gs'),grid
%
%m=294.9;
%ks=5.16e5;
%cs=125;
g=9.81;
m=294.84;
ks=53936;
omega=sqrt(ks/m);
zeta=0.03;
cs=2*zeta*omega*m;
%
A=[0 1 0 0 0;-ks/m -cs/m 0 0 0];
B=[0 1/m]';
E=[0 -1]';
gam=1;
%
umax=2.25;
volt=umax;
%
alpha0=140*100;
alpha1=695*100;
c01=21*100;
c02=3.5*100;
c11=283*100;
c12=2.95*100;
k0=46.9*100;
k1=5*100;
gamma=363*(100^2);
beta=363*(100^2);
Ad=301;
nd=2;
eta=190;
%
tinc=0.01;
tend=1.498;
timn=0:tinc:tend;
%
x0=zeros(5,1);
tol=1e-3;
trace=0;
t0=0;
tfinal=tend;
%[t,x]=ode45('mr1dode4',t0,tfinal,x0,tol,trace);
[t,x]=ode45('mr1dode4',[t0 tfinal],x0);
```

```
%
figure(2)
plot(t,x(:,1)*100),title('Floor Displacement')
xlabel('Time-sec'),ylabel('cm'),grid
%
nt=length(t);
for p=1:nt
   u(p)=m1du4(x(p,:));
end
racc=(-ks/m)*x(:,1)-(cs/m)*x(:,2)+(u'/m);
%
figure(3)
plot(t,racc/9.81),title('Floor gs')
xlabel('Time-sec'),ylabel('gs'),grid
%
figure(4)
plot(t,x(:,5)),title('Control Voltage')
xlabel('Time-sec'),ylabel('gs'),grid
acc=racc/g;
rdisp=x(:,1)*100;
j=1;
   for i=1:nt
      if i==j*10
         t2(j+1)=t(i);
         acc2(j+1)=acc(i);
         rdisp2(j+1)=rdisp(i);
         j=j+1;
      end
   end
   t2=t2';
%end
t=t2;
acc=acc2';
rdisp=rdisp2';
max(abs(x(:,1)))*100
max(abs(racc))*100
max(abs(u))

%mr1dode4.m
function xprime=mr1dode4(t,x)
%
global A B E uv ua gam alpha0 alpha1 c01 c02 c11 c12 k0 k1 gamma beta Ad nd eta P umax
%
t
xin=table1(ua,t);
vc=usbang1d(x,t);
u=m1du4(x);
g=yg1d4(x);
%
xprime=[A*x+B*u+E*xin;(1/((c01+c11)+(c02+c12)*x(5)))*(k0*(x(1)-x(3))+(c01+c02*x(5))*x(2)-
(alpha0+alpha1*x(5))*x(4));-gamma*abs(g-x(2))*x(4)*abs(x(4))^(nd-1)-beta*(g-
x(2))*abs(x(4))^nd+Ad*(g-x(2));-eta*(x(5)-vc)];

%m1du4.m
%
function uout=m1du4(x)
%
global A B E uv ua gam alpha0 alpha1 c01 c02 c11 c12 k0 k1 gamma beta Ad nd eta P umax
%
g=yg1d4(x);
uc=(alpha0+alpha1*x(5))*x(4)-k0*(x(1)-x(3))-(c01+c02*x(5))*(x(2)-g)-k0*x(1);
%uc=-(c11+c12*x(5))*g-k1*x(1);
uout=uc;

%usbang1d.m
%
function vout=usbang1d(x,t)
%
global A B E uv ua gam alpha0 alpha1 c01 c02 c11 c12 k0 k1 gamma beta Ad nd eta umax P
eta
%
```

```
fb=m1du4(x);
xgv=table1(uv,t);
xdot=x(2);
test=-(xdot+gam*xgv)'*gam*fb;
if test>0
   v=umax;
else
   v=0;
end
vout=v;

%yg1d4.m
%
function g=yg1d4(x)
%
global A B E uv ua gam alpha0 alpha1 c01 c02 c11 c12 k0 k1 gamma beta Ad nd eta P umax
%
g=(1/((c01+c11)+(c02+c12)*x(5)))*(k0*(x(1)-x(3))+(c01+c02*x(5))*x(2)-
(alpha0+alpha1*x(5))*x(4));
```

4. Models for Modulated Homogeneous Friction Control

```
%mrsp1d5.m
% 1-D Approx. of Spencer's 3 Floor Model - Addition of B.W. w/Spencer Modulated
Homogeneous Friction Control
%
%clear all
%
global A B E ua alpha0 alpha1 c01 c02 c11 c12 k0 k1 gamma beta Ad nd eta umax eta uv gam
gn xstr vtol
%
%load elcs00e.dat
%load testin.txt
%
%tim=elcs00e(:,1)/5;
%xacc=(elcs00e(:,2)/386.4)*9.81;
%tim=testin(:,1);
%xacc=(testin(:,2)/386.4)*9.81;
%
xacc=(xacc/386.1)*9.81;
ua=[tim xacc];
%
figure(1)
plot(tim,xacc/9.81),title('Base Input')
xlabel('Time-sec'),ylabel('gs'),grid
%
%m=294.9;
%ks=5.16e5;
%cs=125;
g=9.81;
m=294.84;
ks=53936;
omega=sqrt(ks/m);
zeta=0.03;
cs=2*zeta*omega*m;
%
A=[0 1 0 0 0;-ks/m -cs/m 0 0 0];
B=[0 1/m]';
E=[0 -1]';
gam=1;
%
gn=5e6;
xstr=0;
vtol=1e-3;
umax=2.25;
volt=umax;
%
alpha0=140*100;
alpha1=695*100;
```

```
c01=21*100;
c02=3.5*100;
c11=283*100;
c12=2.95*100;
k0=46.9*100;
k1=5*100;
gamma=363*(100^2);
beta=363*(100^2);
Ad=301;
nd=2;
eta=190;
%
tinc=0.01;
tend=1.498;
timn=0:tinc:tend;
%
x0=zeros(5,1);
tol=1e-3;
trace=0;
t0=0;
tfinal=tend;
%[t,x]=ode45('mr1dode5',t0,tfinal,x0,tol,trace);
[t,x]=ode45('mr1dode5',[t0 tfinal],x0);
%
figure(2)
plot(t,x(:,1)*100),title('Floor Displacement')
xlabel('Time-sec'),ylabel('cm'),grid
%
nt=length(t);
for p=1:nt
   u(p)=m1du5(x(p,:));
end
racc=(-ks/m)*x(:,1)-(cs/m)*x(:,2)+(u'/m);
%
figure(3)
plot(tim,xacc/9.81,t,racc/9.81),title('Floor gs')
xlabel('Time-sec'),ylabel('gs'),grid
%
figure(4)
plot(t,x(:,5)),title('Control Voltage')
xlabel('Time-sec'),ylabel('gs'),grid
acc=racc/g;
rdisp=x(:,1)*100;
j=1;
   for i=1:nt
      if i==j*10
         t2(j+1)=t(i);
         acc2(j+1)=acc(i);
         rdisp2(j+1)=rdisp(i);
         j=j+1;
      end
   end
   t2=t2';
%end
t=t2;
acc=acc2';
rdisp=rdisp2';
max(abs(x(:,1)))*100
max(abs(racc/9.81))
max(abs(u))

%mr1dode5.m
function xprime=mr1dode5(t,x)
%
global A B E ua gam alpha0 alpha1 c01 c02 c11 c12 k0 k1 gamma beta Ad nd eta umax
%
t
xin=table1(ua,t);
vc=usmfr1d(x);
u=m1du5(x);
g=yg1d5(x);
```

```
%
xprime=[A*x+B*u+E*xin;(1/((c01+c11)+(c02+c12)*x(5)))*(k0*(x(1)-x(3))+(c01+c02*x(5))*x(2)-
(alpha0+alpha1*x(5))*x(4));-gamma*abs(g-x(2))*x(4)*abs(x(4))^(nd-1)-beta*(g-
x(2))*abs(x(4))^nd+Ad*(g-x(2));-eta*(x(5)-vc)];

%m1du5.m
%
function uout=m1du5(x)
%
global A B E ua gam alpha0 alpha1 c01 c02 c11 c12 k0 k1 gamma beta Ad nd eta umax
%
g=yg1d5(x);
uc=(alpha0+alpha1*x(5))*x(4)-k0*(x(1)-x(3))-(c01+c02*x(5))*(x(2)-g)-k0*x(1);
%uc=-(c11+c12*x(5))*g-k1*x(1);
uout=uc;

%usmfr1d.m
%
function vout=usmfr1d(x,t)
%
global A B E ua gam alpha0 alpha1 c01 c02 c11 c12 k0 k1 gamma beta Ad nd eta umax eta
xstr vtol gn
%
fb=m1du5(x);
if abs(x(2))<=vtol
   xstr=x(1);
end
fc=gn*xstr;
test=fc-abs(fb);
if test>0
   v=umax;
else
   v=0;
end
vout=v;

%yg1d5.m
%
function g=yg1d5(x)
%
global A B E ua gam alpha0 alpha1 c01 c02 c11 c12 k0 k1 gamma beta Ad nd eta umax
%
g=(1/((c01+c11)+(c02+c12)*x(5)))*(k0*(x(1)-x(3))+(c01+c02*x(5))*x(2)-
(alpha0+alpha1*x(5))*x(4));
```

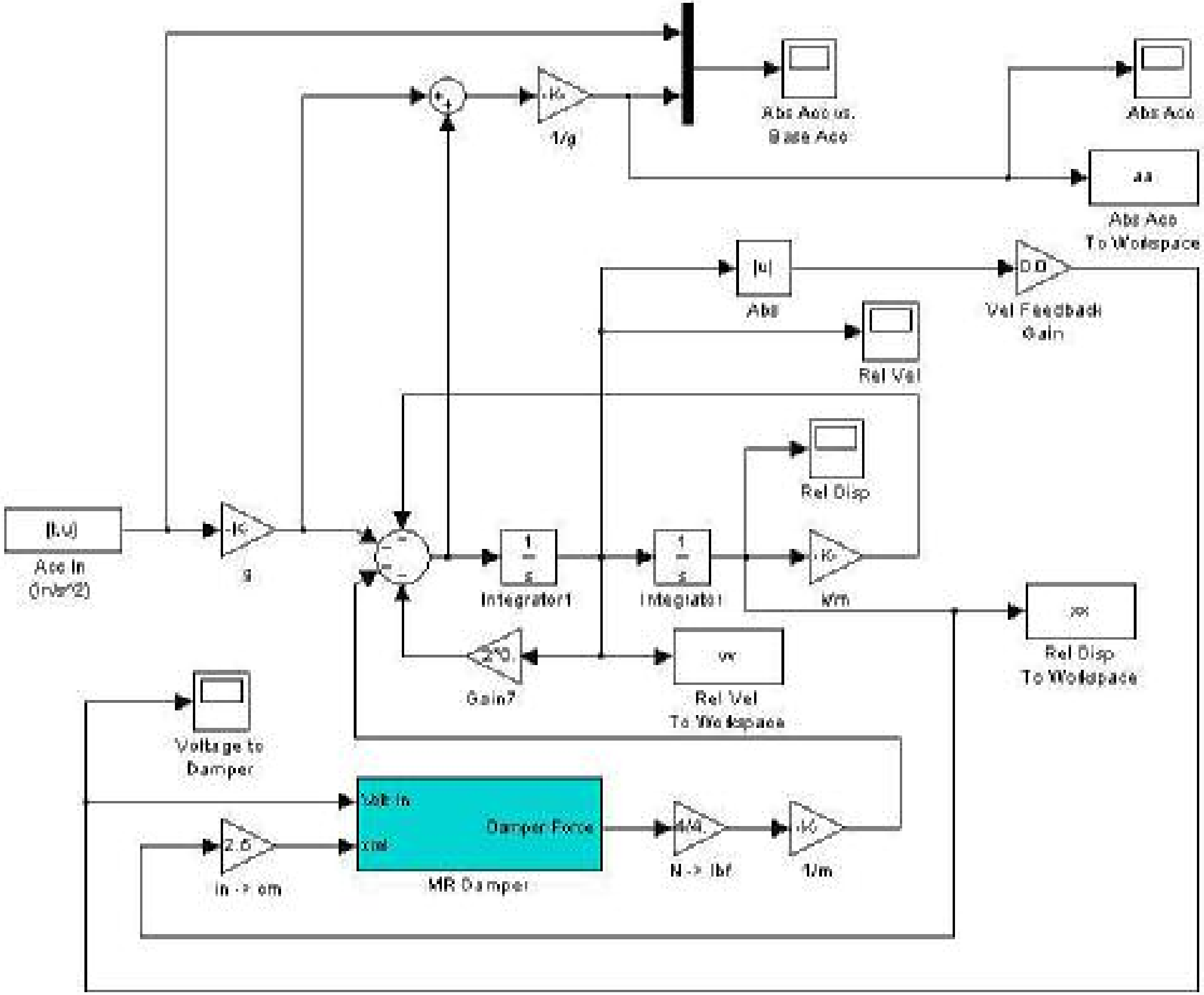
5. Models for Clipped Optimal Control

```
%mrsp1d6.m
% 1-D Approx. of Spencer's 3 Floor Model - Addition of B.W. w/Spencer Clipped Optimal
Control
%
%clear all
%
global A B C D E ua alpha0 alpha1 c01 c02 c11 c12 k0 k1 gamma beta Ad nd eta umax eta uv
gam gn xstr vtol
%
%load elcs00e.dat
%
%tim=elcs00e(:,1)/5;
%xacc=(elcs00e(:,2)/386.4)*9.81;
%
xacc=(xacc/386.4)*9.81;
ua=[tim xacc];
%
figure(1)
plot(tim,xacc/9.81),title('Base Input')
xlabel('Time-sec'),ylabel('gs'),grid
%
%m=294.9;
```

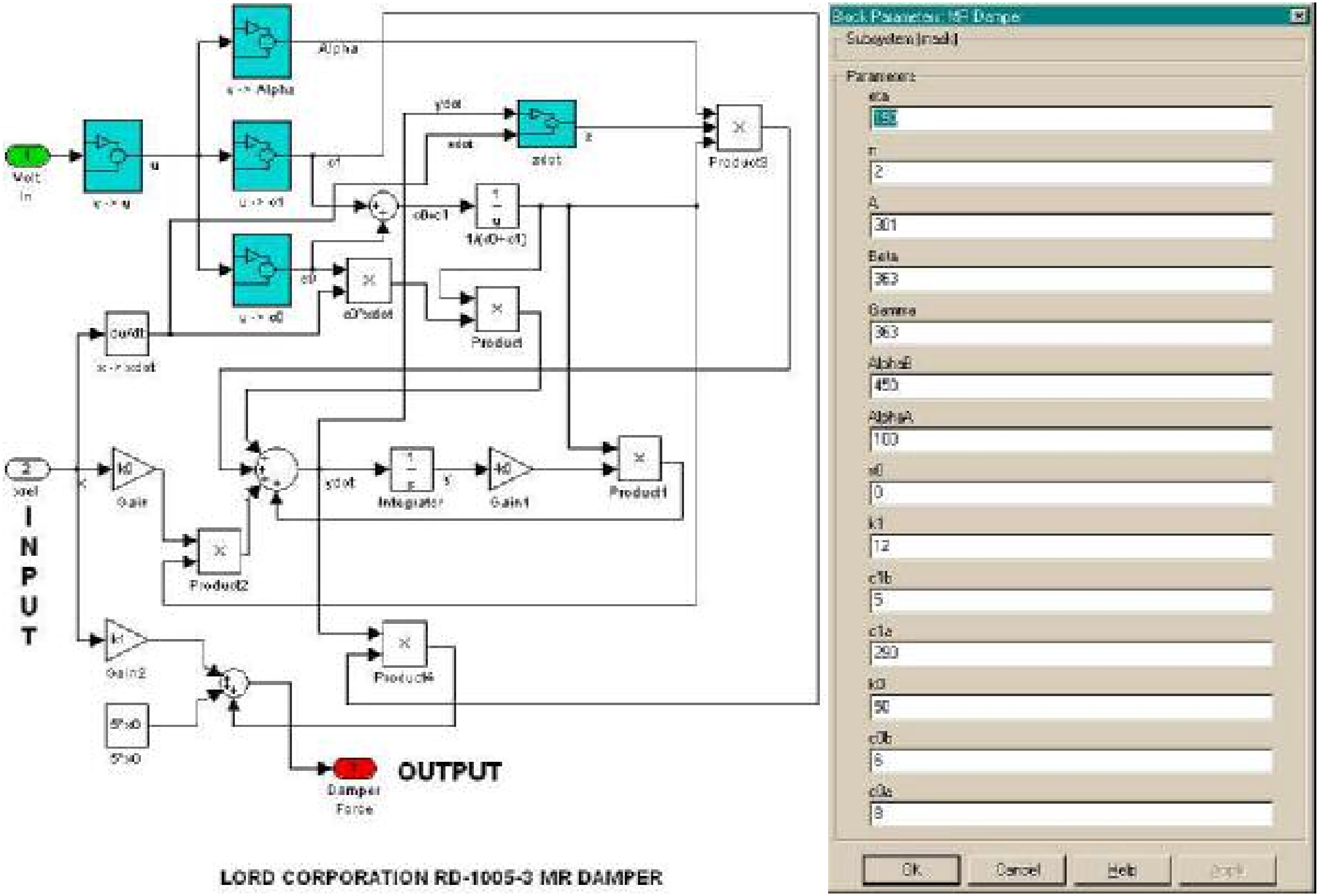
```
%ks=5.16e5;
%cs=125;
g=9.81;
m=294.84;
ks=53936;
omega=sqrt(ks/m);
zeta=0.03;
cs=2*zeta*omega*m;
%
A=[0 1;-ks/m -cs/m];
B=[0 1/m]';
C=[-ks/m -cs/m;1 0];
E=[0 -1]';
gam=1;
D=[m^(-1)*gam 0]';
%
gn=5e6;
xstr=0;
vtol=1e-3;
umax=2.25;
volt=umax;
%
alpha0=140*100;
alpha1=695*100;
c01=21*100;
c02=3.5*100;
c11=283*100;
c12=2.95*100;
k0=46.9*100;
k1=5*100;
gamma=363*(100^2);
beta=363*(100^2);
Ad=301;
nd=2;
eta=190;
%
tinc=0.01;
tend=1.498;
timn=0:tinc:tend;
%
x0=zeros(5,1);
tol=1e-3;
trace=0;
t0=0;
tfinal=tend;
%[t,x]=ode45('mr1dode6',t0,tfinal,x0,tol,trace);
[t,x]=ode45('mr1dode6',[t0 tfinal],x0);
%
figure(2)
plot(t,x(:,1)*100),title('Floor Displacement')
xlabel('Time-sec'),ylabel('cm'),grid
%
nt=length(t);
for p=1:nt
   u(p)=m1du6(x(p,:));
end
racc=(-ks/m)*x(:,1)-(cs/m)*x(:,2)+(u'/m);
%
figure(3)
plot(t,racc/9.81),title('Floor gs')
xlabel('Time-sec'),ylabel('gs'),grid
%
figure(4)
plot(t,x(:,5)),title('Control Voltage')
xlabel('Time-sec'),ylabel('gs'),grid
max(abs(x(:,1)))*100
max(abs(racc))*100
max(abs(u))
acc=racc'/g;
rdisp=x(:,1)*100;
j=1;
```

```
   for i=1:nt
      if i==j*10
         t2(j+1)=t(i);
         acc2(j+1)=acc(i);
         rdisp2(j+1)=rdisp(i);
         j=j+1;
      end
   end
   t2=t2';
%end
t=t2;
acc=acc2';
rdisp=rdisp2';
%
%tout=0:0.01:tend;
%rtab=[t x(:,1)*100];
%atab=[t racc];
%ftab=[t u'];
%vtab=[t x(:,5)];
%rt=table1(rtab,tout');
%at=table1(atab,tout');
%ft=table1(ftab,tout');
%vt=table1(vtab,tout');
%M1=[t x(:,1)*100 racc u' x(:,5)];
%M1=[tout' rt at ft vt];
%dlmwrite('spm1d6.txt',M1)

%mr1dode6.m
function xprime=mr1dode6(t,x)
%
global A B C D E ua gam alpha0 alpha1 c01 c02 c11 c12 k0 k1 gamma beta Ad nd eta umax
%
t
xin=table1(ua,t);
vc=usclip1d(x);
u=m1du6(x);
g=yg1d6(x);
%
xprime=[A*x+B*u+E*xin;(1/((c01+c11)+(c02+c12)*x(5)))*(k0*(x(1)-x(3))+(c01+c02*x(5))*x(2)-
(alpha0+alpha1*x(5))*x(4));-gamma*abs(g-x(2))*x(4)*abs(x(4))^(nd-1)-beta*(g-
x(2))*abs(x(4))^nd+Ad*(g-x(2));-eta*(x(5)-vc)];

%m1du6.m
%
function uout=m1du6(x)
%
global A B C D E ua gam alpha0 alpha1 c01 c02 c11 c12 k0 k1 gamma beta Ad nd eta umax
%
g=yg1d6(x);
uc=(alpha0+alpha1*x(5))*x(4)-k0*(x(1)-x(3))-(c01+c02*x(5))*(x(2)-g)-k0*x(1);
%uc=-(c11+c12*x(5))*g-k1*x(1);
uout=uc;

%usclip1d.m
%
function vout=usclip1d(x,t)
%
global A B C D E ua gam alpha0 alpha1 c01 c02 c11 c12 k0 k1 gamma beta Ad nd eta umax eta
xstr vtol gn
%
fb=m1du6(x);
kc=[4.71593e10+3.62558e12 -7e4+1.86668e9 -1.33297e8-(3.23387e10)/5];
y=C*x(1:2)+D*fb;
xst=[y' fb]';
fc=-kc*xst;
test=(fc-fb)*fb;
if test>0
   v=umax;
else
   v=0;
end
```

```
vout=v;

%yg1d6.m
%
function g=yg1d6(x)
%
global A B C D E ua gam alpha0 alpha1 c01 c02 c11 c12 k0 k1 gamma beta Ad nd eta umax
%
g=(1/((c01+c11)+(c02+c12)*x(5)))*(k0*(x(1)-x(3))+(c01+c02*x(5))*x(2)-
(alpha0+alpha1*x(5))*x(4));
```



II: SIMPLIFIED SDOF MRAM MODEL



Parameters

eta
190

n
2

A
301

Beta
363

Gamma
363

AlphaB
450

AlphaA
100

x0
0

k1
12

c1b
5

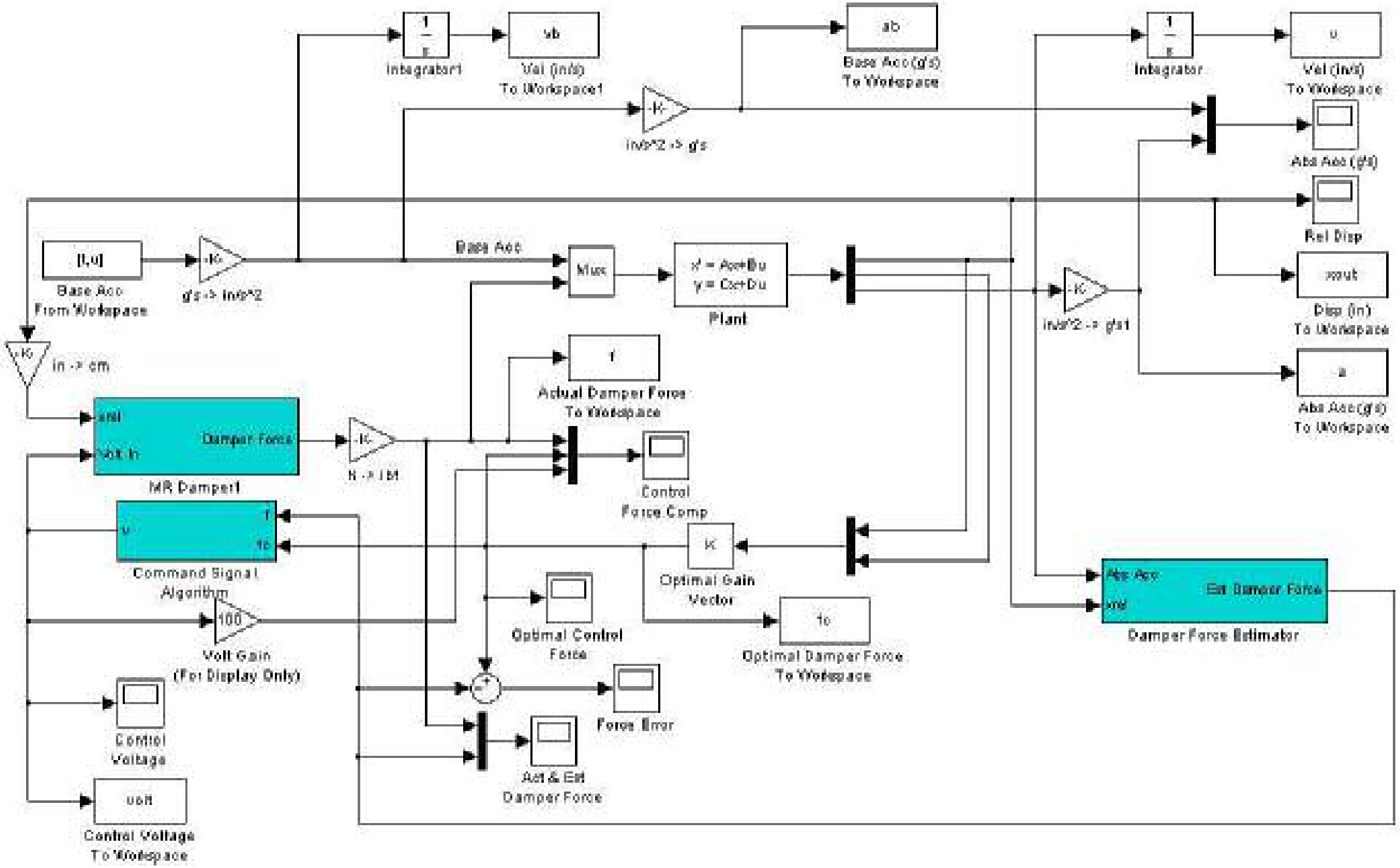
c1a
290

k0
50

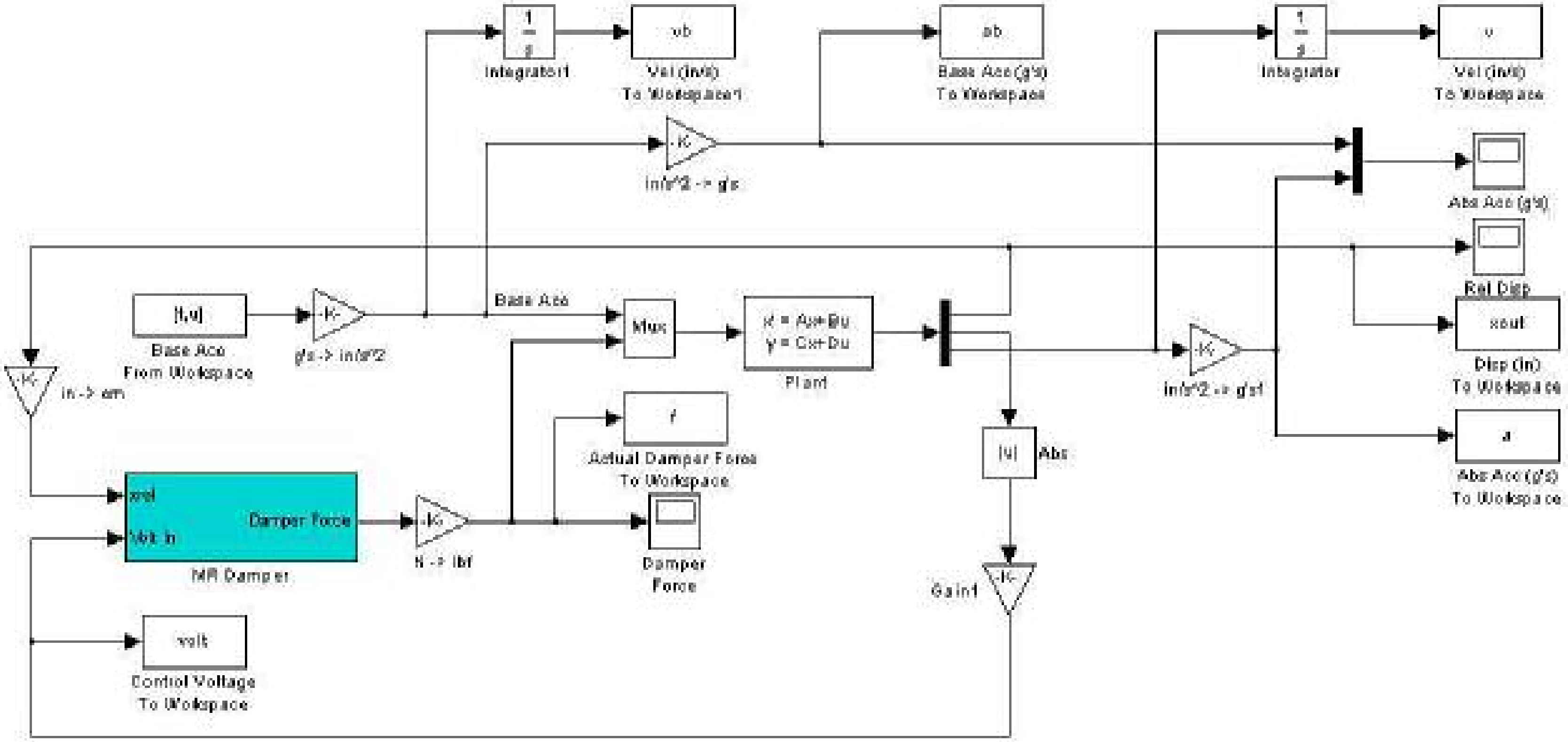
c0b
6

c0a
8

III: MR DAMPER MODEL AND PARAMETER MASK



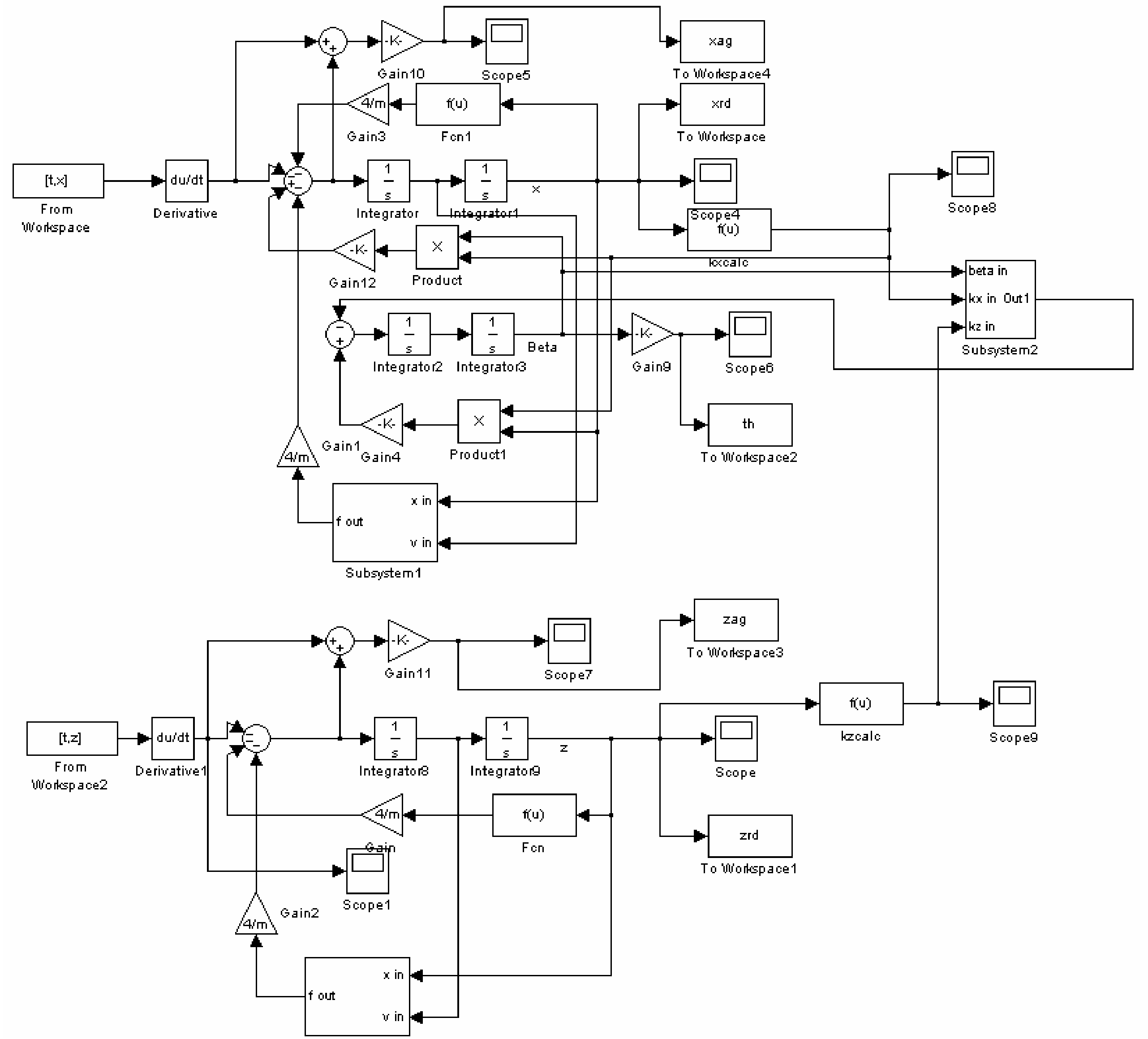
IV: STATE-SPACE SDOF MRAM MODEL (LQR OPTIMAL CONTROL)



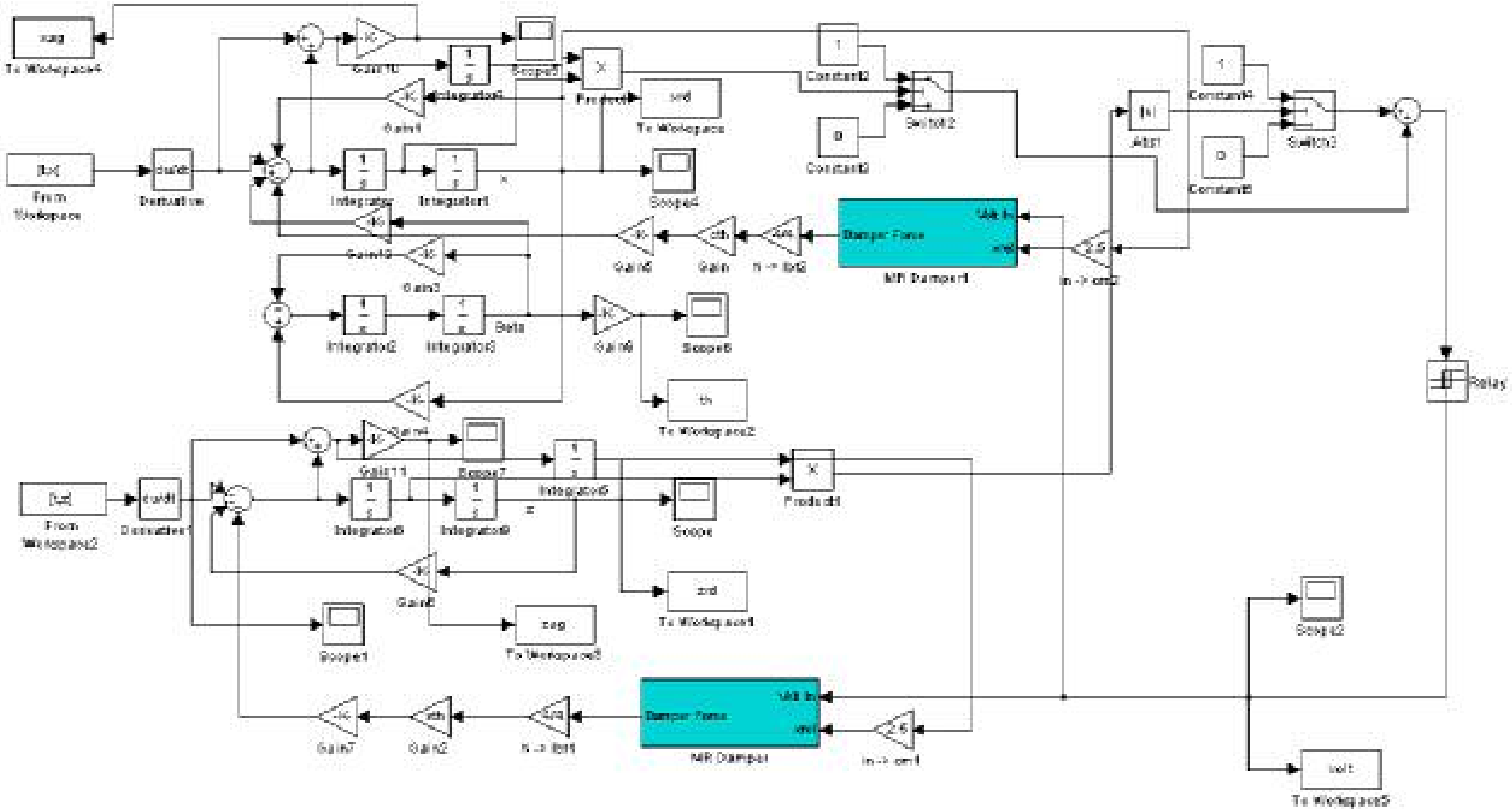
V: STATE-SPACE SDOF MRAM MODEL (VELOCITY FEEDBACK CONTROL)

VI: MATLAB DATA LOADER CODE FOR SDOF STATE-SPACE MODELS

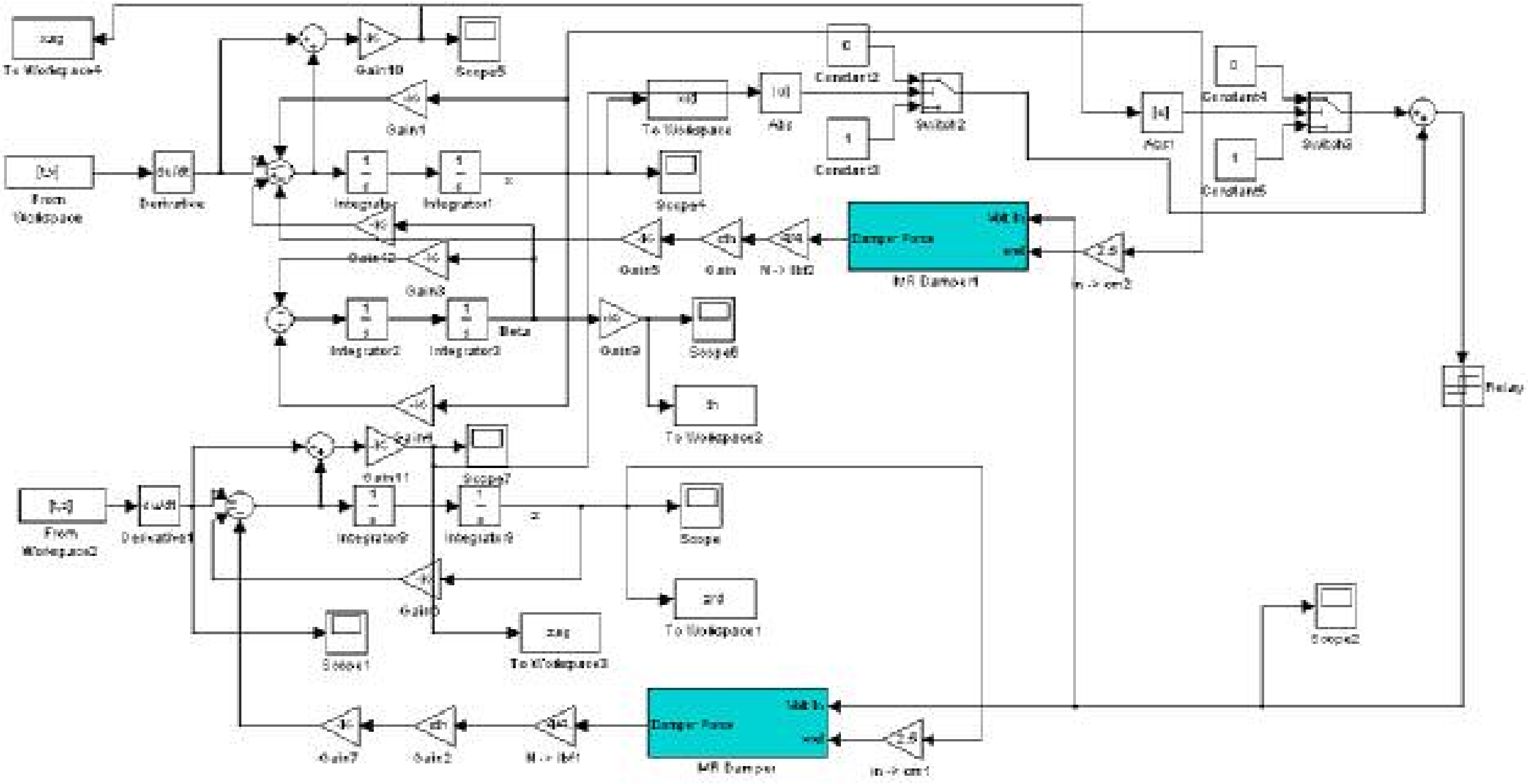
```
% State space model of air spring with MR damper.  LQR control design with output weighing.
% For use with MRAirClippedFSF.mdl
% Written by Troy Tanner
% June 19, 2001
%
%clear all
%
% Isolated mass
m=977/386.1; %LM Cabinet = 730 lb, Old = 990 lb
%
% Air Spring Parameters
omega=sqrt(515/m);
f=omega/2/pi
zeta=0.03; % Air spring damping ratio
%
% Define state space model of the plant (State 1 = relative displacement, State 2 = relative velocity)
Ac=[0 1;-omega^2 -2*zeta*omega];
Bc=[0;-1/m];
Cc=[1 0;-omega^2 -2*zeta*omega];
Dc=Bc;
E=[0;-1];
%B=[Bc E];
B=[E Bc];
A=Ac;
C=[1 0;0 1;-omega^2 -2*zeta*omega];
D=[0 0;0 0;0 -1/m];
% Define state space controller
Q=[800000 0;0 1]; % Weighing function
R=0.3;
sysc=ss(Ac,Bc,Cc,Dc); % Continuous system
ctype=input('Enter (1) for analog, (2) for digital -> ');
if ctype==2
   fs=input('Enter the sampling frequency -> ');
   Ts=1/fs;
   sysd=c2d(sysc,Ts,'zoh'); % Discrete system
end
if ctype==1
   G=lqry(sysc,Q,R) % Optimal gain with output weighing (Continuous system)
else
   G=lqry(sysd,Q,R) % Optimal gain with output weighing (Discrete system)
end
```



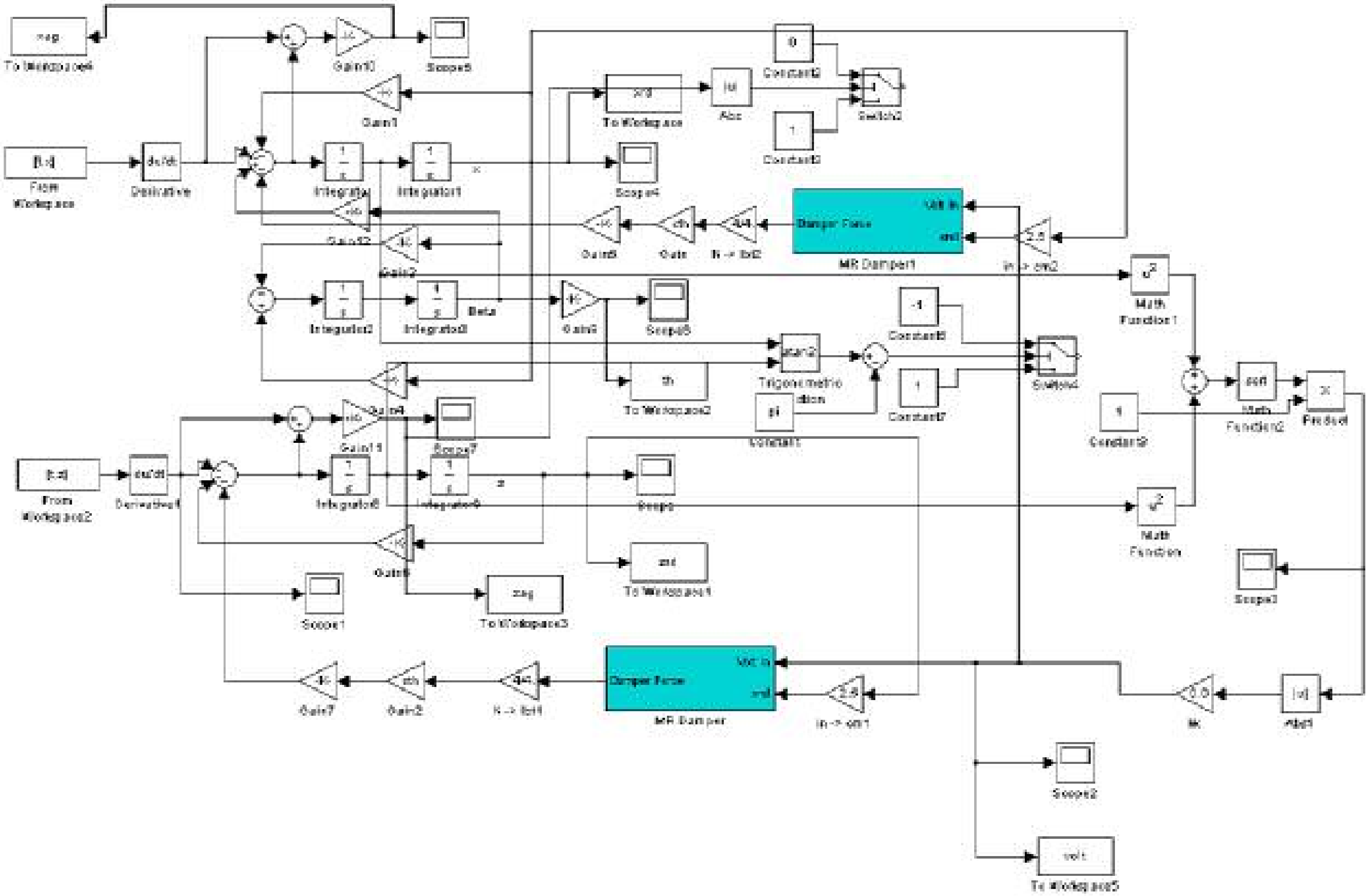
VII: 3DOF MODEL WITH PASSIVE MOUNT



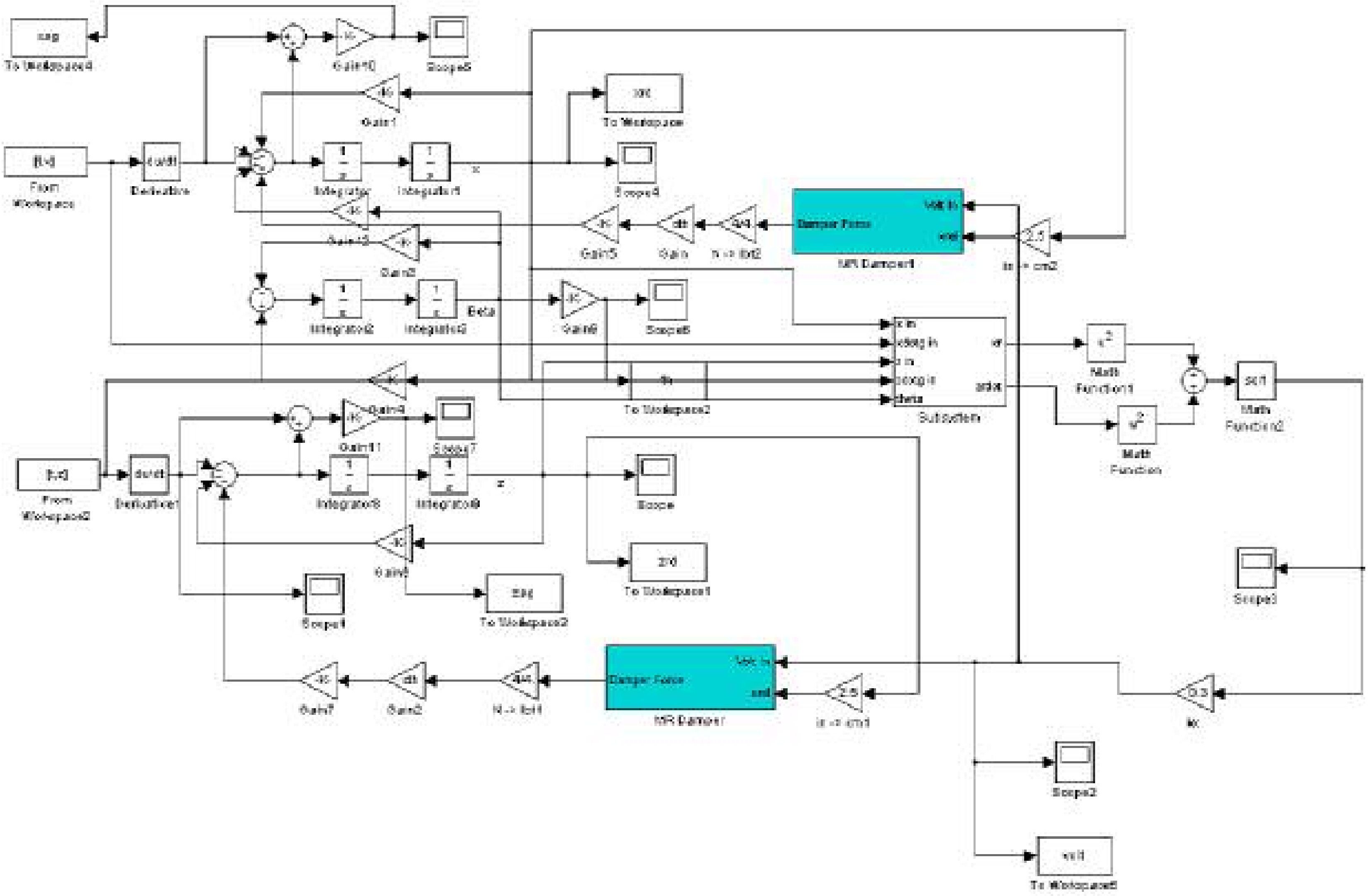
VIII: 3DOF MODEL WITH SKYHOOK CONTROL



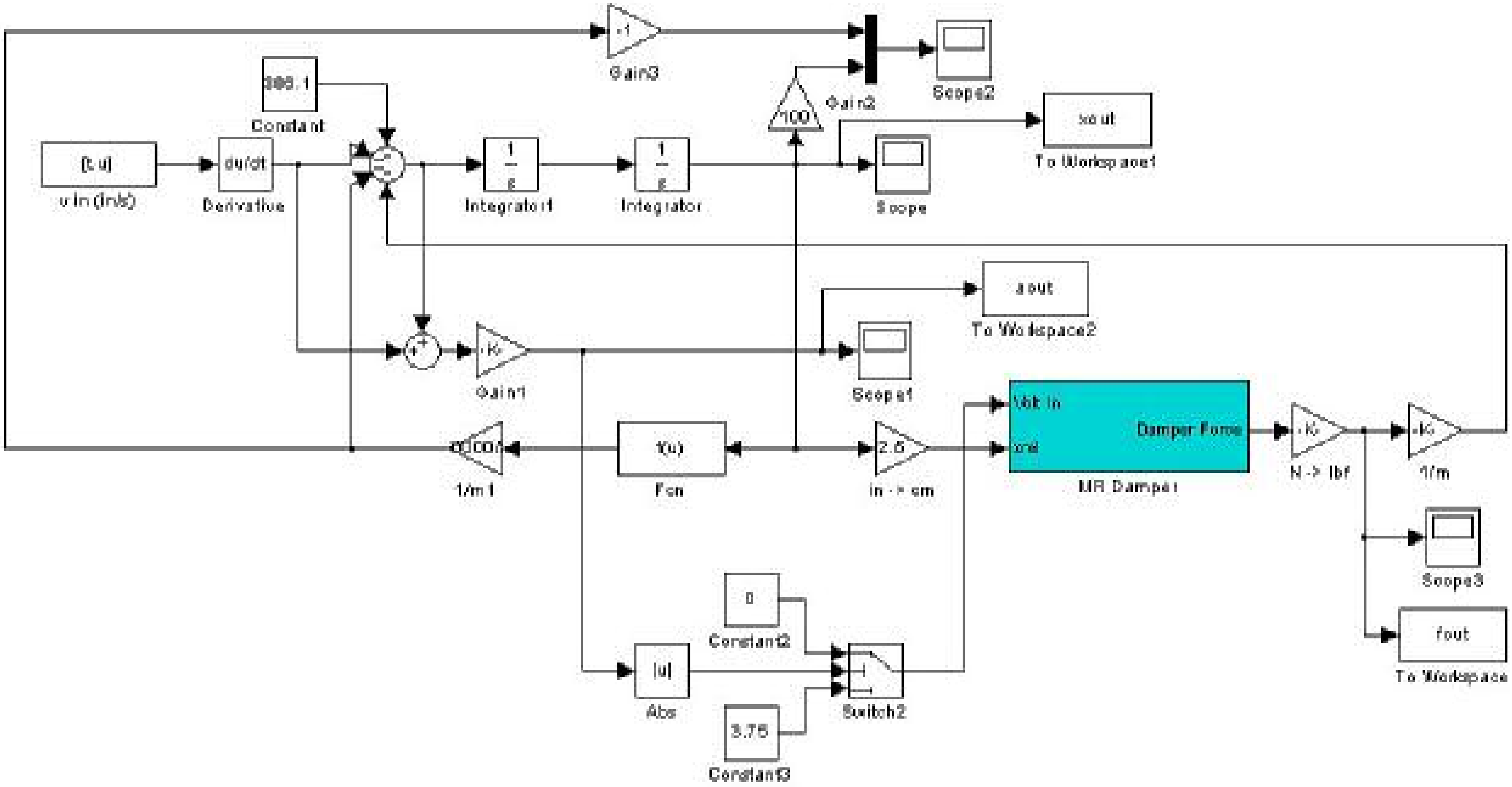
IV: 3DOF MODEL WITH ACCELERATION BANG-BANG CONTROL



X: 3DOF MODEL WITH VELOCITY FEEDBACK CONTROLLER #1



XI: 3DOF MODEL WITH VELOCITY FEEDBACK CONTROLLER #2



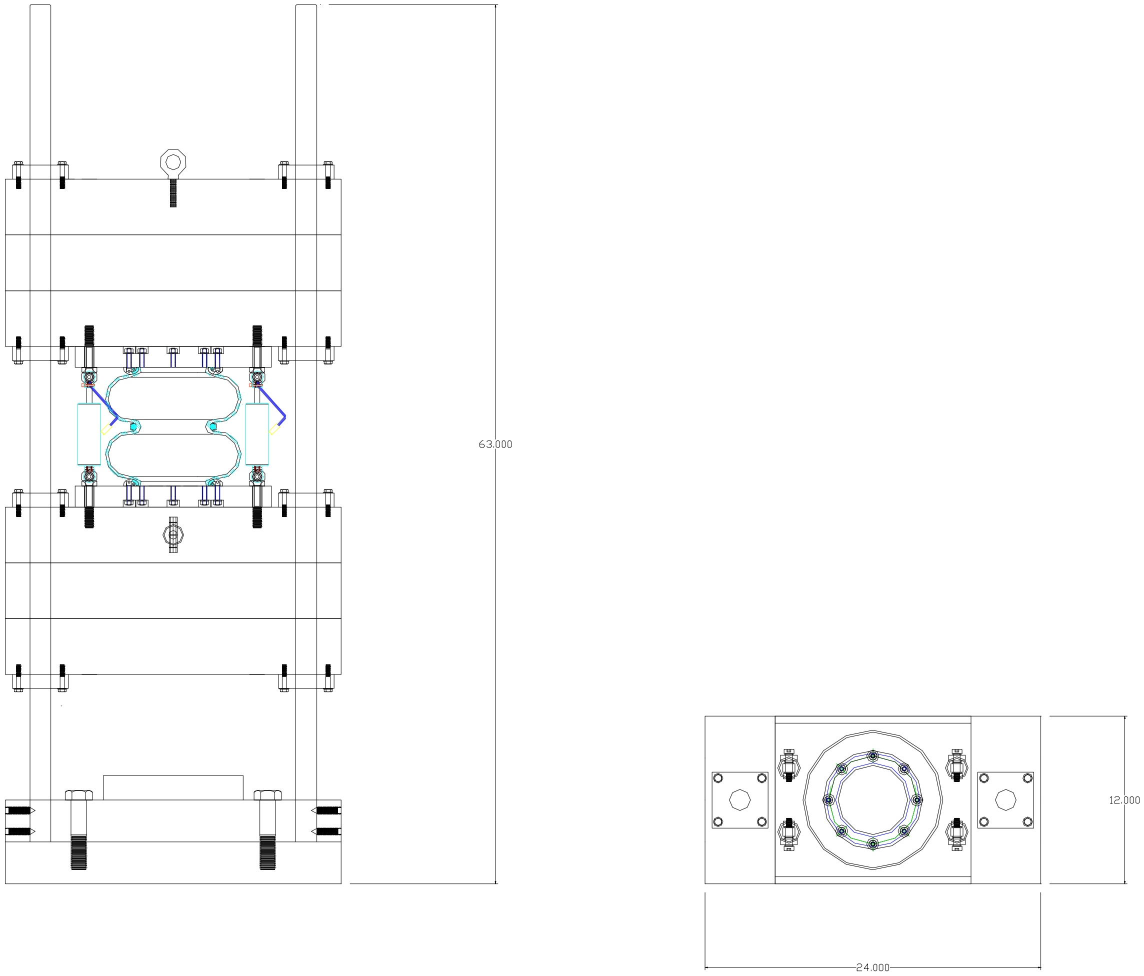
XII: SDOF MODEL (MR DAMPER WITH LPAM AS SPRING ELEMENT)

XIII: DATA LOADER FOR 3DOF MODELS

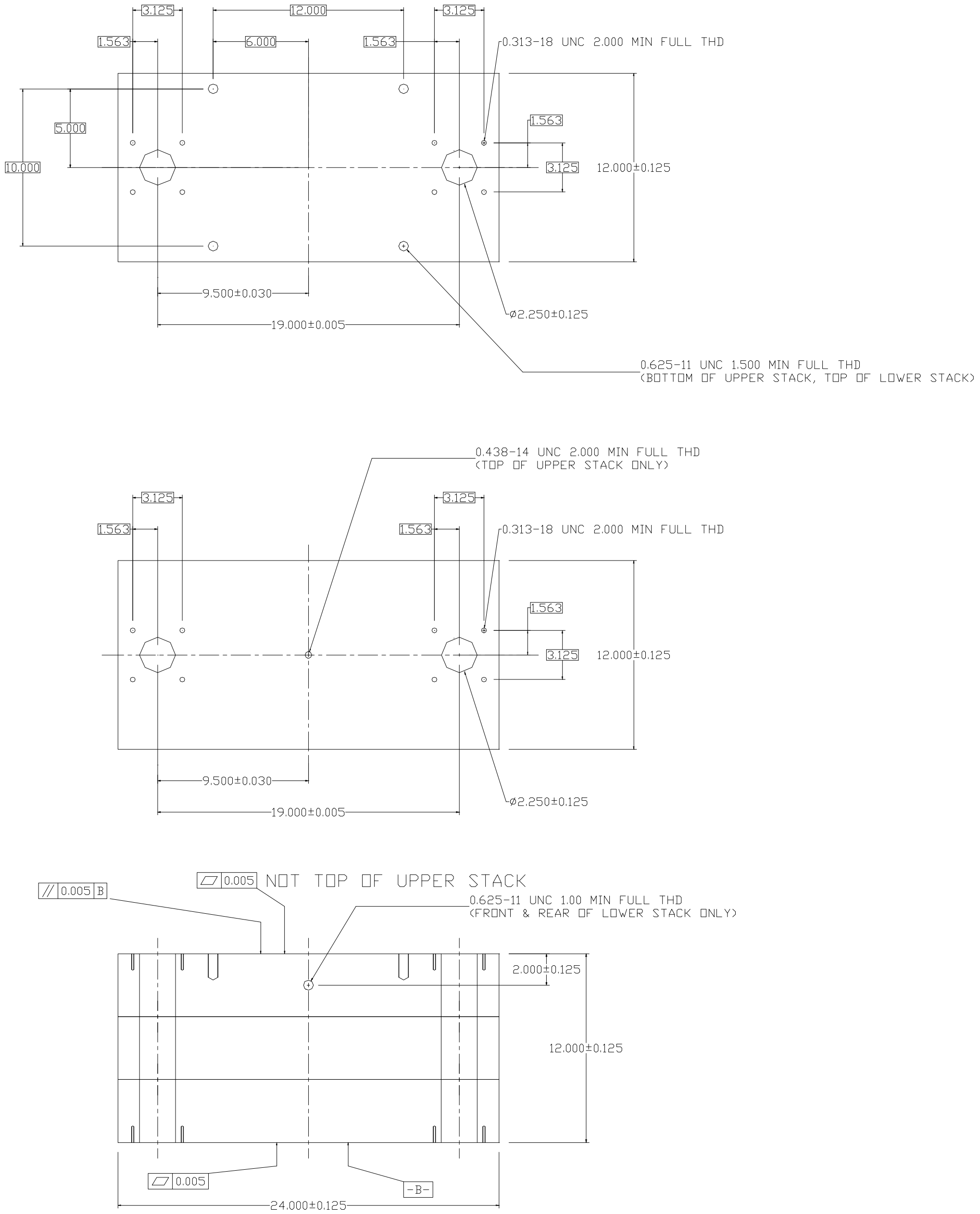
```
% MRAM 3DOF Data Loader
weight=1000;
m=weight/386.1;
theta=71.5*pi/180;
cth=cos(theta);
sth=sin(theta);
dampon=input('Enter (0) to turn dampers off, (1) to turn dampers on -> ');
height=72;
width=24;
depth=24;
r=sqrt(width^2+height^2);
ax=width/2;
ay=depth/2;
az=height/2;
f=2; %Old = 2.27
k=(2*pi*f)^2*m;
%kz=(2*pi*f)^2*m;
%kx=0.4*kz;
kx=k*cos(theta);
kz=k*sin(theta);
fzcalc=sqrt(kz*2/m)/2/pi
fxcalc=sqrt(kx*2/m)/2/pi
%ky=0.4*kz;
Iyy=(1/12)*m*(width^2+height^2);
Ixx=(1/12)*m*(depth^2+height^2);
```

Appendix B

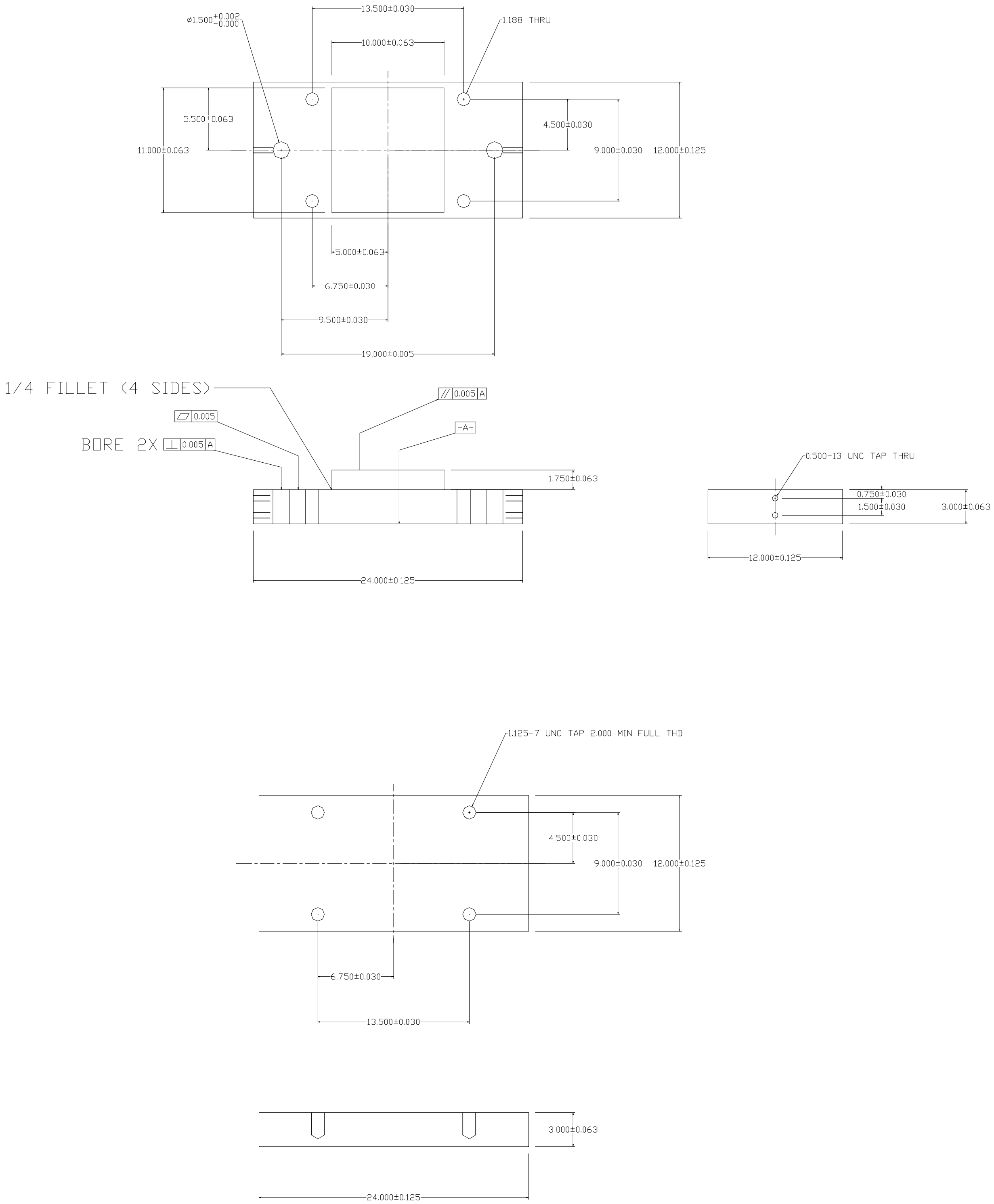
Drop Test Fixture Drawings



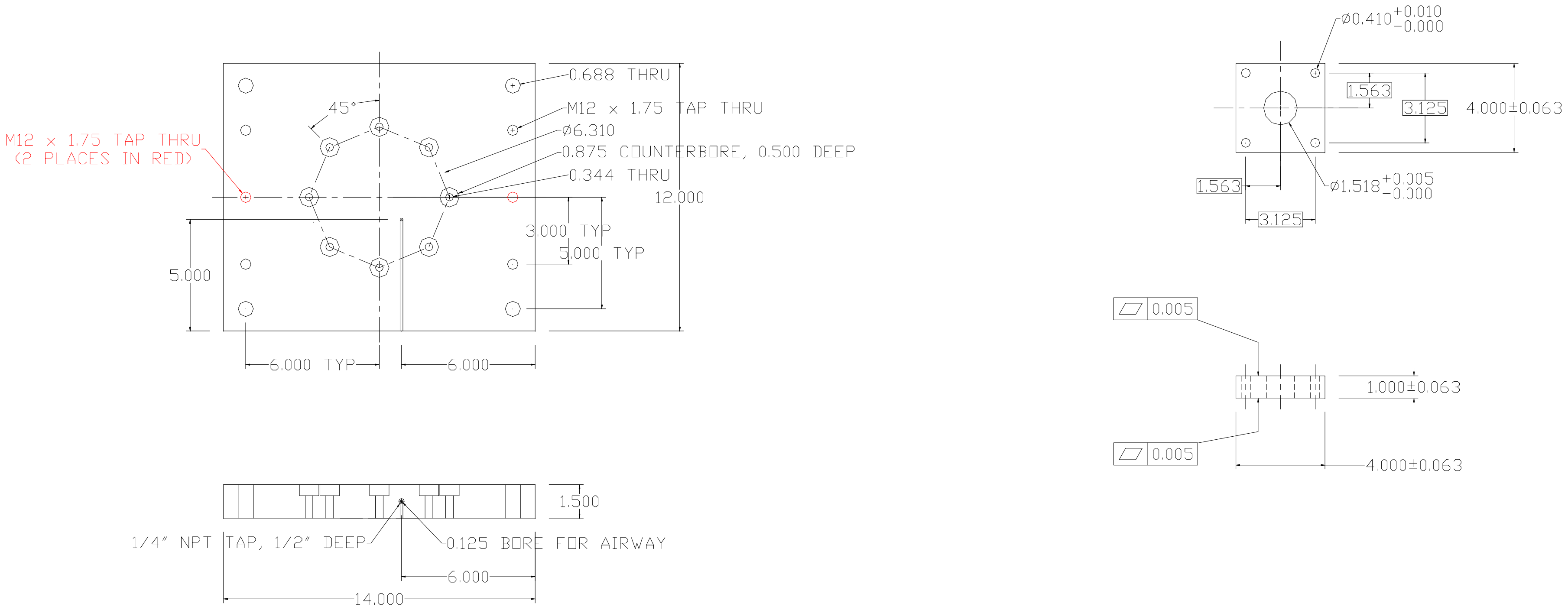
XIV: Drop Test Fixture Assembly



XX: Drop Weight Detail



XXI: Impact Plate and Base Plate Detail



XXII: Mount End Cap and Bearing Detail