Modeling Helicopter UAV

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Common Assumptions for Helicopters

1. The earth is flat, stationary and therefore an approximate inertial reference frame.
2. The atmosphere is at rest relative to the ground (zero wind)
3. The Rotor head RPM is constant
4. The model is only valid in near hover conditions
5. The model can not be derived like previous models and must be identified using experiments.
6. Change in mass during flight is negligible.
7. The Yaw rate gyro is still in place as a very fast rate control on Yaw and there for changes in torque because of control input are neglected

State Formulation

Used in AUV's and UAV's the following state space representation is very convent

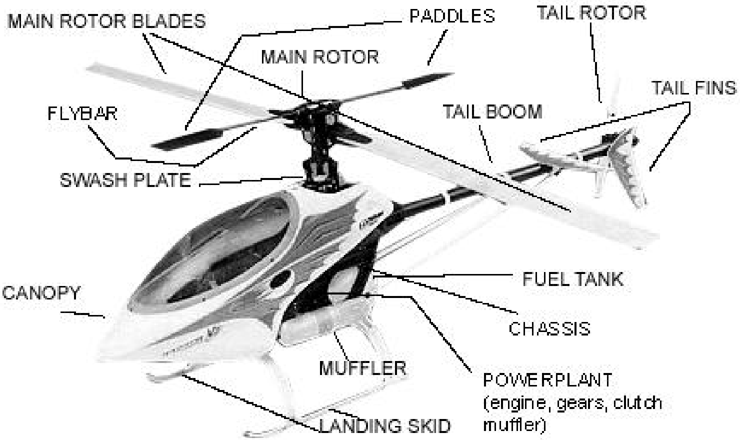
The UAV's position is expresses relative to an inertial reference.

$$\eta_1 = \begin{bmatrix} x \\ y \\ z \end{bmatrix} \quad \eta_2 = \begin{bmatrix} \phi \\ \theta \\ \psi \end{bmatrix} \quad \eta = \begin{bmatrix} \eta_1 \\ \eta_2 \end{bmatrix} = \begin{bmatrix} x \\ y \\ z \\ \phi \\ \theta \\ \psi \end{bmatrix}$$

Also the ν vector holds the linear and angular velocity

$$\nu_1 = \begin{bmatrix} u \\ v \\ w \end{bmatrix} \quad \nu_2 = \begin{bmatrix} p \\ q \\ r \end{bmatrix} \quad \nu = \begin{bmatrix} \nu_1 \\ \nu_2 \end{bmatrix} = \begin{bmatrix} u \\ v \\ w \\ p \\ q \\ r \end{bmatrix}$$

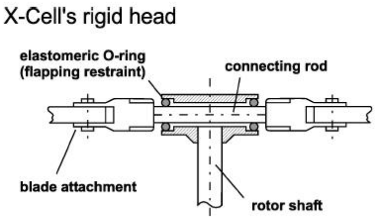
Tour of a helicopter

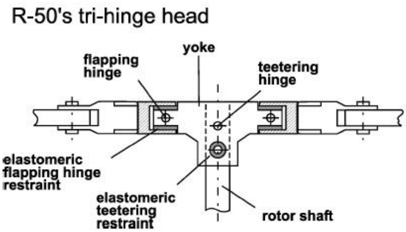


The Rotor head

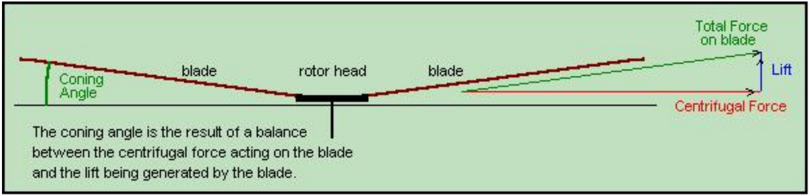
The Rotor head of helicopters will usually fall into two categories the Rigid or Hinged rotor head design full scale

helicopters must use hinged since the structural strength of the blades is too low to support its only moment about the rotor head.



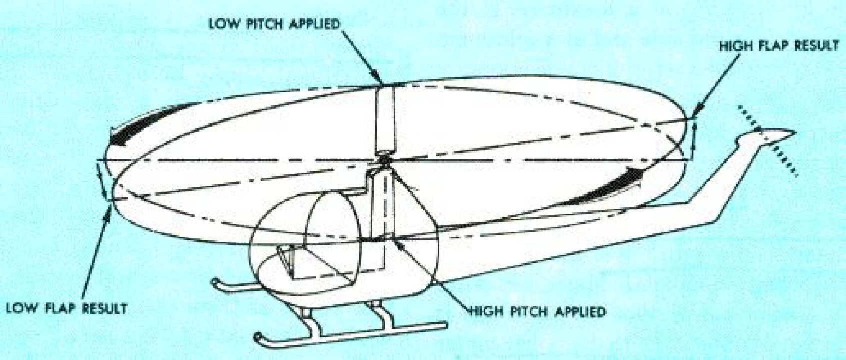


The Coning Angle



As a result of the hinged rotor head or the inherent flexibility of the blades the rotating disk will have an angle called the coning angle. This angle acts a little like the dihedral angle in filed wing planes

The Flapping Angle

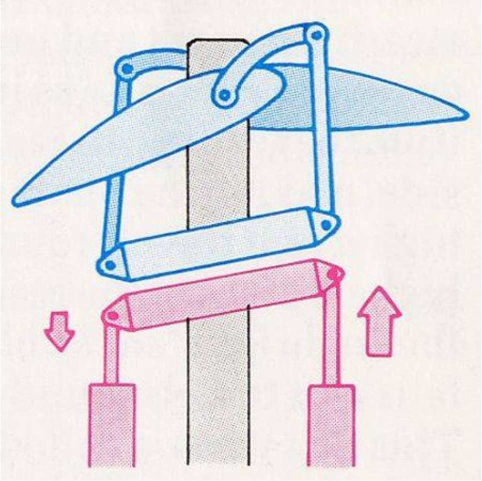


The other two significant angles are the longitudinal and lateral flapping angles. The are the result of control input from the swash plate and actuators. The angle tilts the rotor disk and changes the thrust vector relative to the center of gravity allowing translational motion.

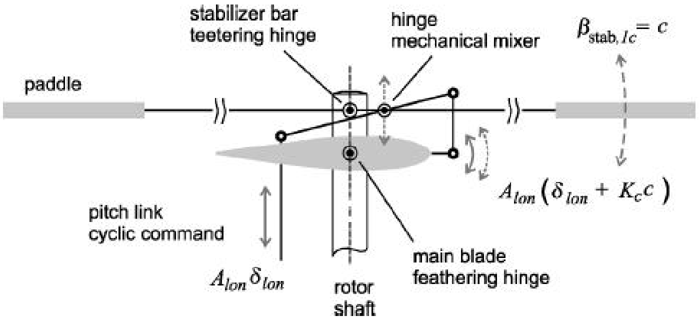
The Swash Plate

The swash plate is what transfers control input from the non rotating body to the rotating rotor head and flybar.

the lower part is actuated by the actuators and is free to move in height roll and pitch but not yaw as that would effect the phase angle where the rotor head is actuated.



The Flybar



The flybar is used to dampen the control inputs for model control since model scale helicopters have smaller rotor inertial in the man rotor disk this type of aerodynamic gearing allows of unassisted human control.

The Full CCPM Rotor Head and Swash Palate

The Parameterized State-space model

$$
\begin{bmatrix} \dot{u} \\ \dot{v} \\ \dot{p} \\ \dot{q} \\ \dot{\phi} \\ \dot{\theta} \\ \tau_f \dot{a} \\ \tau_f \dot{b} \\ \dot{w} \\ \dot{r} \\ \dot{r}_{fb} \\ \tau_s \dot{c} \\ \tau_s \dot{d} \end{bmatrix}
=
\begin{bmatrix}
X_u & 0 & 0 & 0 & 0 & -g & X_a & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & Y_v & 0 & 0 & g & 0 & 0 & Y_b & 0 & 0 & 0 & 0 & 0 \\
L_u & L_v & 0 & 0 & 0 & 0 & 0 & L_b & L_w & 0 & 0 & 0 & 0 \\
M_u & M_v & 0 & 0 & 0 & 0 & M_a & 0 & M_w & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -\tau_f & 0 & 0 & -1 & A_b & 0 & 0 & 0 & A_c & 0 \\
0 & 0 & -\tau_f & 0 & 0 & 0 & B_a & -1 & 0 & 0 & 0 & 0 & B_d \\
0 & 0 & 0 & 0 & 0 & 0 & Z_a & Z_b & Z_w & Z_r & 0 & 0 & 0 \\
0 & N_v & N_p & 0 & 0 & 0 & 0 & 0 & N_w & N_r & N_{rfb} & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & K_r & K_{rfb} & 0 & 0 \\
0 & 0 & 0 & -\tau_s & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 \\
0 & 0 & -\tau_s & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1
\end{bmatrix}
\begin{bmatrix} u \\ v \\ p \\ q \\ \phi \\ \theta \\ a \\ b \\ w \\ r \\ r_{fb} \\ c \\ d \end{bmatrix}
+
\begin{bmatrix}
0 & 0 & 0 & 0 \\
0 & 0 & Y_{ped} & 0 \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & M_{col} \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
A_{lat} & A_{lon} & 0 & 0 \\
B_{lat} & B_{lon} & 0 & 0 \\
0 & 0 & 0 & Z_{col} \\
0 & 0 & N_{ped} & N_{col} \\
0 & 0 & 0 & 0 \\
0 & C_{lon} & 0 & 0 \\
D_{lat} & 0 & 0 & 0
\end{bmatrix}
\begin{bmatrix} \delta_{lat} \\ \delta_{lon} \\ \delta_{ped} \\ \delta_{col} \end{bmatrix}
$$

Identified model from the MIT paper used for the assignment