

Aerodynamics & Flight Mechanics Research Group

Incidence Variation of a Tumbling Wing

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SCHOOL OF ENGINEERING SCIENCES

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Preamble

The analysis concerns the motion of a tumbling wing configured to be a suspended trike microlight aircraft



Nomenclature

Variable	Description
U	Forward Speed
s	Distance along Wing – Origin at Suspension Point
Ω	Tumble Rotational Speed
ψ	Azimuth Angle of Microlight
θ	Pitch Angle of Wing Relative to Trike
ϕ	Angle Centred at Trike Base subtended between Trike and Lin to Control Point
δ	Angle of Rotational Velocity Relative to Wing
β	Inclination of Point Velocity Relative to Wing Surface



Method

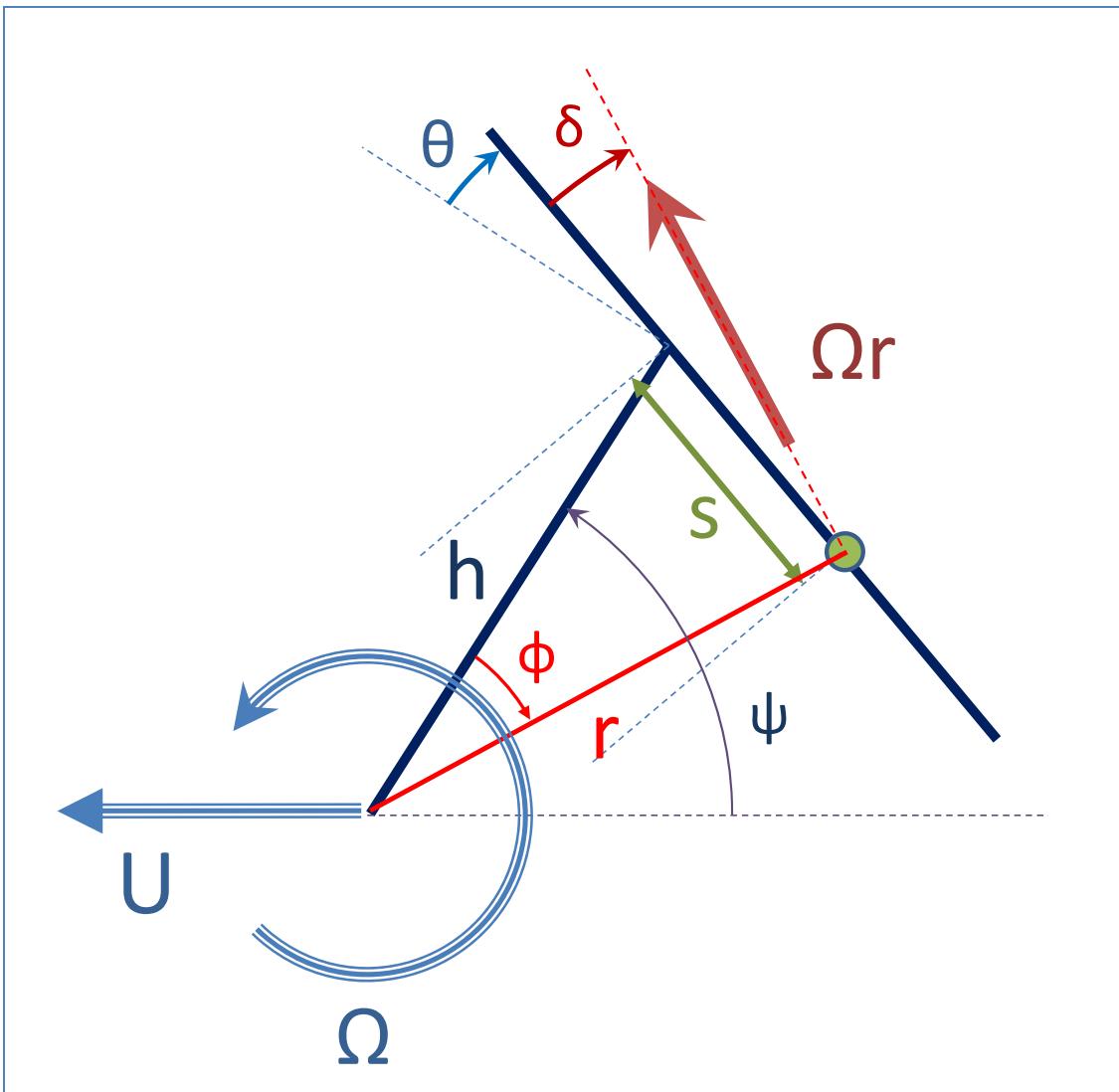


Figure 1

Using the Cosine Rule we have:



$$\begin{aligned}
 r &= \sqrt{h^2 + s^2 - 2hs \cos\left(\frac{\pi}{2} - \theta\right)} \\
 &= \sqrt{h^2 + s^2 - 2hs \sin \theta}
 \end{aligned} \tag{1.}$$

Using the Sine Rule:

$$\begin{aligned}
 u_r &= \Omega r \cdot \cos \delta \\
 v_r &= \Omega r \cdot \sin \delta
 \end{aligned} \tag{4.}$$

$$\frac{s}{\sin \phi} = \frac{r}{\sin\left(\frac{\pi}{2} - \theta\right)} = \frac{r}{\cos \theta} \tag{2.}$$

$$\sin \phi = \frac{s}{r} \cos \theta$$

The rotational velocity of the wing in directions parallel and perpendicular to the wing is:

Via the geometry in Figure 1, we have the following:

$$\delta = \phi - \theta \tag{3.}$$

whence:



The translational velocity of the wing in directions parallel and perpendicular to the wing is:

Using the following definitions:

$$\begin{aligned}
 u_{TOT} &= \Omega r \cdot \cos(\phi - \theta) + U \sin(\psi - \theta) \\
 &= V_T \left\{ \frac{r}{h} \cos(\phi - \theta) + \mu \sin(\psi - \theta) \right\} \\
 &\quad (8.)
 \end{aligned}$$

$$\begin{aligned}
 v_{TOT} &= \Omega r \cdot \sin(\phi - \theta) - U \cos(\psi - \theta) \\
 &= V_T \left\{ \frac{r}{h} \sin(\phi - \theta) - \mu \cos(\psi - \theta) \right\}
 \end{aligned}$$

$$\begin{aligned}
 V_T &= \Omega h \\
 \mu &= \frac{U}{V_T} \\
 &\quad (7.)
 \end{aligned}$$

$$\begin{aligned}
 u_r &= \Omega r \cdot \cos(\phi - \theta) \\
 v_r &= \Omega r \cdot \sin(\phi - \theta) \\
 &\quad (5.)
 \end{aligned}$$

The total velocity components parallel and perpendicular to the wing are given by:

$$\begin{aligned}
 u_t &= U \sin(\psi - \theta) \\
 v_t &= -U \cos(\psi - \theta) \\
 &\quad (6.)
 \end{aligned}$$



From which the total speed is given by:

And the inclination to the wing:

$$\tan \beta = \frac{v_{TOT}}{u_{TOT}} = \frac{\frac{r}{h} \sin(\phi - \theta) - \mu \cos(\psi - \theta)}{\frac{r}{h} \cos(\phi - \theta) + \mu \sin(\psi - \theta)} \quad (10.)$$

$$\begin{aligned} q &= \sqrt{u_{TOT}^2 + v_{TOT}^2} \\ &= V_T \left\{ \left(\frac{r}{h} \right)^2 + \mu^2 + 2 \sin[(\psi - \theta) - (\phi - \theta)] \right\} \\ &= V_T \left\{ \left(\frac{r}{h} \right)^2 + \mu^2 + 2 \sin(\psi - \phi) \right\} \end{aligned} \quad (9.)$$

