```
>
```

Generating the Constraint Manifold

This program determines the screw axes for the movement of the coupler of a Bennett Linkage given by the parameters a, b, c, kappa

Insert Library Functions

```
> with(dualvectors);
```

```
Share Library:  dualvectors
Author: Perez,Alba.
Description:  Performs dual vectors and numbers operations.
```

["linenorm", "angdist", "normaline", "screwframe", "axiscrew", "dualmag", "duvemult", "dumult", "screwdot", "screwcross", "format", "formatn", "passtoE", "passtovec", "isline", "lineplot", "lineplot2", "lineplot3"]

```
> with(quaternion);
```

```
Share Library:  quaternion
Author: Perez,Alba.
Description:  Performs quaternion operations.
```

["quadd", "qusmult", "qumult", "quconj", "qunorm", "quangle", "quinv"]

```
> with(linalg):
> kappa := kappafinal;  b := bfinal; c := cfinal; a := afinal;tA := 0;tB := 0;
```

$$\kappa := -3.623787928$$
$$b := .8860050887$$
$$c := -1.135819936$$
$$a := -.7177139893$$
$$tA := 0$$
$$tB := 0$$

Yu's Coordinates for a Bennett Linkage

```
> Apoint:=vector(3, [a*cos(kappa/2), a*sin(kappa/2), -c/2]);
```

$$Apoint := [.1713676073, .6969551733, .5679099680]$$

```
> Bpoint:=vector(3, [b*cos(kappa/2), -b*sin(kappa/2), c/2]);
```

$$Bpoint := [-.2115502475, .8603787015, -.5679099680]$$

```
> Cpoint:=vector(3, [-b*cos(kappa/2), b*sin(kappa/2), c/2]);
```

$$Cpoint := [.2115502475, -.8603787015, -.5679099680]$$

```
> Dpoint:=vector(3, [-a*cos(kappa/2), -a*sin(kappa/2), -c/2]);
```

$$Dpoint := [-.1713676073, -.6969551733, .5679099680]$$

```
> AC:=evalm(Cpoint-Apoint); AB:=evalm(Bpoint-Apoint);
```

$$AC := [.0401826402, -1.557333875, -1.135819936]$$
$$AB := [-.3829178548, .1634235282, -1.135819936]$$

```
> BA:=evalm(-AB);BD:=evalm(Dpoint-Bpoint);
```

$$BA := [.3829178548, -.1634235282, 1.135819936]$$
$$BD := [.0401826402, -1.557333875, 1.135819936]$$

```
> CA:=evalm(-AC);CD:=evalm(Dpoint-Cpoint);
```

$$CA := [-.0401826402, 1.557333875, 1.135819936]$$
$$CD := [-.3829178548, .1634235282, 1.135819936]$$

```
> DB:=evalm(-BD); DC:=evalm(-CD);
```

$$DB := [-.0401826402, 1.557333875, -1.135819936]$$
$$DC := [.3829178548, -.1634235282, -1.135819936]$$

Evaluate Linkage Dimensions

```
> r:=simplify(sqrt(dotprod(AB,AB, 'orthogonal')));
```
$r := 1.209719083$

```
> x:=simplify(sqrt(dotprod(AC,AC, 'orthogonal')));
```
$x := 1.927949784$

Check lengths

```
> r1:=simplify(sqrt(dotprod(CD,CD, 'orthogonal')));
```
$r1 := 1.209719083$

```
> x1:=simplify(sqrt(dotprod(BD, BD, 'orthogonal')));
```
$x1 := 1.927949784$

Compute rho:

```
> num:=simplify(dotprod(crossprod(crossprod(AB, AC),
  crossprod(AB,BD)),AB/r));
```
$num := 1.620699096$

```
> den:=simplify(dotprod(crossprod(AB, AC),crossprod(AB, BD)));
```
$den := 3.255123099$

```
> rho:=arctan(num,den);
```
$\rho := .4619596264$

```
> degrho:=simplify(rho*180/Pi);
```
$degrho := 26.46833689$

```
> K:=sin(rho)/r;
```
$K := .3684352738$

Compute xi:

```
> num:=simplify(dotprod(crossprod(crossprod(AC, AB),
  crossprod(CD,AC)),AC/x));
```
$num := 2.582935588$

```
> den:=simplify(dotprod(crossprod(AC, AB),crossprod(CD, AC)));
```
$den := 2.559479575$

```
> xi:=arctan(num,den);
```
$\xi := .7899594152$

```
> degxi:=simplify(xi*180/Pi);
```
$degxi := 45.26134045$

```
> K1:=sin(xi)/x;
```
$K1 := .3684352737$

Compute Line Coordinates

G and W:

Compute Gline (fixed axis A)

```
>
```

```
> epsilon:='epsilon';
```
$\varepsilon := \varepsilon$

```
> Gtemp:=simplify(crossprod(AC,AB));
```
$Gtemp := [1.954470563, .4805659771, -.5897641578]$

```
> Gmag:=simplify(sqrt(dotprod(Gtemp, Gtemp, 'orthogonal')));
```
$Gmag := 2.097312710$

```
> Gdir:=evalm(Gtemp/Gmag);
```
$Gdir := [.9318927758, .2291341557, -.2811999160]$

```
> Gmom:=simplify(crossprod(Apoint,Gdir));
```
$Gmom := [-.3261113072, .5774197533, -.6102213191]$

```
> Gline:=evalm(Gdir+epsilon*Gmom);
```
$Gline := [.9318927758 - .3261113072\,\varepsilon, .2291341557 + .5774197533\,\varepsilon, -.2811999160 - .6102213191\,\varepsilon]$

```
> Gscrew:=concat(Gdir, Gmom);
```

$$Gscrew := \begin{bmatrix} .9318927758 & -.3261113072 \\ .2291341557 & .5774197533 \\ -.2811999160 & -.6102213191 \end{bmatrix}$$

Compute Wline (moving axis B)

```
> Wtemp:=simplify(crossprod(BA, BD));
```

$$Wtemp := [1.583231161, -.3892854895, -.5897641578]$$

```
> Wmag:=simplify(sqrt(dotprod(Wtemp, Wtemp, 'orthogonal')));
```

$$Wmag := 1.733777916$$

```
> Wdir:=evalm(Wtemp/Wmag);
```

$$Wdir := [.9131683744, -.2245301927, -.3401613046]$$

```
> Wmom:=simplify(crossprod(Bpoint, Wdir));
```

$$Wmom := [-.4201804762, -.5905586305, -.7381712024]$$

```
> Wline:=evalm(Wdir+epsilon*Wmom);
```

$$Wline := [.9131683744 - .4201804762\,\varepsilon, -.2245301927 - .5905586305\,\varepsilon, -.3401613046 - .7381712024\,\varepsilon]$$

```
> Wscrew:=concat(Wdir,Wmom);
```

$$Wscrew := \begin{bmatrix} .9131683744 & -.4201804762 \\ -.2245301927 & -.5905586305 \\ -.3401613046 & -.7381712024 \end{bmatrix}$$

H and V:

Compute Hline (fixed axis C)

```
> Htemp:=simplify(crossprod(CD,CA));
```

$$Htemp := [-1.583231161, .3892854895, -.5897641578]$$

```
> Hmag:=simplify(sqrt(dotprod(Htemp, Htemp, 'orthogonal')));
```

$$Hmag := 1.733777916$$

```
> Hdir:=evalm(Htemp/Hmag);
```

$$Hdir := [-.9131683744, .2245301927, -.3401613046]$$

```
> Hmom:=simplify(crossprod(Cpoint,Hdir));
```

$$Hmom := [.4201804762, .5905586305, -.7381712024]$$

```
> Hline:=evalm(Hdir+epsilon*Hmom);
```

$$Hline := [-.9131683744 + .4201804762\,\varepsilon, .2245301927 + .5905586305\,\varepsilon, -.3401613046 - .7381712024\,\varepsilon]$$

```
> Hscrew:=concat(Hdir, Hmom);
```

$$Hscrew := \begin{bmatrix} -.9131683744 & .4201804762 \\ .2245301927 & .5905586305 \\ -.3401613046 & -.7381712024 \end{bmatrix}$$

Compute Vline (moving axis D)

```
> Vtemp:=simplify(crossprod(DB, DC));
```

$$Vtemp := [-1.954470563, -.4805659771, -.5897641578]$$

```
> Vmag:=simplify(sqrt(dotprod(Vtemp, Vtemp, 'orthogonal')));
```

$$Vmag := 2.097312710$$

```
> Vdir:=evalm(Vtemp/Vmag);
```

$$Vdir := [-.9318927758, -.2291341557, -.2811999160]$$

```
> Vmom:=simplify(crossprod(Dpoint,Vdir));
```

$$Vmom := [.3261113072, -.5774197533, -.6102213191]$$

```
> Vline:=evalm(Vdir+epsilon*Vmom);
```

$$Vline := [-.9318927758 + .3261113072\,\varepsilon, -.2291341557 - .5774197533\,\varepsilon, -.2811999160 - .6102213191\,\varepsilon]$$

```
> Vscrew:=concat(Vdir, Vmom);
```

$$Vscrew := \begin{bmatrix} -.9318927758 & .3261113072 \\ -.2291341557 & -.5774197533 \\ -.2811999160 & -.6102213191 \end{bmatrix}$$

Computer initial configuration

```
> cbeta0:=dotprod(AB, AC, 'orthogonal')/(x*r);
```

$cbeta0 := .4374244560$

```
> beta0:=arccos(cbeta0);
```

$\beta 0 := 1.118063741$

```
> degbeta0:=evalf(beta0*180/Pi);
```

$degbeta0 := 64.06033358$

```
> degrho:=evalf(rho*180/Pi);
```

$degrho := 26.46833689$

```
> sin(rho)/r;
```

$.3684352738$

```
> sin(xi)/x;
```

$.3684352737$

Define the Bennett Linkage

```
> K1:=sin(rho)/r;
```

$K1 := .3684352738$

```
> tau:=(xi-rho)/2; t:=(x-r)/2; eta:=(xi+rho)/2;
  h:=(x+r)/2;epsilon:='epsilon';
```

$\tau := .1639998944$

$t := .3591153505$

$\eta := .6259595208$

$h := 1.568834434$

$\varepsilon := \varepsilon$

```
> alpha:='alpha';
```

$\alpha := \alpha$

```
> beta:='beta';
```

$\beta := \beta$

Parameters defining the Bennett Linkage: r is the length and ρ is the twist angle, x and ξ are the length and twist of the fixed link.

Quaternions for First RR crank

```
> qW:=vector(4, [cos(alpha/2), sin(alpha/2)*Wline[1],
  sin(alpha/2)*Wline[2],sin(alpha/2)*Wline[3]]);
```

$$qW := \left[\cos\left(\frac{1}{2}\alpha\right), \sin\left(\frac{1}{2}\alpha\right)(.9131683744 - .4201804762\,\varepsilon), \sin\left(\frac{1}{2}\alpha\right)(-.2245301927 - .5905586305\,\varepsilon), \sin\left(\frac{1}{2}\alpha\right)(-.3401613046 - .7381712024\,\varepsilon)\right]$$

```
> qG:=vector(4, [cos(beta/2), sin(beta/2)*Gline[1],
  sin(beta/2)*Gline[2],sin(beta/2)*Gline[3]]);
```

$$qG := \left[\cos\left(\frac{1}{2}\beta\right), \sin\left(\frac{1}{2}\beta\right)(.9318927758 - .3261113072\,\varepsilon), \sin\left(\frac{1}{2}\beta\right)(.2291341557 + .5774197533\,\varepsilon), \sin\left(\frac{1}{2}\beta\right)(-.2811999160 - .6102213191\,\varepsilon)\right]$$

Quaternions for Second RR crank

```
> qV:=vector(4, [cos(alpha/2), sin(alpha/2)*Vline[1],
  sin(alpha/2)*Vline[2],sin(alpha/2)*Vline[3]]);
```

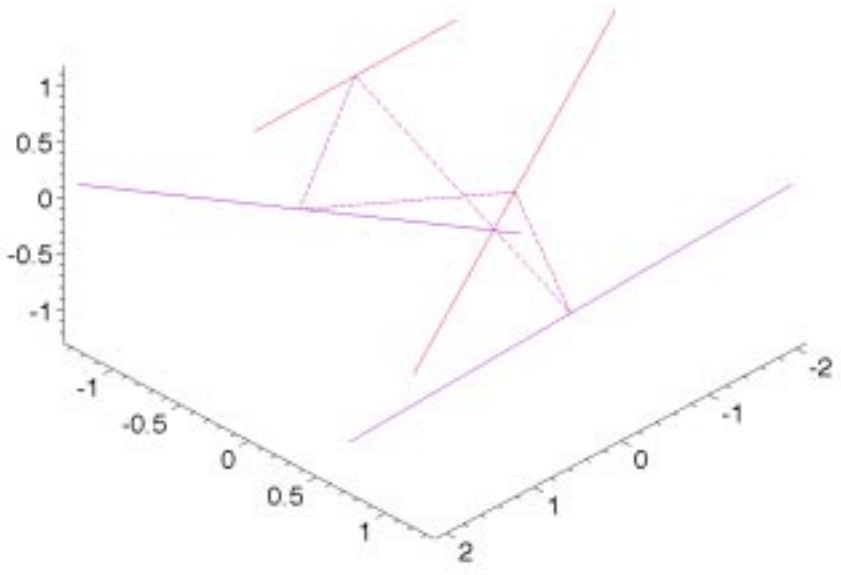
$$qV := \left[\cos\left(\frac{1}{2}\alpha\right), \sin\left(\frac{1}{2}\alpha\right)(-.9318927758 + .3261113072\,\varepsilon), \sin\left(\frac{1}{2}\alpha\right)(-.2291341557 - .5774197533\,\varepsilon), \sin\left(\frac{1}{2}\alpha\right)(-.2811999160 - .6102213191\,\varepsilon)\right]$$

```
> qH:=vector(4, [cos(beta/2), sin(beta/2)*Hline[1],
  sin(beta/2)*Hline[2],sin(beta/2)*Hline[3]]);
```

$$qH := \left[\cos\left(\frac{1}{2}\beta\right), \sin\left(\frac{1}{2}\beta\right)(-.9131683744 + .4201804762\,\varepsilon), \sin\left(\frac{1}{2}\beta\right)(.2245301927 + .5905586305\,\varepsilon), \sin\left(\frac{1}{2}\beta\right)(-.3401613046 - .7381712024\,\varepsilon)\right]$$

Plot Bennett Linkage

```
> plot1:=lineplot3(Gscrew, Wscrew):
Share Library:  dualvectors
Author: Perez,Alba.
Description:  Performs dual vectors and numbers operations.
> plot2:=lineplot3(Gscrew, Hscrew):
Share Library:  dualvectors
Author: Perez,Alba.
Description:  Performs dual vectors and numbers operations.
> plot3:=lineplot3(Hscrew, Vscrew):
Share Library:  dualvectors
Author: Perez,Alba.
Description:  Performs dual vectors and numbers operations.
> plot4:=lineplot3(Wscrew, Vscrew):
Share Library:  dualvectors
Author: Perez,Alba.
Description:  Performs dual vectors and numbers operations.
> display(plot1,plot2, plot3, plot4);
```



```
> 
> 
```

Compute Angles

```
> K2:=evalf(sin((xi+rho)/2)/sin((xi-rho)/2));
```

$$K2 := 3.588475990$$

```
> alpha0:=evalf(2*arctan(-tan(beta0/2)*K2));
```

$$\alpha 0 := -2.303477080$$

```
> dalpha:=evalf(alpha0*180/Pi);
```

$$dalpha := -131.9795149$$

```
> for i from 1 to 72 do theta[i]:=i*(Pi/180)*5+.00001;
  temp:=beta0+theta[i];
  phi[i]:=evalf(2*arctan(-tan(temp/2)*K2))-alpha0;od:
```

Generate Cylindroid

```
> qW:=vector(4, [cos(alpha/2), sin(alpha/2)*Wline[1],
  sin(alpha/2)*Wline[2],sin(alpha/2)*Wline[3]]);
```

$$qW := \left[\cos\left(\frac{1}{2}\alpha\right), \sin\left(\frac{1}{2}\alpha\right)(.9131683744 - .4201804762\,\varepsilon), \sin\left(\frac{1}{2}\alpha\right)(-.2245301927 - .5905586305\,\varepsilon), \sin\left(\frac{1}{2}\alpha\right)(-.3401613046 - .7381712024\,\varepsilon)\right]$$

```
> qG:=vector(4, [cos(beta/2), sin(beta/2)*Gline[1],
  sin(beta/2)*Gline[2],sin(beta/2)*Gline[3]]);
```

$$qG := \left[\cos\left(\frac{1}{2}\beta\right), \sin\left(\frac{1}{2}\beta\right)(.9318927758 - .3261113072\,\varepsilon), \sin\left(\frac{1}{2}\beta\right)(.2291341557 + .5774197533\,\varepsilon), \sin\left(\frac{1}{2}\beta\right)(-.2811999160 - .6102213191\,\varepsilon)\right]$$

```
> qC:=simplify(qumult(qG,qW));
```

$$\begin{aligned}
qC := [&\cos(.5000000000\,\beta)\cos(.5000000000\,\alpha) - .8951808053\sin(.5000000000\,\beta)\sin(.5000000000\,\alpha)\\
&+ .5391756441\sin(.5000000000\,\beta)\sin(.5000000000\,\alpha)\,\varepsilon\\
&- .2464731905\sin(.5000000000\,\beta)\sin(.5000000000\,\alpha)\,\varepsilon^2,\\
&.9131683744\cos(.5000000000\,\beta)\sin(.5000000000\,\alpha)\\
&- .4201804762\cos(.5000000000\,\beta)\sin(.5000000000\,\alpha)\,\varepsilon\\
&+ .9318927758\cos(.5000000000\,\alpha)\sin(.5000000000\,\beta)\\
&- .3261113072\cos(.5000000000\,\alpha)\sin(.5000000000\,\beta)\,\varepsilon\\
&- .1410804447\sin(.5000000000\,\beta)\sin(.5000000000\,\alpha)\\
&- .6686342395\sin(.5000000000\,\beta)\sin(.5000000000\,\alpha)\,\varepsilon\\
&- .7866061001\sin(.5000000000\,\beta)\sin(.5000000000\,\alpha)\,\varepsilon^2,\\
&-.2245301927\cos(.5000000000\,\beta)\sin(.5000000000\,\alpha)\\
&- .5905586305\cos(.5000000000\,\beta)\sin(.5000000000\,\alpha)\,\varepsilon\\
&+ .2291341557\cos(.5000000000\,\alpha)\sin(.5000000000\,\beta)\\
&+ .5774197533\cos(.5000000000\,\alpha)\sin(.5000000000\,\beta)\,\varepsilon\\
&+ .06021099219\sin(.5000000000\,\beta)\sin(.5000000000\,\alpha)\\
&+ .1378858677\sin(.5000000000\,\beta)\sin(.5000000000\,\alpha)\,\varepsilon\\
&+ .01567710869\sin(.5000000000\,\beta)\sin(.5000000000\,\alpha)\,\varepsilon^2,\\
&-.3401613046\cos(.5000000000\,\beta)\sin(.5000000000\,\alpha)\\
&- .7381712024\cos(.5000000000\,\beta)\sin(.5000000000\,\alpha)\,\varepsilon\\
&- .2811999160\cos(.5000000000\,\alpha)\sin(.5000000000\,\beta)
\end{aligned}$$

$$- .6102213191 \cos(.5000000000\,\alpha)\sin(.5000000000\,\beta)\,\varepsilon - .4184761290 \sin(.5000000000\,\beta)\sin(.5000000000\,\alpha) - .9081192456 \sin(.5000000000\,\beta)\sin(.5000000000\,\alpha)\,\varepsilon + .4352083539 \sin(.5000000000\,\beta)\sin(.5000000000\,\alpha)\,\varepsilon^2\,]$$

```
> temp:=map(expand, qC):
> temp1:=subs(epsilon^2=0,eval(temp)):
> temp2:=map(collect, temp1, epsilon):
> qD:=evalm(temp2);
```

$$qD := [\cos(.5000000000\,\beta)\cos(.5000000000\,\alpha) - .8951808053 \sin(.5000000000\,\beta)\sin(.5000000000\,\alpha) + .5391756441 \sin(.5000000000\,\beta)\sin(.5000000000\,\alpha)\,\varepsilon,$$
$$-.4201804762 \cos(.5000000000\,\beta)\sin(.5000000000\,\alpha) - .3261113072 \cos(.5000000000\,\alpha)\sin(.5000000000\,\beta) - .6686342395 \sin(.5000000000\,\beta)\sin(.5000000000\,\alpha))\,\varepsilon + .9131683744 \cos(.5000000000\,\beta)\sin(.5000000000\,\alpha) + .9318927758 \cos(.5000000000\,\alpha)\sin(.5000000000\,\beta) - .1410804447 \sin(.5000000000\,\beta)\sin(.5000000000\,\alpha),$$
$$-.5905586305 \cos(.5000000000\,\beta)\sin(.5000000000\,\alpha) + .5774197533 \cos(.5000000000\,\alpha)\sin(.5000000000\,\beta) + .1378858677 \sin(.5000000000\,\beta)\sin(.5000000000\,\alpha))\,\varepsilon - .2245301927 \cos(.5000000000\,\beta)\sin(.5000000000\,\alpha) + .2291341557 \cos(.5000000000\,\alpha)\sin(.5000000000\,\beta) + .06021099219 \sin(.5000000000\,\beta)\sin(.5000000000\,\alpha),$$
$$-.7381712024 \cos(.5000000000\,\beta)\sin(.5000000000\,\alpha) - .6102213191 \cos(.5000000000\,\alpha)\sin(.5000000000\,\beta) - .9081192456 \sin(.5000000000\,\beta)\sin(.5000000000\,\alpha))\,\varepsilon - .3401613046 \cos(.5000000000\,\beta)\sin(.5000000000\,\alpha) - .2811999160 \cos(.5000000000\,\alpha)\sin(.5000000000\,\beta) - .4184761290 \sin(.5000000000\,\beta)\sin(.5000000000\,\alpha)]$$

```
> Cdual:=vector(4, [coeff(qD[1],epsilon),coeff(qD[2],epsilon),
  coeff(qD[3],epsilon), coeff(qD[4],epsilon)]);
```

$$Cdual := [.5391756441 \sin(.5000000000\,\beta)\sin(.5000000000\,\alpha),$$
$$-.4201804762 \cos(.5000000000\,\beta)\sin(.5000000000\,\alpha) - .3261113072 \cos(.5000000000\,\alpha)\sin(.5000000000\,\beta) - .6686342395 \sin(.5000000000\,\beta)\sin(.5000000000\,\alpha),$$
$$-.5905586305 \cos(.5000000000\,\beta)\sin(.5000000000\,\alpha) + .5774197533 \cos(.5000000000\,\alpha)\sin(.5000000000\,\beta) + .1378858677 \sin(.5000000000\,\beta)\sin(.5000000000\,\alpha),$$
$$-.7381712024 \cos(.5000000000\,\beta)\sin(.5000000000\,\alpha) - .6102213191 \cos(.5000000000\,\alpha)\sin(.5000000000\,\beta) - .9081192456 \sin(.5000000000\,\beta)\sin(.5000000000\,\alpha)]$$

```
> Creal:=evalm(qD-epsilon*Cdual);
```

$$Creal := [\cos(.5000000000\,\beta)\cos(.5000000000\,\alpha) - .8951808053 \sin(.5000000000\,\beta)\sin(.5000000000\,\alpha),$$
$$.9131683744 \cos(.5000000000\,\beta)\sin(.5000000000\,\alpha) + .9318927758 \cos(.5000000000\,\alpha)\sin(.5000000000\,\beta) - .1410804447 \sin(.5000000000\,\beta)\sin(.5000000000\,\alpha),$$
$$-.2245301927 \cos(.5000000000\,\beta)\sin(.5000000000\,\alpha) + .2291341557 \cos(.5000000000\,\alpha)\sin(.5000000000\,\beta) + .06021099219 \sin(.5000000000\,\beta)\sin(.5000000000\,\alpha),$$
$$-.3401613046 \cos(.5000000000\,\beta)\sin(.5000000000\,\alpha) - .2811999160 \cos(.5000000000\,\alpha)\sin(.5000000000\,\beta)$$

$$- .4184761290 \sin(.5000000000\,\beta)\sin(.5000000000\,\alpha)]$$

```
> qDmatrix:=concat(Creal, Cdual);
```

qDmatrix :=

$$[\cos(.5000000000\,\beta)\cos(.5000000000\,\alpha) - .8951808053\sin(.5000000000\,\beta)\sin(.5000000000\,\alpha),$$
$$.5391756441\sin(.5000000000\,\beta)\sin(.5000000000\,\alpha)]$$
$$[.9131683744\cos(.5000000000\,\beta)\sin(.5000000000\,\alpha)$$
$$+ .9318927758\cos(.5000000000\,\alpha)\sin(.5000000000\,\beta)$$
$$- .1410804447\sin(.5000000000\,\beta)\sin(.5000000000\,\alpha),$$
$$-.4201804762\cos(.5000000000\,\beta)\sin(.5000000000\,\alpha)$$
$$- .3261113072\cos(.5000000000\,\alpha)\sin(.5000000000\,\beta)$$
$$- .6686342395\sin(.5000000000\,\beta)\sin(.5000000000\,\alpha)]$$
$$[-.2245301927\cos(.5000000000\,\beta)\sin(.5000000000\,\alpha)$$
$$+ .2291341557\cos(.5000000000\,\alpha)\sin(.5000000000\,\beta)$$
$$+ .06021099219\sin(.5000000000\,\beta)\sin(.5000000000\,\alpha),$$
$$-.5905586305\cos(.5000000000\,\beta)\sin(.5000000000\,\alpha)$$
$$+ .5774197533\cos(.5000000000\,\alpha)\sin(.5000000000\,\beta)$$
$$+ .1378858677\sin(.5000000000\,\beta)\sin(.5000000000\,\alpha)]$$
$$[-.3401613046\cos(.5000000000\,\beta)\sin(.5000000000\,\alpha)$$
$$- .2811999160\cos(.5000000000\,\alpha)\sin(.5000000000\,\beta)$$
$$- .4184761290\sin(.5000000000\,\beta)\sin(.5000000000\,\alpha),$$
$$-.7381712024\cos(.5000000000\,\beta)\sin(.5000000000\,\alpha)$$
$$- .6102213191\cos(.5000000000\,\alpha)\sin(.5000000000\,\beta)$$
$$- .9081192456\sin(.5000000000\,\beta)\sin(.5000000000\,\alpha)]$$

```
> Cscrew:=submatrix(qDmatrix, 2..4, 1..2);
```

Cscrew :=

$$[.9131683744\cos(.5000000000\,\beta)\sin(.5000000000\,\alpha)$$
$$+ .9318927758\cos(.5000000000\,\alpha)\sin(.5000000000\,\beta)$$
$$- .1410804447\sin(.5000000000\,\beta)\sin(.5000000000\,\alpha),$$
$$-.4201804762\cos(.5000000000\,\beta)\sin(.5000000000\,\alpha)$$
$$- .3261113072\cos(.5000000000\,\alpha)\sin(.5000000000\,\beta)$$
$$- .6686342395\sin(.5000000000\,\beta)\sin(.5000000000\,\alpha)]$$
$$[-.2245301927\cos(.5000000000\,\beta)\sin(.5000000000\,\alpha)$$
$$+ .2291341557\cos(.5000000000\,\alpha)\sin(.5000000000\,\beta)$$
$$+ .06021099219\sin(.5000000000\,\beta)\sin(.5000000000\,\alpha),$$
$$-.5905586305\cos(.5000000000\,\beta)\sin(.5000000000\,\alpha)$$
$$+ .5774197533\cos(.5000000000\,\alpha)\sin(.5000000000\,\beta)$$
$$+ .1378858677\sin(.5000000000\,\beta)\sin(.5000000000\,\alpha)]$$
$$[-.3401613046\cos(.5000000000\,\beta)\sin(.5000000000\,\alpha)$$
$$- .2811999160\cos(.5000000000\,\alpha)\sin(.5000000000\,\beta)$$
$$- .4184761290\sin(.5000000000\,\beta)\sin(.5000000000\,\alpha),$$
$$-.7381712024\cos(.5000000000\,\beta)\sin(.5000000000\,\alpha)$$
$$- .6102213191\cos(.5000000000\,\alpha)\sin(.5000000000\,\beta)$$
$$- .9081192456\sin(.5000000000\,\beta)\sin(.5000000000\,\alpha)]$$

```
>
> for i from 1 by 2 to 72 do
> db.i:=evalf(subs(beta=theta[i], alpha=phi[i], evalm(Cscrew)));
> db.(i+1):=evalf(subs(beta=theta[i+1], alpha=phi[i+1],
  evalm(Cscrew)));od:
```

db contains all the unnormalized screws.

Compute Axes

Using displaced moving line

```
>
> for i from 1 by 2 to 72 do
> ipoints:=linenorm(db.i, db.(i+1));
> lb.i:=lineplot2(axiscrew(db.i), col(ipoints,1));
> lb.(i+1):=lineplot2(axiscrew(db.(i+1)), col(ipoints,2));
> od:
> PlotCyl:=lineplot3(axiscrew(db1),
  axiscrew(db30)):PlotAxis:=display(PlotCyl,thickness=3):
```

```
Share Library:  dualvectors
Author: Perez,Alba.
Description:  Performs dual vectors and numbers operations.
```

```
> dis1:=display(plot1,thickness=3):
> dis2:=display(plot3,thickness=3):
> display([seq(lb.k,k=1..70)],dis1,plot2,dis2,plot4);
```