required : system of 2 quads and 1 payload

system elements :

quad 1 - given as system input. x,y coor. θ is not influential

quad 2 - given as system input. x,y coor. θ is not influential

payload (contrained to quads locations)

In[29]:=
```
Quit[]

Needs["VariationalMethods`"]
```

kinematics :

In[15]:=
```
prop2D = {(Xᵢ = (xᵢ[t]
                 yᵢ[t]
                 0)) // MatrixForm // TraditionalForm,
  (Imatᵢ = (I_{i,xx}  0        0
            0         I_{i,yy} 0
            0         0        I_{i,zz})) // MatrixForm // TraditionalForm,
  ωᵢ = D[{0, 0, θᵢ[t]}, t]}
prop2D /. i → 1
prop2D /. i → 2
prop2D /. i → p
(vᵢ = D[Xᵢ, t]) // MatrixForm // TraditionalForm
vᵢ /. i → 1
vᵢ /. i → 2
vᵢ /. i → p
```

Out[15]= $\left\{ \begin{pmatrix} x_i(t) \\ y_i(t) \\ 0 \end{pmatrix}, \begin{pmatrix} \mathbb{i}_{i,xx} & 0 & 0 \\ 0 & \mathbb{i}_{i,yy} & 0 \\ 0 & 0 & \mathbb{i}_{i,zz} \end{pmatrix}, \{0, 0, \theta_i'[t]\} \right\}$

Out[16]= $\left\{ \begin{pmatrix} x_1(t) \\ y_1(t) \\ 0 \end{pmatrix}, \begin{pmatrix} \mathbb{i}_{1,xx} & 0 & 0 \\ 0 & \mathbb{i}_{1,yy} & 0 \\ 0 & 0 & \mathbb{i}_{1,zz} \end{pmatrix}, \{0, 0, \theta_1'[t]\} \right\}$

Out[17]= $\left\{ \begin{pmatrix} x_2(t) \\ y_2(t) \\ 0 \end{pmatrix}, \begin{pmatrix} \mathbb{i}_{2,xx} & 0 & 0 \\ 0 & \mathbb{i}_{2,yy} & 0 \\ 0 & 0 & \mathbb{i}_{2,zz} \end{pmatrix}, \{0, 0, \theta_2'[t]\} \right\}$

Out[18]= $\left\{ \begin{pmatrix} x_p(t) \\ y_p(t) \\ 0 \end{pmatrix}, \begin{pmatrix} \mathbb{i}_{p,xx} & 0 & 0 \\ 0 & \mathbb{i}_{p,yy} & 0 \\ 0 & 0 & \mathbb{i}_{p,zz} \end{pmatrix}, \{0, 0, \theta_p'[t]\} \right\}$

Out[19]//TraditionalForm=

$$\begin{pmatrix} x_i'(t) \\ y_i'(t) \\ 0 \end{pmatrix}$$

Out[20]= $\{\{x_1'[t]\}, \{y_1'[t]\}, \{0\}\}$

Out[21]= $\{\{x_2'[t]\}, \{y_2'[t]\}, \{0\}\}$

Out[22]= $\{\{x_p'[t]\}, \{y_p'[t]\}, \{0\}\}$

In[23]:=
```
dispSimp = {a_[t] → a, Cos[a_] → c[a], Sin[a_] → s[a], 𝕚_{i_,zz} -> I_i};
{(Rp2I = RotationMatrix[θp[t]]) // MatrixForm,
  x1dotSqr = (Transpose[v_i].v_i)[[1, 1]] /. i → 1,
x2dotSqr = (Transpose[v_i].v_i)[[1, 1]] /. i → 2,
  IωSqr1 = ω_i.Imat_i .ω_i /. i → 1,
  IωSqr2 = ω_i.Imat_i .ω_i /. i → 2,
  xpdotSqr = (Transpose[v_i].v_i)[[1, 1]] /. i → p,
  IωSqrp = ω_i.Imat_i .ω_i /. i → p,
```

$$r_1[t] = \begin{pmatrix} x_1[t] \\ y_1[t] \end{pmatrix} - \left(\begin{pmatrix} x_p[t] \\ y_p[t] \end{pmatrix} + \text{Rp2I}.\left\{-\frac{l_p}{2}, \frac{h_p}{2}\right\}\right),$$

$$r_2[t] = \begin{pmatrix} x_2[t] \\ y_2[t] \end{pmatrix} - \left(\begin{pmatrix} x_p[t] \\ y_p[t] \end{pmatrix} + \text{Rp2I}.\left\{\frac{l_p}{2}, \frac{h_p}{2}\right\}\right),$$

$$\Delta_1 = \sqrt{(r_1[t][[1]])^2 + (r_1[t][[2]])^2} - L0_1,$$

$$\Delta_2 = \sqrt{(r_2[t][[1]])^2 + (r_2[t][[2]])^2} - L0_2\};$$

$$\left(T = \frac{1}{2} m_1 \,\text{x1dotSqr} + \frac{1}{2} \,\text{I}\omega\text{Sqr1} + \frac{1}{2} m_2 \,\text{x2dotSqr} + \frac{1}{2} \,\text{I}\omega\text{Sqr2} + \frac{1}{2} m_p \,\text{xpdotSqr} + \frac{1}{2} \,\text{I}\omega\text{Sqrp}\right);$$

(*$r_i = l_i + \Delta l$*)

$$V = m_1\, g\, (X_i[[2]] \;/.\; i \to 1) + m_2\, g\, (X_i[[2]] \;/.\; i \to 2) + m_p\, g\, (X_i[[2]] \;/.\; i \to p) + \frac{1}{2} k_1 \Delta_1^2 + \frac{1}{2} k_2 \Delta_2^2;$$

L = (T - V)[[1]] (*$T_{quad\#1} + T_{quad\#2} + T_{payload}$ - ($V_{quad\#1} + V_{quad\#2} + V_{payload} + V_{spring\#1} + V_{spring\#2}$)*)

Out[27]=

$$-g\, m_1\, y_1[t] - g\, m_2\, y_2[t] - \frac{1}{2} k_1 \left(-L0_1 + \sqrt{\left(\left(\frac{1}{2}\text{Sin}[\theta_p[t]]\, h_p + \frac{1}{2}\text{Cos}[\theta_p[t]]\, l_p + x_1[t] - x_p[t]\right)^2 + \left(-\frac{1}{2}\text{Cos}[\theta_p[t]]\, h_p + \frac{1}{2}\text{Sin}[\theta_p[t]]\, l_p + y_1[t] - y_p[t]\right)^2\right)}\right)^2 -$$

$$\frac{1}{2} k_2 \left(-L0_2 + \sqrt{\left(\left(\frac{1}{2}\text{Sin}[\theta_p[t]]\, h_p - \frac{1}{2}\text{Cos}[\theta_p[t]]\, l_p + x_2[t] - x_p[t]\right)^2 + \left(-\frac{1}{2}\text{Cos}[\theta_p[t]]\, h_p - \frac{1}{2}\text{Sin}[\theta_p[t]]\, l_p + y_2[t] - y_p[t]\right)^2\right)}\right)^2 -$$

$$g\, m_p\, y_p[t] + \frac{1}{2} m_1 \left(x_1'[t]^2 + y_1'[t]^2\right) + \frac{1}{2} m_2 \left(x_2'[t]^2 + y_2'[t]^2\right) +$$

$$\frac{1}{2} m_p \left(x_p'[t]^2 + y_p'[t]^2\right) +$$

$$\frac{1}{2} \mathbb{i}_{1,zz}\, \theta_1'[t]^2 + \frac{1}{2} \mathbb{i}_{2,zz}\, \theta_2'[t]^2 +$$

$$\frac{1}{2} \mathbb{i}_{p,zz}\, \theta_p'[t]^2$$

In[28]:=
```
L //. dispSimp // TraditionalForm
```

Out[28]//TraditionalForm=

$$-\frac{1}{2} k_1 \left(\sqrt{\left(\left(\frac{1}{2} l_p\, c(\theta_p) + \frac{1}{2} h_p\, s(\theta_p) - x_p + x_1\right)^2 + \left(-\frac{1}{2} h_p\, c(\theta_p) + \frac{1}{2} l_p\, s(\theta_p) - y_p + y_1\right)^2\right)} - \mathrm{L0}_1\right)^2 - \frac{1}{2} k_2 \left(\sqrt{\left(\left(-\frac{1}{2} l_p\, c(\theta_p) + \frac{1}{2} h_p\, s(\theta_p) - x_p + x_2\right)^2 + \left(-\frac{1}{2} h_p\, c(\theta_p) - \frac{1}{2} l_p\, s(\theta_p) - y_p + y_2\right)^2\right)} - \mathrm{L0}_2\right)^2 - g\, m_p\, y_p - g\, m_1\, y_1 - g\, m_2\, y_2 + \frac{1}{2} i_1 (\theta_1')^2 + \frac{1}{2} i_2 (\theta_2')^2 + \frac{1}{2} m_p \left((x_p')^2 + (y_p')^2\right) + \frac{1}{2} m_1 \left((x_1')^2 + (y_1')^2\right) + \frac{1}{2} m_2 \left((x_2')^2 + (y_2')^2\right) + \frac{1}{2} i_p (\theta_p')^2$$

```
(quadEqNominal = EulerEquations[L,
    {(*x1[t],y1[t],θ1[t],x2[t],y2[t],θ2[t],*)xp[t], yp[t], θp[t]}, t]
    (*[[All,1]]*)(*==Q*) // Simplify) // MatrixForm // TraditionalForm
```

$$\left(\begin{array}{l} \frac{k_1 (h_p \sin(\theta_p(t)) + l_p \cos(\theta_p(t)) - 2\, x_p(t) + 2\, x_1}{2 \sqrt{\frac{1}{4} (h_p \sin(\theta_p}} \\ \frac{k_1 \left(-\frac{1}{2} h_p \cos(\theta_p(t)) + \frac{1}{2} l_p \sin(\theta_p(t)) - y_p(t) + y_1(t)\right)}{\sqrt{\frac{1}{4} (h_p \sin(\theta_p(t)) + l_i}} \\ i_{p,zz}\, \theta_p''(t) + \frac{k_1 (h_p (x_1(t) \cos(\theta_p(t)) - x_p(t) \cos(\theta_p(t)) + (y_1(t) - y_p(t)) \sin(\theta_p(t))) + l_p (x_1(t) (-\sin(\theta_p(t))) + x_p(t) \sin(\theta_p(t)) + (y_1(}{2 \sqrt{\frac{1}{4} (h_p \sin(\theta_p(t)) + l_p \cos(\theta_p(t)) - 2\, x_p(}} \end{array}\right.$$

```
In[2]:= terms2 = {
   (Sin[θp[t]] hp + Cos[θp[t]] lp + 2 x1[t] - 2 xp[t])^1 → (2 r1x),
   (-1/2 Cos[θp[t]] hp + 1/2 Sin[θp[t]] lp + y1[t] - yp[t])^1 → r1y,
   1/2 Cos[θp[t]] hp - 1/2 Sin[θp[t]] lp - y1[t] + yp[t] → -r1y,
   (1/2 Sin[θp[t]] hp - 1/2 Cos[θp[t]] lp + x2[t] - xp[t])^1 → r2x,
   (-1/2 Cos[θp[t]] hp - 1/2 Sin[θp[t]] lp + y2[t] - yp[t])^1 → r2y,
   Cos[θp[t]] hp + Sin[θp[t]] lp - 2 y2[t] + 2 yp[t] → (-2 r2y),
   lp (-Sin[θp[t]] x1[t] + Sin[θp[t]] xp[t] + Cos[θp[t]] (y1[t] - yp[t])) → dr1,
   hp (Cos[θp[t]] x1[t] - Cos[θp[t]] xp[t] + Sin[θp[t]] (y1[t] - yp[t])) → dr2,
   hp (Cos[θp[t]] x2[t] - Cos[θp[t]] xp[t] + Sin[θp[t]] (y2[t] - yp[t])) → dr4,
   lp (Sin[θp[t]] x2[t] - Sin[θp[t]] xp[t] + Cos[θp[t]] (-y2[t] + yp[t])) → dr3
  };

(simpStep1 =
   (quadEqNominal(*//Simplify*)) /. terms2)
  (*//.dispSimp*)(*//Simplify*) //
 MatrixForm(*//TraditionalForm*)
```

$$\left(\begin{array}{c}
\frac{r1x\,k_1\left(\sqrt{r1x^2+r1y^2}-L0_1\right)}{\sqrt{r1x^2+r1y^2}}+\frac{r2x\,k_2\left(\sqrt{r2x^2+r2y^2}-L0_2\right)}{\sqrt{r2x^2+r2y^2}} == \mathrm{I} \\
\frac{r1y\,k_1\left(\sqrt{r1x^2+r1y^2}-L0_1\right)}{\sqrt{r1x^2+r1y^2}}+\frac{r2y\,k_2\left(\sqrt{r2x^2+r2y^2}-L0_2\right)}{\sqrt{r2x^2+r2y^2}} == m_p \\
\frac{(dr1+dr2)\,k_1\left(\sqrt{r1x^2+r1y^2}-L0_1\right)}{2\sqrt{r1x^2+r1y^2}}+\frac{(dr3+dr4)\,k_2\left(\sqrt{r2x^2+r2y^2}-L0_2\right)}{2\sqrt{r2x^2+r2y^2}}\ -
\end{array}\right.$$

```
In[3]:= terms3 = {
   Sqrt[r1x^2 + r1y^2] → a,
   Sqrt[r2x^2 + r2y^2] → b,
   (dr1 + dr2) → (2 c1),
   (dr3 + dr4) → (2 c2),
   r1x^2 + r1y^2 → a^2, r2x^2 + r2y^2 → b^2,
   Sqrt[a^2] → a, Sqrt[b^2] → b}
```

Out[3]= $\left\{\sqrt{r1x^2+r1y^2}\to a,\ \sqrt{r2x^2+r2y^2}\to b,\ dr1+dr2\to 2\,c1,\ dr3+dr4\to 2\,c2,\ r1x^2+r1y^2\to a^2,\ r2x^2+r2y^2\to b^2,\ \sqrt{a^2}\to a,\ \sqrt{b^2}\to b\right\}$

```
(*simpStep1//InputForm*)

(*simpStep1//TreeForm*)
```

```
(simpStep2 =
    (simpStep1 //. terms3) // Simplify) //
  MatrixForm(*//TraditionalForm*)
```

$$\begin{pmatrix} \frac{r1x\,k_1\,(a-L0_1)}{\sqrt{a^2}} + \frac{r2x\,k_2\,(b-L0_2)}{\sqrt{b^2}} == m_p\,x_p''[t] \\ \frac{r1y\,k_1\,(a-L0_1)}{\sqrt{a^2}} + \frac{r2y\,k_2\,(b-L0_2)}{\sqrt{b^2}} == m_p\,(g + y_p''[t]) \\ \frac{c1\,k_1\,(a-L0_1)}{\sqrt{a^2}} + \frac{c2\,k_2\,(b-L0_2)}{\sqrt{b^2}} + \mathbb{i}_{p,zz}\,\theta_p''[t] == 0 \end{pmatrix}$$

```
(simpStep3 =
   Map[Map[Times[#, a b ] &, #] &, simpStep2] // Expand //
    Simplify) // MatrixForm
```

$$\begin{pmatrix} \frac{\sqrt{a^2}\,b^2\,r1x\,k_1\,(a-L0_1)+a^2\sqrt{b^2}\,r2x\,k_2\,(b-L0_2)}{a\,b} == a\,b\,m_p\,x_p''[t] \\ \frac{\sqrt{a^2}\,b^2\,r1y\,k_1\,(a-L0_1)+a^2\sqrt{b^2}\,r2y\,k_2\,(b-L0_2)}{a\,b} == a\,b\,m_p\,(g + y_p''[t]) \\ \frac{\sqrt{a^2}\,b^2\,c1\,k_1\,(a-L0_1)+a^2\left(\sqrt{b^2}\,c2\,k_2\,(b-L0_2)+b^2\,\mathbb{i}_{p,zz}\,\theta_p''[t]\right)}{a\,b} == 0 \end{pmatrix}$$

```
simpStep3 //. dispSimp //
   Expand // MatrixForm //
  TraditionalForm
```

$$\begin{pmatrix} -\frac{\sqrt{a^2}\, b\, k_1\, \mathrm{L0}_1\, \mathrm{r1x}}{a} + \sqrt{a^2}\, b\, k_1\, \mathrm{r1x} - \frac{a\sqrt{b^2} \cdots}{} \\ -\frac{\sqrt{a^2}\, b\, k_1\, \mathrm{L0}_1\, \mathrm{r1y}}{a} + \sqrt{a^2}\, b\, k_1\, \mathrm{r1y} - \frac{a\sqrt{b^2}\, k_2\, \mathrm{L0}_2\, \mathrm{r} \cdots}{b} \\ -\frac{\sqrt{a^2}\, b\, \mathrm{c1}\, k_1\, \mathrm{L0}_1}{a} + \sqrt{a^2}\, b\, \mathrm{c1}\, k_1 - \frac{a\sqrt{b^2}\, \mathrm{c} \cdots}{b} \end{pmatrix}$$

$$\left(\text{simpStep4} = k_1\, b\, (a - \mathrm{L0}_1) \begin{pmatrix} \mathrm{r1x} \\ \mathrm{r1y} \\ \mathrm{c1} \end{pmatrix} + k_2\, a\, (b - \mathrm{L0}_1) \begin{pmatrix} \mathrm{r2x} \\ \mathrm{r2y} \\ \mathrm{c2} \end{pmatrix} + \begin{pmatrix} 0 \\ -m_p\, g\, a\, b \\ 0 \end{pmatrix} - a\, b \begin{pmatrix} m_p & 0 & 0 \\ 0 & m_p & 0 \\ 0 & 0 & -I_p \end{pmatrix} . \begin{pmatrix} x_p''[t] \\ y_p''[t] \\ \theta_p''[t] \end{pmatrix} - \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}\right) \text{// MatrixForm}$$

$$\begin{pmatrix} b\, \mathrm{r1x}\, k_1\, (a - \mathrm{L0}_1) + a\, \mathrm{r2x}\, k_2\, (b - \mathrm{L0}_1) - a\, b\, m_p\, x_p''[t] \\ b\, \mathrm{r1y}\, k_1\, (a - \mathrm{L0}_1) + a\, \mathrm{r2y}\, k_2\, (b - \mathrm{L0}_1) - a\, b\, g\, m_p - a\, b\, m_p\, y_p''[t] \\ b\, \mathrm{c1}\, k_1\, (a - \mathrm{L0}_1) + a\, \mathrm{c2}\, k_2\, (b - \mathrm{L0}_1) + a\, b\, \mathbb{i}_p\, \theta_p''[t] \end{pmatrix}$$

```
terms2 //. dispSimp // MatrixForm // TraditionalForm
terms3 //. dispSimp // MatrixForm // TraditionalForm
```

$$\begin{pmatrix} l_p\, c(\theta_p) + h_p\, s(\theta_p) - 2\,x_p + 2\,x_1 \to 2\,\text{r1x} \\ -\frac{1}{2}\,h_p\, c(\theta_p) + \frac{1}{2}\,l_p\, s(\theta_p) - y_p + y_1 \to \text{r1y} \\ \frac{1}{2}\,h_p\, c(\theta_p) - \frac{1}{2}\,l_p\, s(\theta_p) + y_p - y_1 \to -\text{r1y} \\ -\frac{1}{2}\,l_p\, c(\theta_p) + \frac{1}{2}\,h_p\, s(\theta_p) - x_p + x_2 \to \text{r2x} \\ -\frac{1}{2}\,h_p\, c(\theta_p) - \frac{1}{2}\,l_p\, s(\theta_p) - y_p + y_2 \to \text{r2y} \\ h_p\, c(\theta_p) + l_p\, s(\theta_p) + 2\,y_p - 2\,y_2 \to -2\,\text{r2y} \\ l_p\,((y_1 - y_p)\, c(\theta_p) + x_1\,(-s(\theta_p)) + x_p\, s(\theta_p)) \to \text{dr1} \\ h_p\,(x_1\, c(\theta_p) - x_p\, c(\theta_p) + (y_1 - y_p)\, s(\theta_p)) \to \text{dr2} \\ h_p\,(x_2\, c(\theta_p) - x_p\, c(\theta_p) + (y_2 - y_p)\, s(\theta_p)) \to \text{dr4} \\ l_p\,((y_p - y_2)\, c(\theta_p) + x_2\, s(\theta_p) - x_p\, s(\theta_p)) \to \text{dr3} \end{pmatrix}$$

$$\begin{pmatrix} \sqrt{\text{r1x}^2 + \text{r1y}^2} \to a \\ \sqrt{\text{r2x}^2 + \text{r2y}^2} \to b \\ \text{dr1} + \text{dr2} \to 2\,\text{c1} \\ \text{dr3} + \text{dr4} \to 2\,\text{c2} \\ \text{r1x}^2 + \text{r1y}^2 \to a^2 \\ \text{r2x}^2 + \text{r2y}^2 \to b^2 \\ \sqrt{a^2} \to a \\ \sqrt{b^2} \to b \end{pmatrix}$$

(*x_p, y_p, θ_p=f(x_1, y_1, x_2, y_2, k_1, k_2, l_p, h_p)*)

---

non - conver forces :

aerodynamic = f ($\dot{x}_p$, $\dot{y}_p$, θ_p, w_x, w_y) ,

w for wind components. = f (relV_x, relV_y) , relV is relative to air

dumping = f ($\dot{l}_i$) = f ($\dot{x}_i$, $\dot{y}_i$, $\dot{x}_p$, $\dot{y}_p$)

---

non dim the full equations

```
quadEqNominal /. terms2
 (*/.terms3*) // MatrixForm
```

$$\left(\begin{array}{l} \frac{r1x\,k_1\left(\sqrt{r1x^2+r1y^2}-L0_1\right)}{\sqrt{r1x^2+r1y^2}}+\frac{r2x\,k_2\left(\sqrt{r2x^2+r2y^2}-L0_2\right)}{\sqrt{r2x^2+r2y^2}} == \\ \frac{r1y\,k_1\left(\sqrt{r1x^2+r1y^2}-L0_1\right)}{\sqrt{r1x^2+r1y^2}}+\frac{r2y\,k_2\left(\sqrt{r2x^2+r2y^2}-L0_2\right)}{\sqrt{r2x^2+r2y^2}} == m_p \\ \frac{(dr1+dr2)\,k_1\left(\sqrt{r1x^2+r1y^2}-L0_1\right)}{2\sqrt{r1x^2+r1y^2}}+\frac{(dr3+dr4)\,k_2\left(\sqrt{r2x^2+r2y^2}-L0_2\right)}{2\sqrt{r2x^2+r2y^2}} \end{array}\right.$$

```
(smallEqs =
    quadEqNominal /. terms2 /.
     terms3) // MatrixForm
```

$$\left(\begin{array}{l} \frac{r1x\,k_1\,(a-L0_1)}{\sqrt{a^2}}+\frac{r2x\,k_2\,(b-L0_2)}{\sqrt{b^2}} == m_p \\ \frac{r1y\,k_1\,(a-L0_1)}{\sqrt{a^2}}+\frac{r2y\,k_2\,(b-L0_2)}{\sqrt{b^2}} == m_p\,(g \\ \frac{c1\,k_1\,(a-L0_1)}{\sqrt{a^2}}+\frac{c2\,k_2\,(b-L0_2)}{\sqrt{b^2}}+\mathbb{i}_{p,zz}\,\theta_p' \end{array}\right.$$

```
(*(NonDimEq=Map[Map[Times[#, 1/(mp ωs^2 L01)]&,#]&,
    (*simpStep1*)smallEqs](*//Expand*)//
   FullSimplify)//MatrixForm*)
```

NonDimEq manually settings the terms:

$\tilde{y_p}[t] = y_p[t] \,/ \, L0_1$ or any other of the lengths varialbes $(x_p, r1x, r1y, r2x, r2y, h_p, l_p)$

$t = \tau / \omega_s$

$\omega_s{}^2 = \frac{k_1}{m_p}\left[\frac{g}{l} = \frac{1}{s^2}\right]$

A is non - dimentional form of ' a '

B is non - dimentional form of ' b '

$$\left(\text{NonDimEq} = \left\{\frac{k_1}{m_p}\left(1 - \frac{1}{A}\,\frac{L0_1}{L0_1}\right) \text{r1x}\, L0_1 + \frac{k_2}{k_1}\,\frac{k_1}{m_p}\left(1 - \frac{1}{B}\,\frac{L0_2}{L0_1}\right) \text{r2x}\, L0_1 == L0_1\, \omega_s^2\, x_p{}''[t],\ \frac{k_1}{m_p}\left(1 - \frac{1}{A}\,\frac{L0_1}{L0_1}\right) \text{r1y}\, L0_1 + \frac{k_2}{k_1}\,\frac{k_1}{m_p}\left(1 - \frac{1}{B}\,\frac{L0_2}{L0_1}\right) \text{r2y}\, L0_1 - g == L0_1\, \omega_s^2\, y_p{}''[t],\ \frac{k_1}{-i_{p,zz}}\left(1 - \frac{1}{A}\,\frac{L0_1}{L0_1}\right) c_1\, L0_1{}^2 + \frac{k_2}{k_1}\,\frac{k_1}{-i_{p,zz}}\left(1 - \frac{1}{B}\,\frac{L0_2}{L0_1}\right) c_2\, L0_1{}^2 == \omega_s^2\, \theta_p{}''[t]\right\}\right) //$$

Flatten // MatrixForm // TraditionalForm

$$\begin{pmatrix} \frac{\left(1-\frac{1}{A}\right) k_1\, L0_1\, \text{r1x}}{m_p} + \frac{k_2\, L0_1\, \text{r2x}\left(1-\frac{L0_2}{B\, L0_1}\right)}{m_p} = L0_1\, \omega_s^2\, x_p''(t) \\ \frac{\left(1-\frac{1}{A}\right) k_1\, L0_1\, \text{r1y}}{m_p} + \frac{k_2\, L0_1\, \text{r2y}\left(1-\frac{L0_2}{B\, L0_1}\right)}{m_p} - g = L0_1\, \omega_s^2\, y_p''(t) \\ -\frac{\left(1-\frac{1}{A}\right) c_1\, k_1\, L0_1^2}{i_{p,zz}} - \frac{c_2\, k_2\, L0_1^2\left(1-\frac{L0_2}{B\, L0_1}\right)}{i_{p,zz}} = \omega_s^2\, \theta_p''(t) \end{pmatrix}$$

```
(*terms4={(*1- LO1/a → A,
  1- LO2/b → B,*)
  k2/k1 → k, (*=k_ratio,*)
  g/LO1 1/ωs^2 → γ,
  LO1^2 k1/(Ip,zz ωs^2) → E,
  k1/mp -> ωs^2
 }*)

(*Delta_Equilibrium = mp g/k1 *)

(* g/LO1 1/ωs^2 == g 1/LO1 1/k1 mp [ m/s^2 1/m 1/(kg/s^2) kg]
  LO1^2 k1/(Ip,zz ωs^2) == LO1^2 k1/(Ip,zz k1) mp [ m^2 kg/(kg m^2) ] *)
```

greekTerms = {

$$\frac{k_2}{k_1} \to \kappa,\quad \frac{LO_2}{LO_1} \to \mathcal{L},\quad \frac{k_1}{m_p} \to \omega_s{}^2,\quad \frac{m_p\, LO_1{}^2}{I_p}\left(=\frac{LO_1{}^2\, k_1}{I_p\, \omega_s{}^2}\right) \to \alpha,\quad \frac{g}{LO_1\, \omega_s^2}\left(=\frac{g\, m_p}{LO_1\, k_1}\right) \to \gamma$$

}

(NonDimEq = {

$$\omega_s^2\, LO_1\left(1-\frac{1}{A}\right) r1x + \kappa\, \omega_s^2\, LO_1\left(1-\frac{1}{B}\mathcal{L}\right) r2x == LO_1\, \omega_s^2\, x_p''[t],$$

$$\omega_s^2\, LO_1\left(1-\frac{1}{A}\right) r1y + \kappa\, \omega_s^2\, LO_1\left(1-\frac{1}{B}\mathcal{L}\right) r2y - \frac{g}{LO_1\,\omega_s^2} LO_1\, \omega_s^2 == LO_1\, \omega_s^2\, y_p''[t],$$

$$\frac{k_1}{-i_{p,zz}} \frac{LO_1{}^2}{\omega_s^2}\, \omega_s^2 \left(1-\frac{1}{A}\right) c_1 + \kappa \frac{k_1}{-i_{p,zz}} \frac{LO_1{}^2}{\omega_s^2}\, \omega_s^2\left(1-\frac{1}{B}\mathcal{L}\right) c_2 == \omega_s^2\, \theta_p''[t]$$

}) // Flatten // MatrixForm // TraditionalForm

$$\begin{pmatrix} \left(1-\frac{1}{A}\right) LO_1\, r1x\, \omega_s^2 + \kappa\, LO_1\, r2x\left(1-\frac{\mathcal{L}}{B}\right)\omega_s^2 = LO_1\, \omega_s^2\, x_p''(t) \\ \left(1-\frac{1}{A}\right) LO_1\, r1y\, \omega_s^2 + \kappa\, LO_1\, r2y\left(1-\frac{\mathcal{L}}{B}\right)\omega_s^2 - g = LO_1\, \omega_s^2\, y_p''(t) \\ -\frac{\left(1-\frac{1}{A}\right) c_1\, k_1\, LO_1^2}{i_{p,zz}} - \frac{c_2\, \kappa\, k_1\, LO_1^2\left(1-\frac{\mathcal{L}}{B}\right)}{i_{p,zz}} = \omega_s^2\, \theta_p''(t) \end{pmatrix}$$

using ' greekTerms ' list :

In[1]:=

```
(NonDimEq = {
    xp''[t] == (1 - 1/A) r1x + κ (1 - 1/B ℒ) r2x ,
    yp''[t] == (1 - 1/A) r1y + κ (1 - 1/B ℒ) r2y - γ,
    θp''[t] == -α ((1 - 1/A) c1 + κ (1 - 1/B ℒ) c2)
  }) // Flatten // MatrixForm // TraditionalForm
```

Out[1]//TraditionalForm=

$$\begin{pmatrix} x_p''(t) = \left(1 - \frac{1}{A}\right) \mathrm{r1x} + \kappa\, \mathrm{r2x} \left(1 - \frac{\mathcal{L}}{B}\right) \\ y_p''(t) = \left(1 - \frac{1}{A}\right) \mathrm{r1y} + \kappa\, \mathrm{r2y} \left(1 - \frac{\mathcal{L}}{B}\right) - \gamma \\ \theta_p''(t) = -\alpha \left(\left(1 - \frac{1}{A}\right) c_1 + c_2\, \kappa \left(1 - \frac{\mathcal{L}}{B}\right)\right) \end{pmatrix}$$

$$\mathcal{V}_1 = \begin{pmatrix} \mathrm{r1x} \\ \mathrm{r1y} \\ c_1 \end{pmatrix} \quad (x_1,\, x_p,\, \theta_p, ..)$$

$$\mathcal{V}_2 = \begin{pmatrix} \mathrm{r2x} \\ \mathrm{r2y} \\ c_2 \end{pmatrix}$$

$$\dot{\mathcal{X}} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -\alpha \end{pmatrix} \left(1 - \frac{1}{A}\right) \mathcal{V}_1 + \kappa \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -\alpha \end{pmatrix} \left(1 - \frac{1}{B} \mathcal{L}\right) \mathcal{V}_2 - \begin{pmatrix} 0 \\ \gamma \\ 0 \end{pmatrix}$$

In[8]:=
```
terms2
terms3
```

Out[8]=
$$\{\mathrm{Sin}[\theta_p[t]]\, h_p + \mathrm{Cos}[\theta_p[t]]\, l_p + 2\, x_1[t] - 2\, x_p[t] \to 2\, r1x,$$
$$-\frac{1}{2}\mathrm{Cos}[\theta_p[t]]\, h_p + \frac{1}{2}\mathrm{Sin}[\theta_p[t]]\, l_p + y_1[t] - y_p[t] \to r1y,$$
$$\frac{1}{2}\mathrm{Cos}[\theta_p[t]]\, h_p - \frac{1}{2}\mathrm{Sin}[\theta_p[t]]\, l_p - y_1[t] + y_p[t] \to -r1y,$$
$$\frac{1}{2}\mathrm{Sin}[\theta_p[t]]\, h_p - \frac{1}{2}\mathrm{Cos}[\theta_p[t]]\, l_p + x_2[t] - x_p[t] \to r2x,$$
$$-\frac{1}{2}\mathrm{Cos}[\theta_p[t]]\, h_p - \frac{1}{2}\mathrm{Sin}[\theta_p[t]]\, l_p + y_2[t] - y_p[t] \to r2y,$$
$$\mathrm{Cos}[\theta_p[t]]\, h_p + \mathrm{Sin}[\theta_p[t]]\, l_p - 2\, y_2[t] + 2\, y_p[t] \to -2\, r2y,$$
$$l_p\, (-\mathrm{Sin}[\theta_p[t]]\, x_1[t] + \mathrm{Sin}[\theta_p[t]]\, x_p[t] + \mathrm{Cos}[\theta_p[t]]\, (y_1[t] - y_p[t])) \to dr1,$$
$$h_p\, (\mathrm{Cos}[\theta_p[t]]\, x_1[t] - \mathrm{Cos}[\theta_p[t]]\, x_p[t] + \mathrm{Sin}[\theta_p[t]]\, (y_1[t] - y_p[t])) \to dr2,$$
$$h_p\, (\mathrm{Cos}[\theta_p[t]]\, x_2[t] - \mathrm{Cos}[\theta_p[t]]\, x_p[t] + \mathrm{Sin}[\theta_p[t]]\, (y_2[t] - y_p[t])) \to dr4,$$
$$l_p\, (\mathrm{Sin}[\theta_p[t]]\, x_2[t] - \mathrm{Sin}[\theta_p[t]]\, x_p[t] + \mathrm{Cos}[\theta_p[t]]\, (-y_2[t] + y_p[t])) \to dr3\}$$

Out[9]=
$$\{\sqrt{r1x^2 + r1y^2} \to a,\ \sqrt{r2x^2 + r2y^2} \to b,\ dr1 + dr2 \to 2\, c1,$$
$$dr3 + dr4 \to 2\, c2,\ r1x^2 + r1y^2 \to a^2,\ r2x^2 + r2y^2 \to b^2,\ \sqrt{a^2} \to a,\ \sqrt{b^2} \to b\}$$

In[117]:=
$$\mathcal{X} = \begin{pmatrix} x_p[t] \\ y_p[t] \\ \theta_p[t] \end{pmatrix} (*//\mathrm{Flatten}*)$$

greekTermsSymetricCase = {
$$(*\frac{k_2}{k_1}\to*)\ \kappa \to 1,$$
$$(*\frac{L0_2}{L0_1}\to*)\ \mathcal{L} \to 1$$
}

greekTermsGeneral = {
$$(*\frac{k_2}{k_1}\to*)\ \kappa \to 1,$$
$$(*\frac{L0_2}{L0_1}\to*)\ \mathcal{L} \to 1,$$
$$(*\frac{k_1}{m_p}{-}{>}*)\ \omega_s{}^2 \to 1,$$
$$(*\frac{m_p L0_1{}^2}{I_p}\left(=\frac{L0_1{}^2 k_1}{I_p \omega_s{}^2}\right)\to*)\ \alpha \to 1,$$
$$(*\frac{q}{L0_1\ \omega_s^2}\left(=\frac{q\ m_p}{L0_1 k_1}\right)\to\ *)\ \gamma \to 1\ \text{(* make sure it is not over-determined constant *)}$$

}

(* already here : replacing all former h_p,l_p with new $2h_p$,$2l_p$*)

$$A(*\to\sqrt{r1x^2{+}r1y^2}\ *) = \sqrt{\left((\mathrm{Sin}[\theta_p[t]]\, h_p + \mathrm{Cos}[\theta_p[t]]\, l_p + (x_1[t] - x_p[t]))^2 + (-\,\mathrm{Cos}[\theta_p[t]]\, h_p + \mathrm{Sin}[\theta_p[t]]\, l_p + (y_1[t] - y_p[t]))^2\right)}$$

$$B(*\to\sqrt{r2x^2{+}r2y^2}\ *) = \sqrt{\left((\mathrm{Sin}[\theta_p[t]]\, h_p - \mathrm{Cos}[\theta_p[t]]\, l_p + (x_2[t] - x_p[t]))^2 + (-\,\mathrm{Cos}[\theta_p[t]]\, h_p - \mathrm{Sin}[\theta_p[t]]\, l_p + (y_2[t] - y_p[t]))^2\right)}$$

```
(*c1(*→dr1+dr2*)=lp (-Sin[θp[t]] (x1[t]- xp[t])+Cos[θp[t]] (y1[t]-yp[t]))+
   hp (Cos[θp[t]]( x1[t]- xp[t])+Sin[θp[t]] (y1[t]-yp[t]))
    c2(*→dr3+dr4*)=lp (Sin[θp[t]] (x2[t]- xp[t])+Cos[θp[t]] (-y2[t]+yp[t]))+
   hp (Cos[θp[t]]( x2[t]- xp[t])+Sin[θp[t]] (y2[t]-yp[t]))*)
```

$\mathcal{V}_1$ (*= $\begin{pmatrix} r1x \\ r1y \\ c_1 \end{pmatrix}$ *) =

$$\begin{pmatrix} (\mathrm{Sin}[\theta_p[t]]\, h_p + \mathrm{Cos}[\theta_p[t]]\, l_p + (x_1[t] - x_p[t])) \\ (-\mathrm{Cos}[\theta_p[t]]\, h_p + \mathrm{Sin}[\theta_p[t]]\, l_p + (y_1[t] - y_p[t])) \\ l_p\, (-\mathrm{Sin}[\theta_p[t]]\, (x_1[t] - x_p[t]) + \mathrm{Cos}[\theta_p[t]]\, (y_1[t] - y_p[t])) + h_p\, (\mathrm{Cos}[\theta_p[t]]\, (x_1[t] - x_p[\end{pmatrix}$$

$\mathcal{V}_2$ (*= $\begin{pmatrix} r2x \\ r2y \\ c_2 \end{pmatrix}$ *) =

$$\begin{pmatrix} (\mathrm{Sin}[\theta_p[t]]\, h_p - \mathrm{Cos}[\theta_p[t]]\, l_p + (x_2[t] - x_p[t])) \\ (-\mathrm{Cos}[\theta_p[t]]\, h_p - \mathrm{Sin}[\theta_p[t]]\, l_p + (y_2[t] - y_p[t])) \\ l_p\, (\mathrm{Sin}[\theta_p[t]]\, (x_2[t] - x_p[t]) + \mathrm{Cos}[\theta_p[t]]\, (-y_2[t] + y_p[t])) + h_p\, (\mathrm{Cos}[\theta_p[t]]\, (x_2[t] - x_p[\end{pmatrix}$$

"equations with no general forces :"

EOM =

$$D[\mathcal{X}, \{t, 2\}] == \left(\begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -\alpha \end{pmatrix} \left(1 - \frac{1}{A}\right)\right).\mathcal{V}_1 + \left(\kappa \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -\alpha \end{pmatrix} \left(1 - \frac{1}{B} \mathcal{L}\right)\right).\mathcal{V}_2 - \begin{pmatrix} 0 \\ \gamma \\ 0 \end{pmatrix} \text{ // Flatten;}$$

Out[117]= $\{\{x_p[t]\}, \{y_p[t]\}, \{\theta_p[t]\}\}$

Out[118]= $\{\kappa \to 1, \mathcal{L} \to 1\}$

Out[119]= $\{\kappa \to 1, \mathcal{L} \to 1, \omega_s^2 \to 1, \alpha \to 1, \gamma \to 1\}$

Out[120]= $\sqrt{\left((\mathrm{Sin}[\theta_p[t]]\, h_p + \mathrm{Cos}[\theta_p[t]]\, l_p + x_1[t] - x_p[t])^2 + (-\mathrm{Cos}[\theta_p[t]]\, h_p + \mathrm{Sin}[\theta_p[t]]\, l_p + y_1[t] - y_p[t])^2\right)}$

Out[121]= $\sqrt{\left((\mathrm{Sin}[\theta_p[t]]\, h_p - \mathrm{Cos}[\theta_p[t]]\, l_p + x_2[t] - x_p[t])^2 + (-\mathrm{Cos}[\theta_p[t]]\, h_p - \mathrm{Sin}[\theta_p[t]]\, l_p + y_2[t] - y_p[t])^2\right)}$

Out[122]= $\{\{\mathrm{Sin}[\theta_p[t]]\, h_p + \mathrm{Cos}[\theta_p[t]]\, l_p + x_1[t] - x_p[t]\},$
$\{-\mathrm{Cos}[\theta_p[t]]\, h_p + \mathrm{Sin}[\theta_p[t]]\, l_p + y_1[t] - y_p[t]\},$
$\{l_p\, (-\mathrm{Sin}[\theta_p[t]]\, (x_1[t] - x_p[t]) + \mathrm{Cos}[\theta_p[t]]\, (y_1[t] - y_p[t])) +$
$h_p\, (\mathrm{Cos}[\theta_p[t]]\, (x_1[t] - x_p[t]) + \mathrm{Sin}[\theta_p[t]]\, (y_1[t] - y_p[t]))\}\}$

Out[123]= $\{\{\mathrm{Sin}[\theta_p[t]]\, h_p - \mathrm{Cos}[\theta_p[t]]\, l_p + x_2[t] - x_p[t]\},$
$\{-\mathrm{Cos}[\theta_p[t]]\, h_p - \mathrm{Sin}[\theta_p[t]]\, l_p + y_2[t] - y_p[t]\},$
$\{h_p\, (\mathrm{Cos}[\theta_p[t]]\, (x_2[t] - x_p[t]) + \mathrm{Sin}[\theta_p[t]]\, (y_2[t] - y_p[t])) +$
$l_p\, (\mathrm{Sin}[\theta_p[t]]\, (x_2[t] - x_p[t]) + \mathrm{Cos}[\theta_p[t]]\, (-y_2[t] + y_p[t]))\}\}$

Out[124]= equations with no general forces :

In[128]:= **nameChange = {l_p → w_p};**
EOM /. nameChange /. greekTermsSymetricCase // Flatten // MatrixForm // TraditionalForm

Out[129]//TraditionalForm=

$$\begin{pmatrix} x_p''(t) \\ y_p''(t) \\ \theta_p''(t) \end{pmatrix} = \left(\begin{array}{r} (\sin(\theta_p(t))\, h_p + \cos(\theta_p(t))\, w_p + x_1(t) - x_p(t) \\ -\gamma + \left(1 - \frac{1}{\sqrt{(\sin(\theta_p(t))\, h_p + \cos(\theta_p(t))\, w_p + x_1(t) - x_p(t))^2 + (-\mathrm{co}}} \right. \\ -\alpha\, (w_p\, (\cos(\theta_p(t))\, (y_1(t) - y_p(t)) - \sin(\theta_p(t))\, (x_1(t) - x_p(t))) + h_p\, (\cos(\theta_p(t))\, (x_1(t) - x_p(t)) + \sin(\theta_p(t))\, (y_1(t) - y_p(t)) \end{array} \right.$$

In[144]:= **"set derivatives to zero: "**
(equibTerms = {Map[Rule[#, 0] &, D[𝒳 // Flatten, {t, 1}]],
Map[Rule[#, 0] &, D[𝒳 // Flatten, {t, 2}]]} // Flatten)
(*//MatrixForm*) // TraditionalForm

Out[144]= set derivatives to zero:

Out[145]//TraditionalForm=

$$\{x_p'(t) \to 0,\ y_p'(t) \to 0,\ \theta_p'(t) \to 0,\ x_p''(t) \to 0,\ y_p''(t) \to 0,\ \theta_p''(t) \to 0\}$$

(*EquibStartConditions={x_1[0]→0,y_1[0]→0,x_2[0]→D,y_2[0]→y_1[0]}*)

In[150]:= **EquibInputConditions = {x_1[t] → 0, y_1[t] → 0, x_2[t] → 2 w_p, y_2[t] → y_1[t]}**

Out[150]= {x_1[t] → 0, y_1[t] → 0, x_2[t] → 2 w_p, y_2[t] → y_1[t]}

In[152]:= **(SymetricEquib = EOM /. nameChange /. greekTermsSymetricCase /. equibTerms //.**
EquibInputConditions) // MatrixForm // TraditionalForm

Out[152]//TraditionalForm=

$$\begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix} = \left(\begin{array}{r} (\sin(\theta_p(t))\, h_p - \cos(\theta_p(t))\, w_p + 2\, w_p - x_p(t)) \left(1 - \frac{}{\sqrt{(\sin(\theta_p(t))\, h_p - \cos(\theta_p(t))}} \right. \\ -\gamma + \left(1 - \frac{1}{\sqrt{(\sin(\theta_p(t))\, h_p - \cos(\theta_p(t))\, w_p + 2\, w_p - x_p(t))^2 + (-\cos(\theta_p(t))\, h_p - \sin(\theta_p(t))\, w_p - y_p(t))^2}} \right. \\ -\alpha \left(1 - \frac{1}{\sqrt{(\sin(\theta_p(t))\, h_p - \cos(\theta_p(t))\, w_p + 2\, w_p - x_p(t))^2 + (-\cos(\theta_p(t))\, h_p - \sin(\theta_p(t))\, w_p - y_p(t))^2}} \right) (w_p\, (\sin(\theta_p(t))\, (2\, w_p - x_p(t)) + \cos(\theta_p(t))\, y_p(t)) + \end{array} \right.$$

In[158]:= **horizontalState = {θ_p[t] → 0}**

Out[158]= {θ_p[t] → 0}

In[160]:= **SymetricEquibWithAssumption = SymetricEquib /. horizontalState**

Out[160]=
$$\{\{0\},\{0\},\{0\}\} == \Big\{\Big\{2\,(w_p - x_p[t])\left(1 - \frac{1}{\sqrt{(w_p - x_p[t])^2 + (-h_p - y_p[t])^2}}\right)\Big\},$$
$$\Big\{-\gamma + 2\left(1 - \frac{1}{\sqrt{(w_p - x_p[t])^2 + (-h_p - y_p[t])^2}}\right)(-h_p - y_p[t])\Big\},$$
$$\Big\{-\alpha\left(1 - \frac{1}{\sqrt{(w_p - x_p[t])^2 + (-h_p - y_p[t])^2}}\right)(-h_p\, x_p[t] - w_p\, y_p[t]) -$$
$$\alpha\left(1 - \frac{1}{\sqrt{(w_p - x_p[t])^2 + (-h_p - y_p[t])^2}}\right)(h_p\,(2\,w_p - x_p[t]) + w_p\, y_p[t])\Big\}\Big\}$$

In[164]:= **simpleEquibXYSolution =**
Solve[SymetricEquibWithAssumption, {x_p[t], y_p[t]}] // MatrixForm // TraditionalForm

Out[164]//TraditionalForm=
$$\begin{pmatrix} x_p(t) \to w_p & y_p(t) \to \frac{1}{2}(-\gamma - 2\,h_p - 2) \\ x_p(t) \to w_p & y_p(t) \to \frac{1}{2}(-\gamma - 2\,h_p + 2) \end{pmatrix}$$

In[163]:= **Solve[SymetricEquib, {x_p[t], y_p[t], θ_p[t]}]**

Out[163]= $Aborted

simple case testings:

(*y_1=y_2 , k_1=k_2, $L0_1$=$L0_2$
θ_p=0, $x_p=\frac{x_1+x_2}{2}$, $\frac{y_p}{L0_1}=-\left(1+\frac{1}{2}D\right)$*)

(*trajectory:
τ=0: $\ddot{y}$=1m/s^2 until y_1=y_2=10L0$_1$
$\ddot{y}$=-1m/s^2 until $\dot{y}_1$=$\dot{y}_2$=0
$\ddot{x}_1$=$\ddot{x}_2$=1m/s^2 until $\dot{x}_1$=$\dot{x}_2$=2m/s
disterbunce can be input by x_1+=5L0$_1$ over $\frac{1}{100\sqrt{\omega_s}}$*)

```
(*what needs to be done in order to keep horizontal payload?(θp[t]→0) :
simpStep1/.θp[t]→0/.dispSimp//MatrixForm//TraditionalForm
```

$$\begin{pmatrix} \frac{k_1\ r1x\ \left(\sqrt{r1x^2+r1y^2}-L0_1\right)}{\sqrt{r1x^2+r1y^2}}+\frac{k_2\ r2x\ \left(\sqrt{r2x^2+r2y^2}-L0_2\right)}{\sqrt{r2x^2+r2y^2}}=m_p\ x_p'' \\ \frac{k_1\ r1y\ \left(\sqrt{r1x^2+r1y^2}-L0_1\right)}{\sqrt{r1x^2+r1y^2}}+\frac{k_2\ r2y\ \left(\sqrt{r2x^2+r2y^2}-L0_2\right)}{\sqrt{r2x^2+r2y^2}}=m_p\ (g+y_p'') \\ \frac{k_1\ (dr1+dr2)\ \left(\sqrt{r1x^2+r1y^2}-L0_1\right)}{2\ \sqrt{r1x^2+r1y^2}}+\frac{k_2\ (dr3+dr4)\ \left(\sqrt{r2x^2+r2y^2}-L0_2\right)}{2\ \sqrt{r2x^2+r2y^2}}+i_p\ \theta_p''=0 \end{pmatrix}$$

```
what needs to be done in order to keep horizontal payload±ϵ?(θp[t]→δθ[t]) :*)
```