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%toast.m
%Hugh Hunt, Cambridge, April 2009

mu=0.3;
x0=0.003;
a=0.07;
xd0=0;
g=9.81;
dt=0.002;
[t1,z1]=ode45(@toastfun1,[0:dt:0.4],[0 0]',[],a,g,x0);
z1d=toastfun1(t1,z1',a,g,x0)';
th1=z1(:,1);th1d=z1d(:,1);th1dd=z1d(:,2);
N1=g*cos(th1)-x0*th1dd;
F1=g*sin(th1)+x0*th1d.^2;
T1=interp1(F1./N1-mu,t1,0,'cubic');
M1=round(T1/dt);
T1=(M1+1)*dt;
er=cos(th1)-i*sin(th1);
eth=-i*er;
r=x0*er;
y1=real(r);
z1=imag(r);
Y1=y1(M1+1);
Z1=z1(M1+1);
NN1=N1(M1+1);
FF1=F1(M1+1);
TH1=th1(M1+1);
TH1D=th1d(M1+1);
%TH1=atan(mu/(1+6*(x0/a)^2));
%TH1D=sqrt(2*g*x0*sin(TH1)/(x0^2+a^2/3));

[t2,z2]=ode45(@toastfun2,[0:dt:0.2],[x0 TH1 xd0 TH1D]',[],a,g,mu);
z2d=toastfun2(t2,z2',a,g,mu)';
x2=z2(:,1);th2=z2(:,2);x2d=z2d(:,1);th2d=z2d(:,2);x2dd=z2d(:,3);th2dd=z2 ↙
d(:,4);
N2=g*cos(th2)-2*x2d.*th2d-x2.*th2dd;
F2=mu*N2;
[mx,M2]=max(th2d);
M2=M2-1;
T2=t2(M2+1);
TH2=th2(M2+1);
TH2D=th2d(M2+1);
X2=x2(M2+1);
X2D=x2d(M2+1);
er=cos(th2)-i*sin(th2);
eth=-i*er;
r=x2.*er;
y2=real(r);
z2=imag(r);
t2=t2+T1;
T2=T2+T1;

er=cos(TH2)-i*sin(TH2);
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eth=-i*er;
r=X2*er;
Y2=real(r);
Z2=imag(r);
rdot=X2D*er+X2.*TH2D*eth;
Y2d=real(rdot);
Z2d=imag(rdot);
t3=[0:dt:0.4]';
th3=TH2+TH2D*t3;
th3d=TH2D*ones(size(t3));
y3=Y2+Y2d*t3;
z3=Z2+Z2d*t3-0.5*g*t3.^2;
T3=interp1(th3,t3,pi,'cubic');
M3=round(T3/dt);
T3=(M3+1)*dt;
Y3=y3(M3+1);
Z3=z3(M3+1);
t3=t3+T2;
T3=T3+T2;

set(0,'defaultlinelinewidth',2)
figure(1)
f=180/pi;
subplot(4,5,1:4),plot(t1,f*th1,'b',T1,f*TH1,'o',t2,f*th2,'g',T2,f*TH2,'o ↙
',t3,f*th3,'r',T3,f*pi,'o')
ax=axis;axis([ax(1:2) 0 200])
grid,ylabel('rotation (deg)')
hold on
plot([T1 T1],[0 200],'b',[T2 T2],[0 200],'g',[T3 T3],[0 200],'r')
text(T1/2,180,'no slip','color','b','horizontalal','center')
text(T1+(T2-T1)/2,180,'slip','color','g','horizontalal','center')
text(T2+(T3-T2)/2,180,'free fall','color','r','horizontalal','center')
title('Falling Toast - Hugh Hunt, April 2009')
hold off
subplot(4,5,6:9),plot(t1,th1d,'b',T1,TH1D,'o',t2,th2d,'g',T2,TH2D,'o',t3 ↙
,th3d,'r')
grid,ylabel('angular velocity (rad/s)')
subplot(4,5,11:14),plot(t1,N1,'b',T1,NN1,'o',t1,F1,'b--',T1,FF1,'o',t2,N ↙
2,'g',t2,F2,'g--',T2,0,'o',t3,zeros(size(t3)),'r')
grid,ylabel('Forces N and F (dashed)')
subplot(4,5,16:19),plot(t1,z1,'b',T1,Z1,'o',t2,z2,'g',T2,Z2,'o',t3,z3,'r ↙
',T3,Z3,'o')
axis([ax(1:2) -0.8 0.1])
grid,xlabel('time (s)'),ylabel('height (m)')
subplot(1,5,5)
plot(y1,z1,'b',y2,z2,'g',y3,z3,'r')
plot(Y1,Z1,'o',Y2,Z2,'o',Y3,Z3,'o')
hold on
plot(x0+[-a a],[0 0],'k','linewidth',5)
plot(Y1+[-a a]*cos(TH1),Z1+[-a a]*sin(-TH1),'b','linewidth',5)
plot(Y2+[-a a]*cos(TH2),Z2+[-a a]*sin(-TH2),'g','linewidth',5)
plot(Y3+[-a a],Z3+[0 0],'r','linewidth',5)
plot(Y1,Z1,'o',Y2,Z2,'o',Y3,Z3,'o')
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n3=length(t3);
nj=6;
dN3=floor(n3/nj);
for jj=1:nj
    j=jj*dN3+1;
    plot(y3(j)+[-a a]*cos(th3(j)),z3(j)+[-a a]*sin(-th3(j)),'r','linewid ↙
th',2)
end
hold off
xlabel('m'),ylabel('m')
title(['L=' num2str(2*a*1000) ' x=' num2str(1000*x0) ' \mu =' num2str(mu ↙
) ])
axis([-.1 .2 -0.8 0.05])
grid

t=[0:M1+M2+M3-1]'*dt;
Y=[y1(1:M1);y2(1:M2);y3(1:M3)];
Z=[z1(1:M1);z2(1:M2);z3(1:M3)];
TH=[th1(1:M1);th2(1:M2);th3(1:M3)];

Nadd=100;
t=[[-Nadd:-1]'*dt;t];
Y=[([-Nadd:-1]'/Nadd).^3*a+x0;Y];
Z=[zeros(Nadd,1);Z];
TH=[zeros(Nadd,1);TH];

anim=1;
if anim==1
    figure(2)
    %set(gcf,'position',[1   281   280   420])
    set(gcf,'position',[201   1   280   560])
    set(gcf,'color',[.7 .7 .7])
    clf
    axes('position',[0 0 1 1])
    set(2,'doublebuffer','on')
    N=length(t);
    for jj=1:N
        dz=0.003;
        s=0.00001;
        plot([-.5 0 [0 i*Z3+[0 -1 1]]-0.17]-2*dz*(1+2*i),'k','linewidth' ↙
,5)
        hold on
        plot(([-a a]-  2*i*dz)*exp(-i*TH(jj))+Y(jj)+i*Z(jj)+s*i,'color', ↙
[.4 .2 .1],'linewidth',2)
        plot(([-a a]       )*exp(-i*TH(jj))+Y(jj)+i*Z(jj)+s*i,'color',[. ↙
5 .3 .1],'linewidth',6)
        plot(([-a a]+  2*i*dz)*exp(-i*TH(jj))+Y(jj)+i*Z(jj)+s*i,'color', ↙
[1 1 0],'linewidth',3)
        plot(Y(jj)+i*Z(jj)+s*i,'o','markerfacecolor','w','markeredgecolo ↙
r','w','markersize',3)
        if jj==N        txt2=' ';txt1=' ';
        elseif t(jj)<0  txt2='wait ...';txt1='push toast near to the edg ↙
e';
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        elseif t(jj)<T1 txt2='NO SLIP';txt1='falling:';
        elseif t(jj)<T2 txt2='SLIPPING';
        else            txt2='FREE FALL';
        end
        text(-0.15,-0.05,txt1,'fontsize',14,'color','k')
        text(-0.15,-0.1,txt2,'fontsize',14,'color','b')
        if jj==N text(-0.15,Z3+0.05,'SPLAT !','fontsize',14,'color','b') ↙
,end
        axis([-.2 .2 -.7 .1])
        axis('off')
        text(-0.2,Z3-0.025,'www.hughhunt.com','fontsize',8)
        text(-0.1,0.07,'Buttered toast','fontsize',14,'fontangle','itali ↙
c')
        hold off
        drawnow
        pause(dt)
        MOV(jj)=getframe(gcf);

    end
  %  movie2avi(MOV,['toast.avi'],'fps',8,'compression','Indeo5','quality ↙
',65)
  %  print -f1 -djpeg toast

end
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