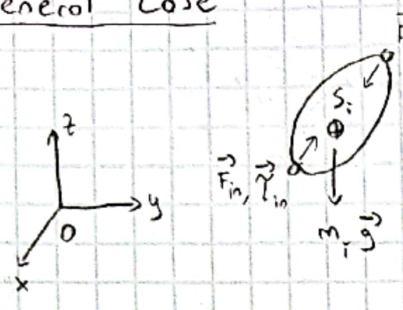
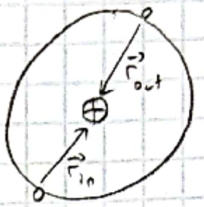
General Case



$\vec{V}_i = \frac{d\vec{OS}_i}{dt}$, $\vec{\omega}_i$



N-E : $\begin{cases} \vec{F}_{in} + \vec{F}_{out} + m_i \vec{g} = m_i \dot{\vec{V}}_i \\ \vec{\tau}_{in} + \vec{\tau}_{out} + \vec{r}_{in} \times \vec{F}_{in} + \vec{r}_{out} \times \vec{F}_{out} = I_i \dot{\vec{\omega}}_i + \vec{\omega}_i \times (I_i \vec{\omega}_i) \end{cases}$

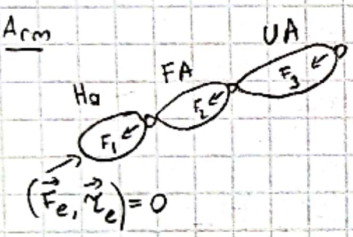
$\vec{F}_{out} = m_i \dot{\vec{V}}_i - \vec{F}_{in} - m_i \vec{g}$

$\vec{\tau}_{out} = I_i \dot{\vec{\omega}}_i + \vec{\omega}_i \times (I_i \vec{\omega}_i) - \vec{\tau}_{in} - \vec{r}_{in} \times \vec{F}_{in} - \vec{r}_{out} \times \vec{F}_{out}$

Hanavan Model

- Legs and arms considered as 3 segal bodies

Arm

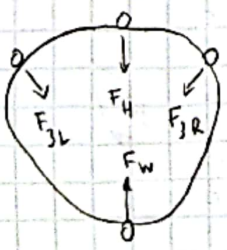


- Ha : $\begin{cases} \vec{F}_1 = m_{Ha} \dot{\vec{V}}_{Ha} - m_{Ha} \vec{g} \\ \vec{\tau}_1 = I_{Ha} \dot{\vec{\omega}}_{Ha} + \vec{\omega}_{Ha} \times (I_{Ha} \vec{\omega}_{Ha}) - \vec{r}_1 \times \vec{F}_1 \end{cases}$

- FA : $\begin{cases} \vec{F}_2 = m_{FA} \dot{\vec{V}}_{FA} + \vec{F}_1 - m_{FA} \vec{g} \\ \vec{\tau}_2 = I_{FA} \dot{\vec{\omega}}_{FA} + \vec{\omega}_{FA} \times (I_{FA} \vec{\omega}_{FA}) + \vec{r}_1 \times \vec{F}_1 - \vec{r}_2 \times \vec{F}_2 + \vec{\tau}_1 \end{cases}$

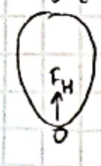
- UA : $\begin{cases} \vec{F}_3 = m_{UA} \dot{\vec{V}}_{UA} + \vec{F}_2 - m_{UA} \vec{g} \\ \vec{\tau}_3 = I_{UA} \dot{\vec{\omega}}_{UA} + \vec{\omega}_{UA} \times (I_{UA} \vec{\omega}_{UA}) + \vec{r}_2 \times \vec{F}_2 - \vec{r}_3 \times \vec{F}_3 + \vec{\tau}_2 \end{cases}$

- UT



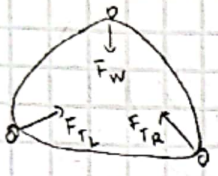
- UT : $\begin{cases} \vec{F}_W = m_{UT} \dot{\vec{V}}_{UT} + \vec{F}_{3L} + \vec{F}_{3R} + \vec{F}_H - m_{UT} \vec{g} \\ \vec{\tau}_W = I_{UT} \dot{\vec{\omega}}_{UT} + \vec{\omega}_{UT} \times (I_{UT} \vec{\omega}_{UT}) + \vec{r}_{3L} \times \vec{F}_{3L} + \vec{r}_{3R} \times \vec{F}_{3R} + \vec{r}_H \times \vec{F}_H \\ \qquad + \vec{\tau}_{3L} + \vec{\tau}_{3R} + \vec{\tau}_H - \vec{r}_W \times \vec{F}_W \end{cases}$

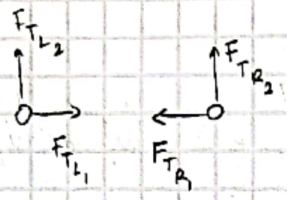
- H



$$-H: \begin{cases} \vec{F}_H = m_H \dot{\vec{V}}_H - m_H \vec{g} \\ \vec{\tau}_H = I_H \dot{\vec{\omega}}_H + \vec{\omega}_H \times (I_H \vec{\omega}_H) - \vec{r}_H \times \vec{F}_H \end{cases}$$

- LT



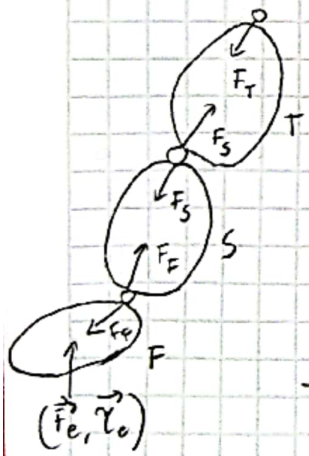


$$\vec{F}_{T_{L_1}} + \vec{F}_{T_{R_1}} = 0$$

$$\vec{F}_{T_{L_2}} = \vec{F}_{T_{R_2}}$$

$$-LT: \begin{cases} 2\vec{F}_{T_L} = m_{LT} \dot{\vec{V}}_{LT} - m_{LT} \vec{g} + \vec{F}_W \\ 2\tau_L = I_{LT} \dot{\vec{\omega}}_{LT} + \vec{\omega}_{LT} \times (I_{LT} \vec{\omega}_{LT}) + \vec{\tau}_W + \vec{r}_W \times \vec{F}_W \\ \quad - \underbrace{(\vec{r}_{T_L} \times \vec{F}_{T_L} + \vec{r}_{T_R} \times \vec{F}_{T_R})}_{=0} \end{cases}$$

Leg



$$-T: \begin{cases} \vec{F}_S = m_T \dot{\vec{V}}_T - m_T \vec{g} + \vec{F}_T \\ \vec{\tau}_S = I_T \dot{\vec{\omega}}_T + \vec{\omega}_T \times (I_T \vec{\omega}_T) + \vec{\tau}_T - \vec{r}_S \times \vec{F}_S + \vec{r}_T \times \vec{F}_T \end{cases}$$

$$-S: \begin{cases} \vec{F}_F = m_S \dot{\vec{V}}_S - m_S \vec{g} + F_S \\ \vec{\tau}_F = I_S \dot{\vec{\omega}}_S + \vec{\omega}_S \times (I_S \vec{\omega}_S) + \vec{\tau}_S + r_S \times \vec{F}_S - \vec{r}_F \times \vec{F}_F \end{cases}$$

$$-F: \begin{cases} \vec{F}_e = m_F \dot{\vec{V}}_F - m_F \vec{g} + \vec{F}_F \\ \vec{\tau}_e = I_F \dot{\vec{\omega}}_F + \vec{\omega}_F \times (I_F \vec{\omega}_F) + \vec{\tau}_F + \vec{r}_f \times \vec{F}_F - \vec{r}_e \times \vec{F}_e \end{cases}$$