Project, Linear Systems, Fall 2008

- Your report should include WORD document, Matlab codes, 姓名, 學號, 系級, 日期, etc.
- Assigned: 9/17/08, Due on 1/20/09, 5pm, by e-mail to fengli@ntu.edu.tw

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- **(Controller and Estimator Design for Bicycle-Rider System)**

  Please e-mail me your report by 5pm, Tue., Jan 20, 2009 (Tentative). Late report will NOT be graded.

  (A bicycle-rider system)

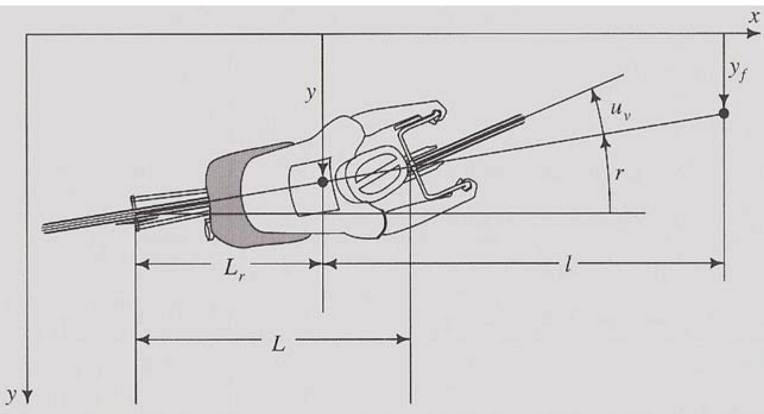
  Consider the following figures. Let $x_1 = r, x_2 = y, x_3 = v_1, x_4 = v_2, u_1 = u_v, u_2 = u_h$, and $y_1 = r, y_2 = y$, (or $y_1 = y_f, y_2 = \theta$). Assume that the equations of motion are discribed as follows.

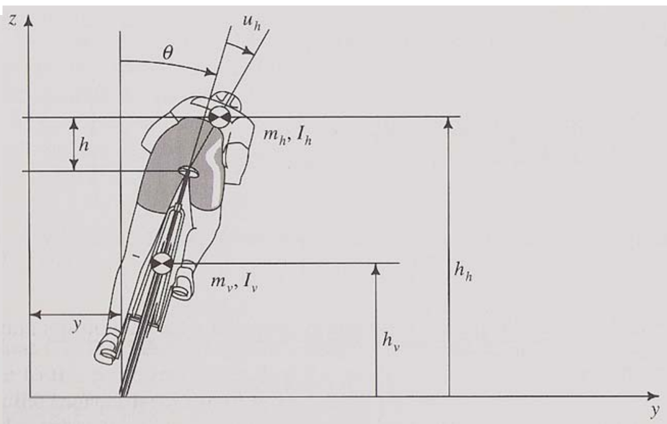
$$
\begin{aligned}
\dot{r} &= \tfrac{1}{L} V u_v \\
\dot{y} &= -\tfrac{L_r}{L} V u_v - V r \\
\ddot{\theta} &+ \tfrac{w^2}{g}\ddot{y} + f_u \ddot{u}_h = w^2\theta + f_0 w^2 u_h
\end{aligned}
$$

where

$$
\begin{aligned}
w^2 &= \frac{(m_v h_v + m_h h_h) g}{(I_v + I_h + m_v h_v^2 + m_h h_h^2)} \\
f_u &= \frac{(m_h h_h^2 + I_n) h}{[h_h (I_v + I_h + m_v h_v^2 + m_h h_h^2)]} \\
f_0 &= \frac{m_h h_h}{(m_v h_v + m_h h_h)} \\
v_1 &= y + (\theta + f_u u_h) g / w^2 \\
v_2 &= \dot{v}_1
\end{aligned}
$$

h	:	human
v	:	vehicle
r	:	yaw angle
y	:	lateral position
θ	:	roll angle
u_h	:	lean angle of the human rider
u_v	:	handlebar steering angle of vehicle
V	:	forward speed
h	:	distance
hu_h	:	lateral position





For the problem, please find the associated state-space model. That is, find the matrices, $\mathbf{A}, \mathbf{B}, \mathbf{C}, \mathbf{D}$, in the equations:

$$\dot{\mathbf{x}}(t) = \mathbf{A}\mathbf{x}(t) + \mathbf{B}\mathbf{u}(t)$$

$$\mathbf{y}(t) = \mathbf{C}\mathbf{x}(t) + \mathbf{D}\mathbf{u}(t).$$

Consider the following specifications are used for the system.

Weight of vehicle	$m_v g$	136.0	N
Weight of human	$m_h g$	9.11	N
Height of center of gravity of vehicle	h_v	0.334	m
Height of center of gravity of human	h_h	0.465	m
Moment of inertia of vehicle	I_v	2.25	kgm^2
Moment of inertia of human	I_h	0.201	kgm^2
Wheel base	L	0.665	m
Longitudinal distance	L_r	0.313	m
Rider's distance	h	0.08	m
Forward speed	V	1	m/s
Length	l	0.7	m
	B_1	$1/L$	
	B_2	L_r/L	

Assume that the inputs are constant or sinusoidal functions, that is, $u_i = a_i$ or $u_i = a_i * \sin(b_i t + c_i)$.
You may choose different values of a_i, b_i, c_i and try to simulate the system. Plot the numerical result and explain your plots.

- First, you need to
  simulate the **dynamical behavior** of the bicycle-rider system, and
  analyze the **stability condition** of the bicycle-rider system.
  Also, you also checke the **controllability** and **observability** of the system under certain conditions.

- Then, in the second part of the project,
  please try to design (some) **state beedback controller(s)**
  to stablize the system as well as
  to improve the system performance.

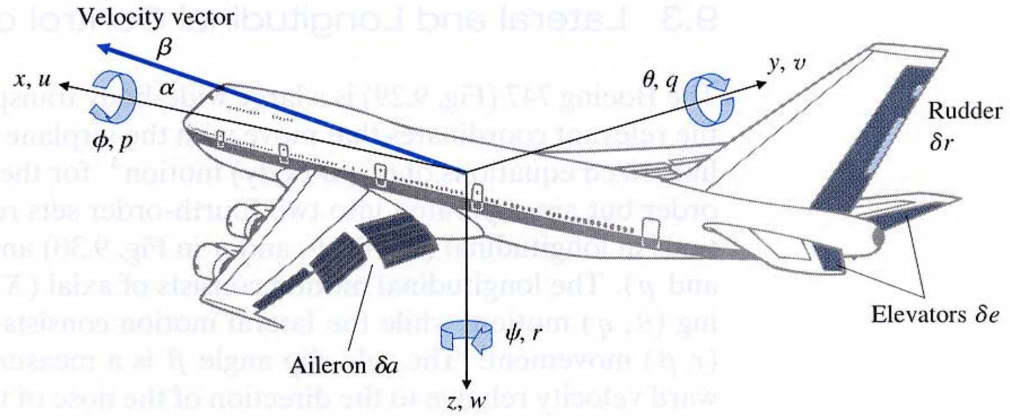
- Also, in the third part of the project,
  if some of the states are **not measureable** by the sensors,
  please design some faster stable **state estimators**
  for the un-measureable states.

- You should at least answer the following questions and show related data or plots to justify your answer.

- First, you need to simulate the dynamical behavior of the bicycle-rider system, and analyze the stability condition of the bicycle-rider system. Also, you also checke the controllability and observability of the system under certain conditions. So, in the first part of the project, please try to design (some) state beedback controller(s) to stablize the system as well as to improve the system performance. Also, in the second part of the project, if some of the states are not directly measured by the sensors, please design some faster stable state estimators for the un-measureable states. You should at least answer the following questions and show related data or plots to justify your answer.

- You can use the **state-space model** for the following analysis, design, and simulation.
- Show the result of the **analysis without control**.
- Identify the **stability** condition.
- Analyze the **controllability** and **observability**.
- Desgin a **state feedback controller** to stabilize the system. What is the closed-loop poles or eigenevalues after the feedback? Plot the trajectory of all the states for about a reasonable time interval.
- If only r, y can be measured by the sensors, design **state estimators** for the other states. What are the closed-up poles or eigenvalues of the estimators. Plot the trajectory of the actual states and the estimated states together and plot the difference between these two types of states.
- If only y_f, θ can be measured by the sensors, design **state estimators** for the other states. What are the closed-up poles or eigenvalues of the estimators. Plot the trajectory of the actual states and the estimated states together and plot the difference between these two types of states.
- Use all the **estimated states** to design the **state feedback controller**. Plot the trajectory of (1) the states controlled by full state feedback, (2) the states controlled by the feedback of estimated states.
- Use the **measureable states** (i.e., the output) and the **estimated states** to design the state feedback controller. Plot the trajectory of (1) the states controlled by full state feedback, (2) the states controlled by the feedback of measureable states.
- **Compare** all the possible cases discussed above in terms of **tables of data, plots of state trajectories, etc.**

- Lateral and Longitudinal Control a Boeing 747



x, y, z = position coordinates
u, v, w = velocity coordinates
p = roll rate
q = pitch rate
r = yaw rate
ϕ = roll angle
θ = pitch angle
ψ = yaw angle
β = side-slip angle
α = angle of attack

$$m\,(\dot{U} + qW - rV) = X - mg\sin\theta + \kappa T\cos\theta,$$

$$m\,(\dot{V} + rU - pW) = Y + mg\cos\theta\sin\phi,$$

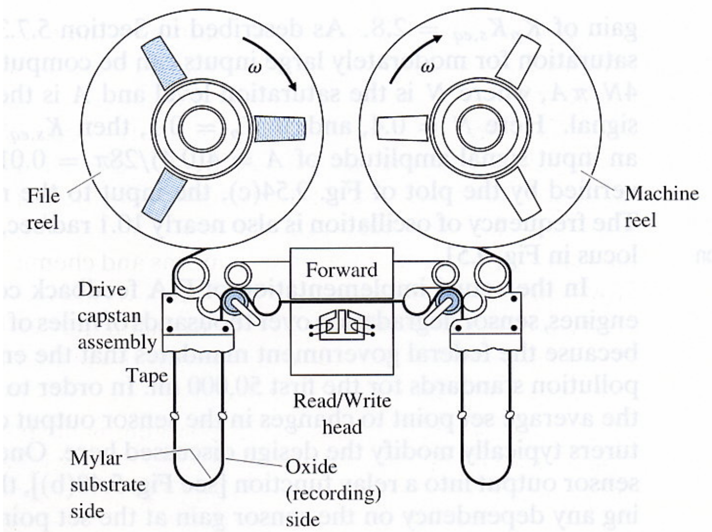
$$m\,(\dot{W} + pV - qU) = Z + mg\cos\theta\cos\phi - \kappa T\sin\theta,$$

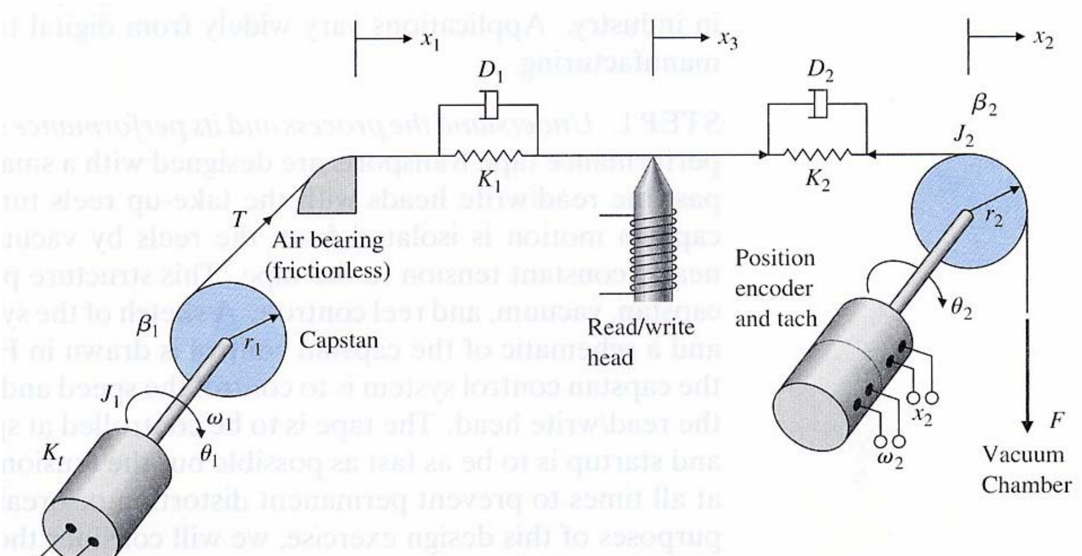
$$I_x\dot{p} + I_{xz}\dot{r} + (I_z - I_y)\,qr + I_{xz}\,qp = L,$$

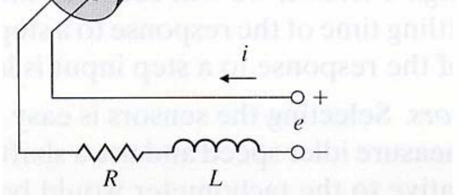
$$I_y\dot{q} + (I_x - I_z)\,pr + I_{xz}\,(r^2 - p^2) = M,$$

$$I_z\dot{r} + I_{xz}\dot{p} + (I_y - I_x)\,qp - I_{xz}\,qr = N,$$

- Analysis and Control of Digital Tape Transport







$$J_1 \frac{d\omega_1}{dt} + \beta_1 \omega_1 - r_1 T = K_t i,$$

$$\dot{x}_1 = r_1 \omega_1,$$

$$L \frac{di}{dt} + Ri + K_e \, \omega_1 = e,$$

$$\dot{x}_2 = r_2 \omega_2,$$

$$J_2 \frac{d\omega_2}{dt} + \beta_2 \omega_2 + r_2 T = 0,$$

$$T = K_1(x_3 - x_1) + D_1(\dot{x}_3 - \dot{x}_1)$$

$$T = K_2(x_2 - x_3) + D_2(\dot{x}_2 - \dot{x}_3),$$

$$x_1 = r_1 \theta_1,$$

$$x_2 = r_2 \theta_2,$$

$$x_3 = \frac{x_1 + x_2}{2},$$