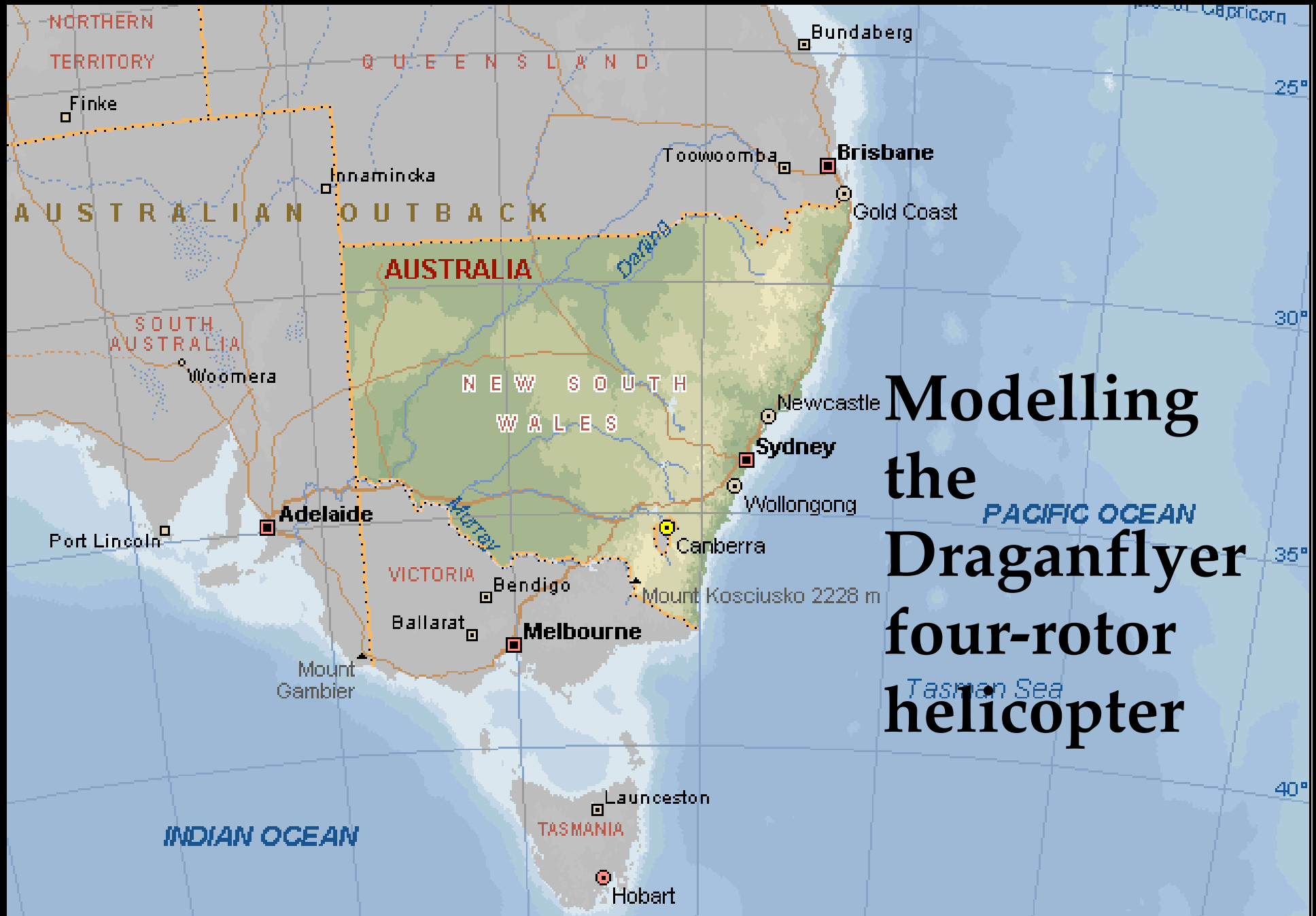


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University of Wollongong
Australia

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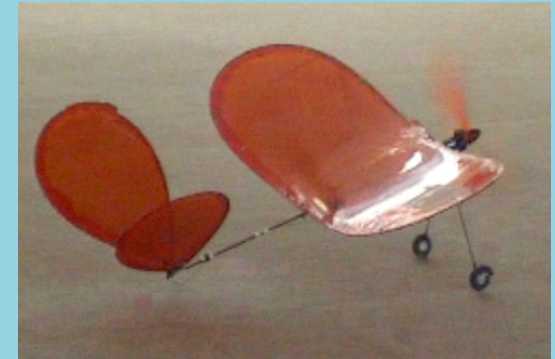


Modelling the Draganflyer four-rotor helicopter

Indoor Flight - three types of flying craft:

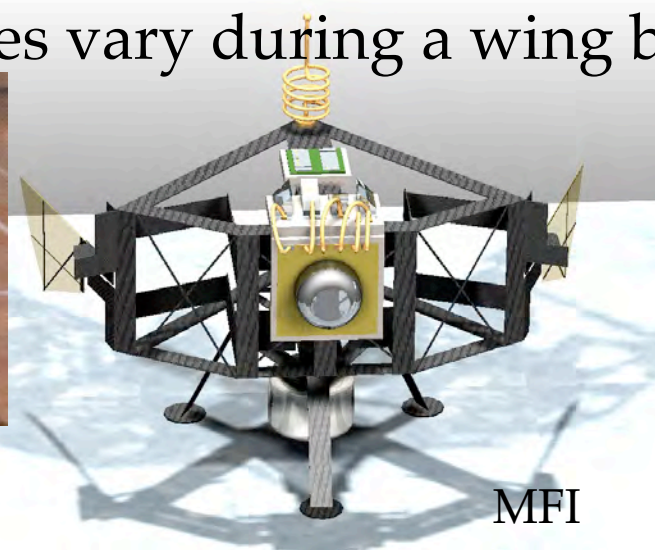
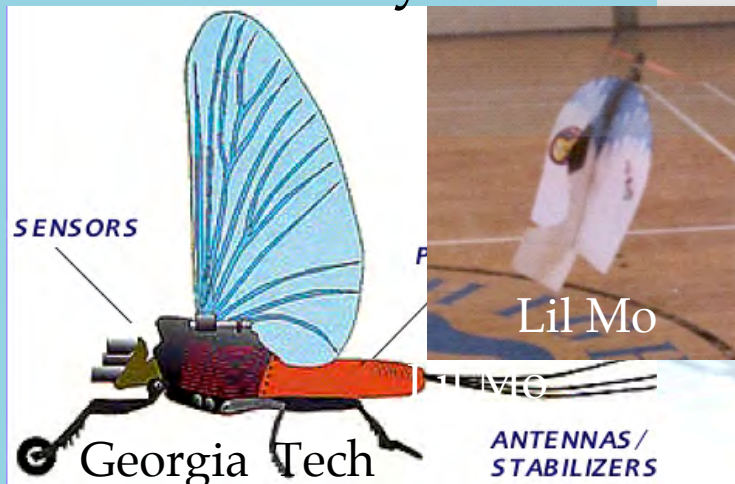
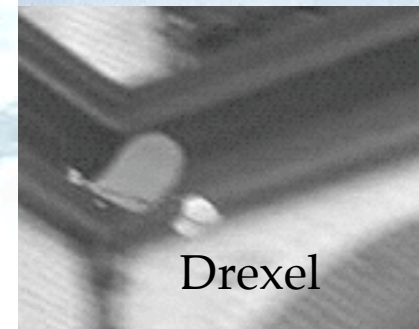
1 ultra-light fixed-wing planes

- require space to turn
- can't hover
- rotate thrust system, or vanes in air flow



2 micro-mechanical flying insects and

- attitude control: tilt body to alter direction of force
- sustained flight demonstrated
- position control inadequate for navigation
- aerodynamic forces vary during a wing beat



3 Multi-rotor helicopters:

- balance force from 4 rotors
- rotors are smaller and can be enclosed
- longer time constant - should be easier to stabilize
- counter rotating torque balance through airframe



Moller



UrbanAero



UrbanAero



Moller

Single-rotor helicopters:

- tail rotor to balance counter rotating torques
- exposed rotor is very dangerous indoors
- several months to learn to fly an R/C helicopter
- very short time constant - all mass under a single rotor
- can vary rotor speed, pitch angle, cyclic pitch angle



Draganflyer

- r/c toy with a carbon fibre air frame
- user commands - throttle, roll, pitch, yaw
- 3 axis gyro to convert to 4 forces
- not easy to fly - exceedingly difficult inside
- hover - drifts away from location
- wanders about a trajectory
- oscillatory motion



- control - rotor speed of 4 rotors
- lift force is $f(\text{sum of rotor speeds})$
- torque is $f(\text{difference between rotor speeds})$
- underactuated - 4 input forces \rightarrow 6 DOF motion
- control requires continuous fine corrections
- close loop in rotation dimensions with gyros
 - rotation proportional to operator command
 - attempt to correct for external disturbances
- induced moment
 - counter rotating rotors

DM Aero



DM Aero

- $1/r$ torques balance f/b torques
- stresses airframe



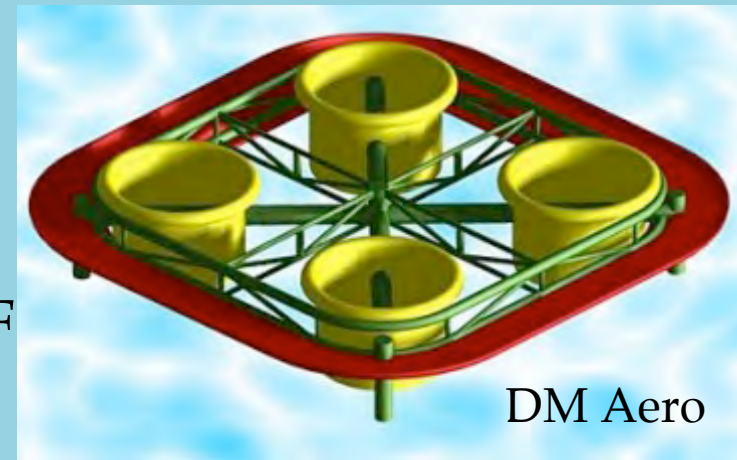
AeroVironment

Draganflyer

- highly coupled motion
- change speed of one rotor
 - > motion in at least 3 DOF

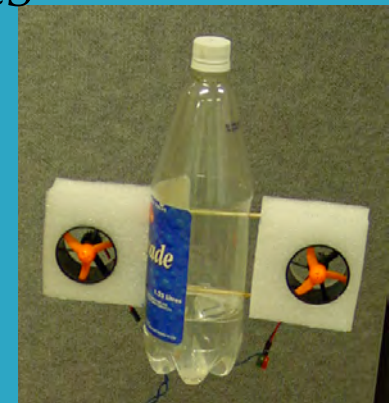
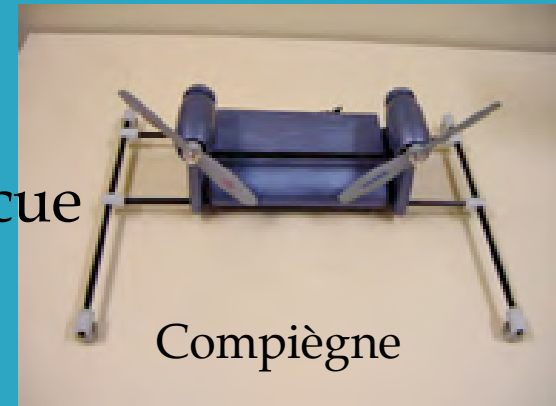
e.g.

- reduce speed of right rotor
 - > roll to right left force \leftrightarrow right force
 - > translate to right force component to left
 - > yaw to right induced moment
 - > change direction of translation
 - > fall - reduced vertical thrust



Indoor Flight:

- surveillance in urban search and rescue
- flight in restricted spaces
 - hallways, stairwells, windows
 - width of opening $< 2 * \text{wingspan}$
- constraints
 - fly through opening without touching sides
 - * requires stable control of flight
 - turn within opening to scan environment
 - * requires stable control of hovering
 - navigate a sequence of restricted spaces
 - * requires accurate localisation
 - can only be achieved with sensor controlled motion



Indoor flight sub problems:

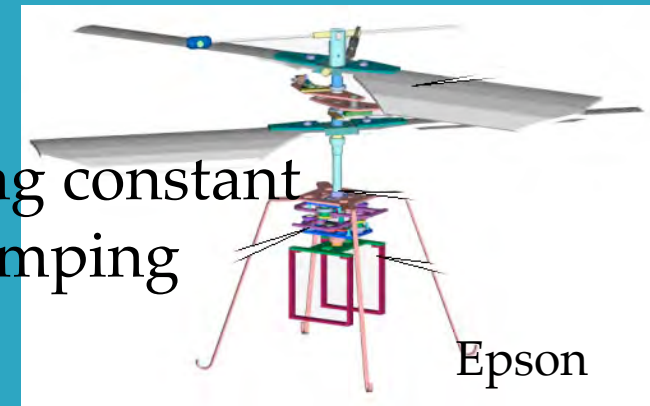
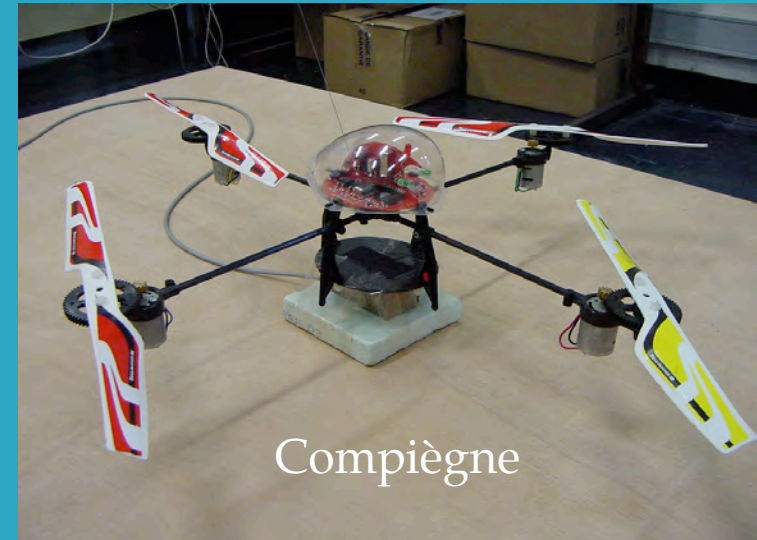
- 1 flying through an opening
- 2 flying along a corridor
- 3 turning

Control problems

- 1 control of stable hovering - forces opposing motion?
- 2 control of directed motion - reduce cross coupling?
- 3 transition

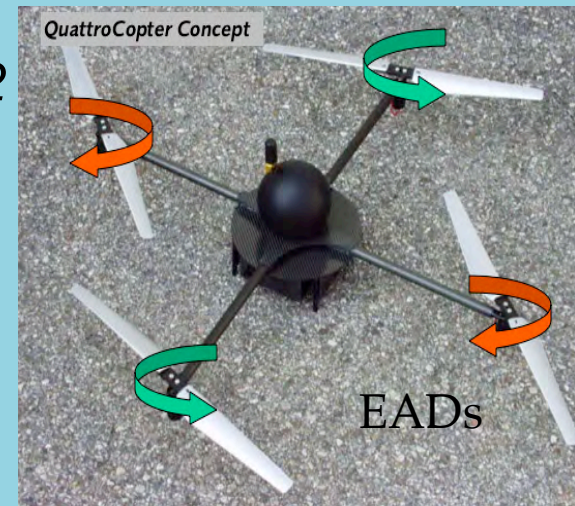
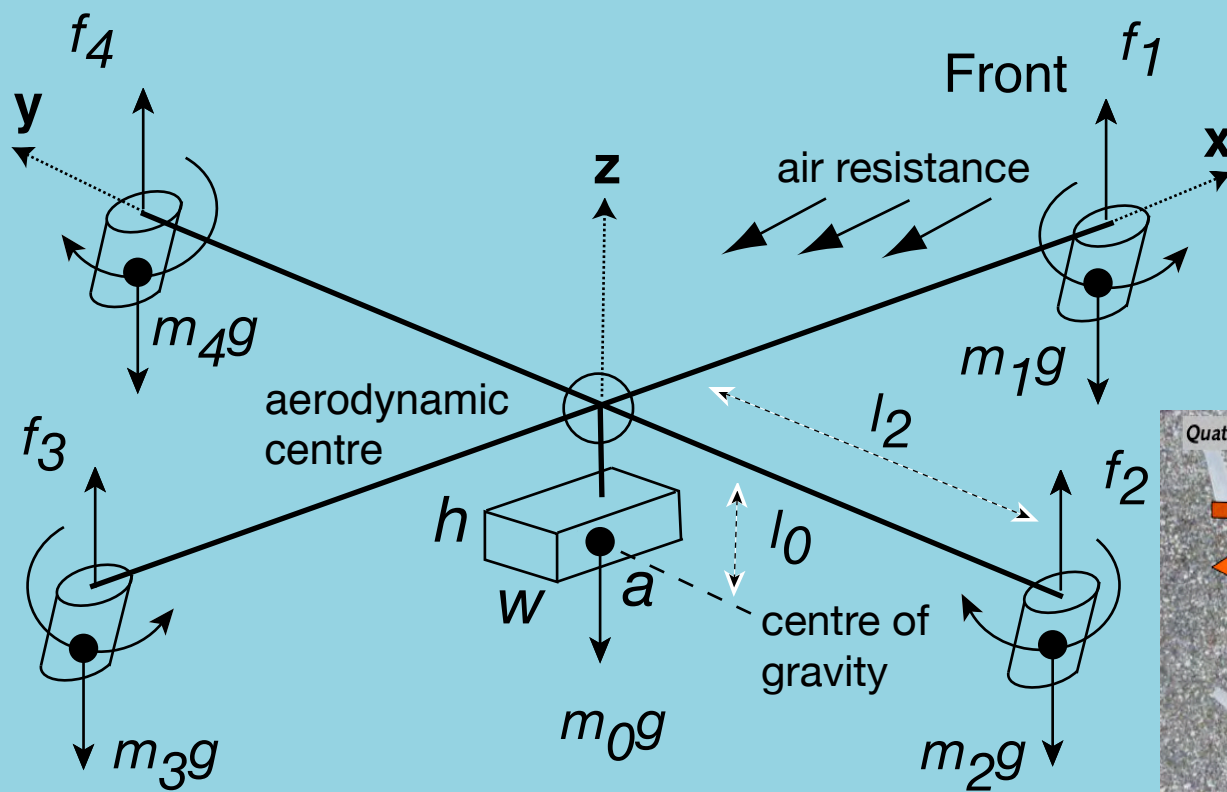
Constraints on motion

- no air flow over airfoils = no spring constant
- miniscule viscous friction = no damping
- lots of mass => inertia
- marginally stable system



Force Balance:

$$f_1 + f_2 + f_3 + f_4 = (m_0 + m_1 + m_2 + m_3 + m_4) * g$$



Inertia:

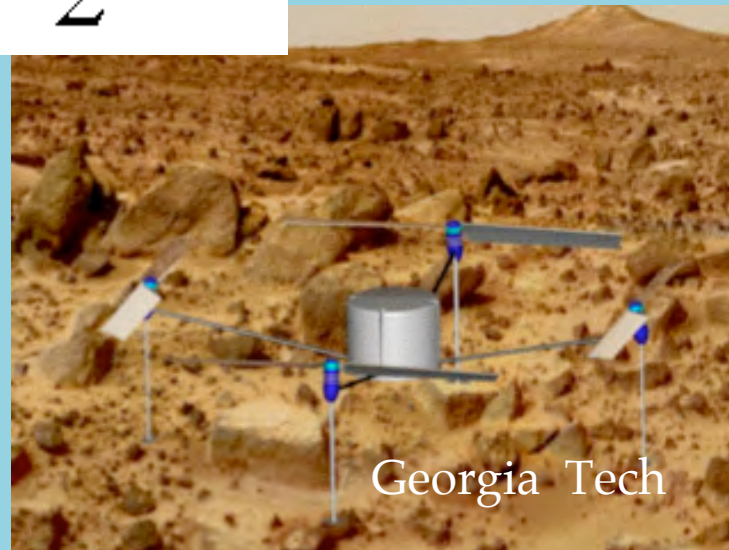
- 5 masses attached to centre of rotation by thin rods

1. Cross spars - two intersecting rods

l = length, d = radius

$$I_{cx} = I_{cy} = \frac{m_c l^2}{12} + \frac{m_c d^2}{2}$$

$$I_{cz} = \frac{m_c l^2}{6}$$

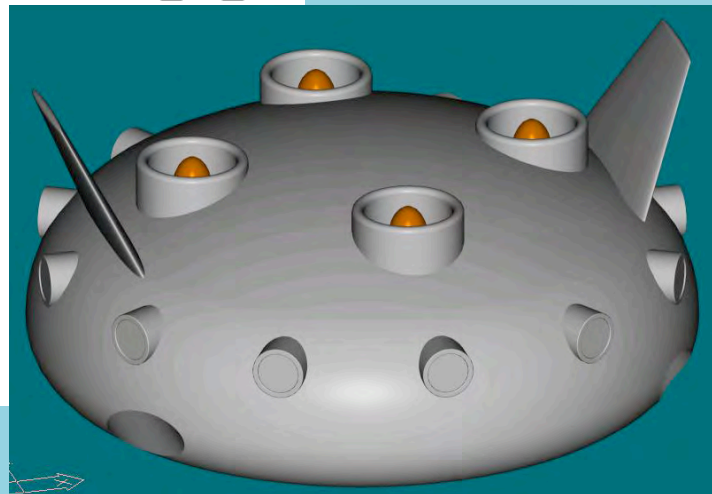
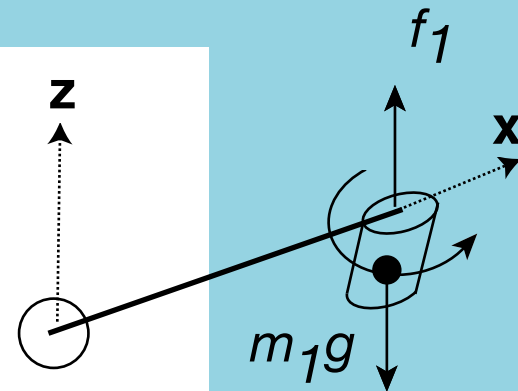


2. Motors as cylinders that hang below the cross
 $p = \text{length}, r = \text{radius}$

$$I_{mx1} = \frac{m_1 r^2}{4} + \frac{m_1 p^2}{3}$$

$$I_{my1} = \frac{m_1 r^2}{4} + \frac{m_1 p^2}{3} + m_1 l_1^2$$

$$I_{mz1} = \frac{m_1 r^2}{2} + m_1 l_1^2$$



3. Battery hanging below cross dimensions a, w, h

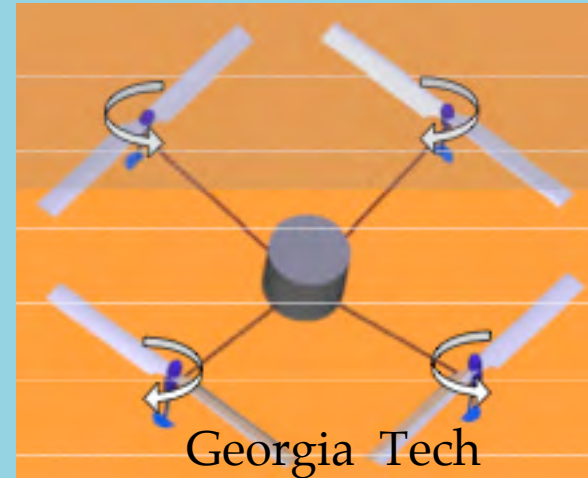
$$I_{bx} = \frac{m_b(w^2 + h^2)}{12} + m_b l_0^2$$

$$I_{by} = \frac{m_b(a^2 + h^2)}{12} + m_b l_0^2$$

$$I_{bz} = \frac{m_b(w^2 + a^2)}{12}$$

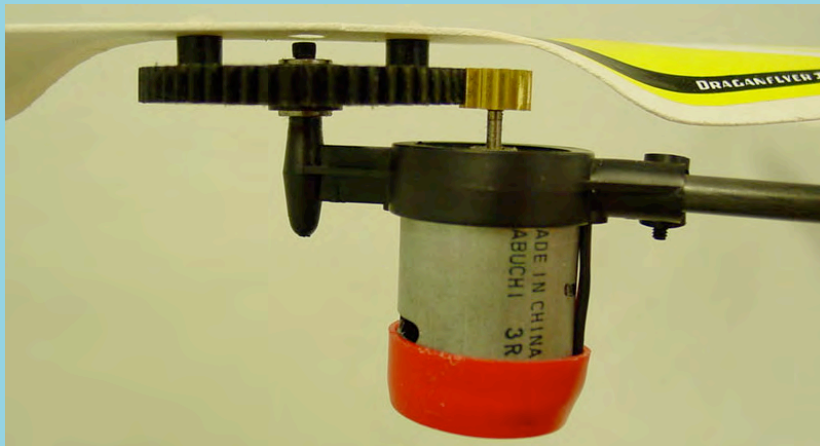
Roll inertia

$$I_x = I_{cx} + I_{mx1} + I_{mx2} + I_{mx3} + I_{mx4} + I_{bx}$$



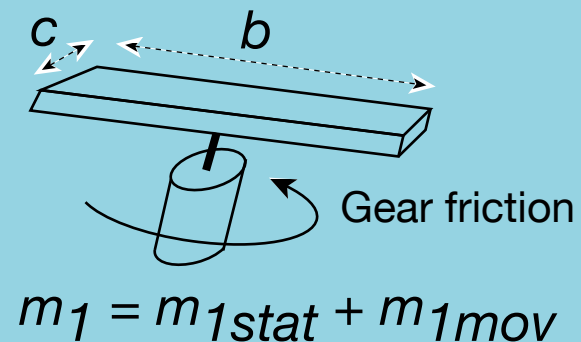
Gyroscopic torques

- motor spin axes parallel to z axis
- roll & pitch change direction of motor rotation axis
- turn spin axis to align it with precession axis
- roll around x, spin around z, torque around y



$$I_{pz} = \frac{m_{1mov} (b^2 + c^2)}{12}$$

$$\tau_y = I_{pz} \omega_{pz} \times \omega_x$$
$$\tau_x = I_{pz} \omega_{pz} \times \omega_y$$



Coriolis acceleration

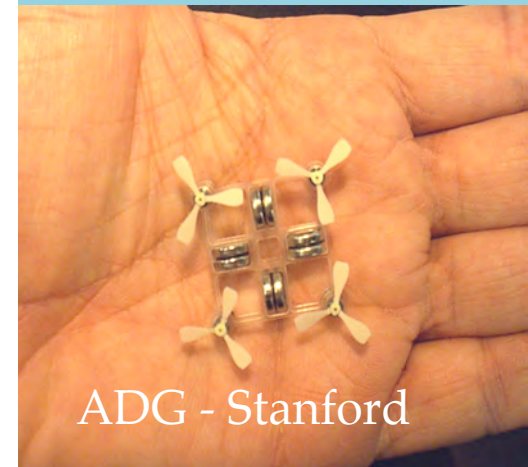
- the difference between non-rotating and rotating axes
- yaw - blades experience coriolis acceleration

$$\mathbf{a}_c = \boldsymbol{\omega}_{pm} \times \mathbf{v}_{lin}$$

Propeller thrust

$$F_{lift} = \frac{\rho C_l U^2 S}{2} = K_l \omega_{mp}^2$$

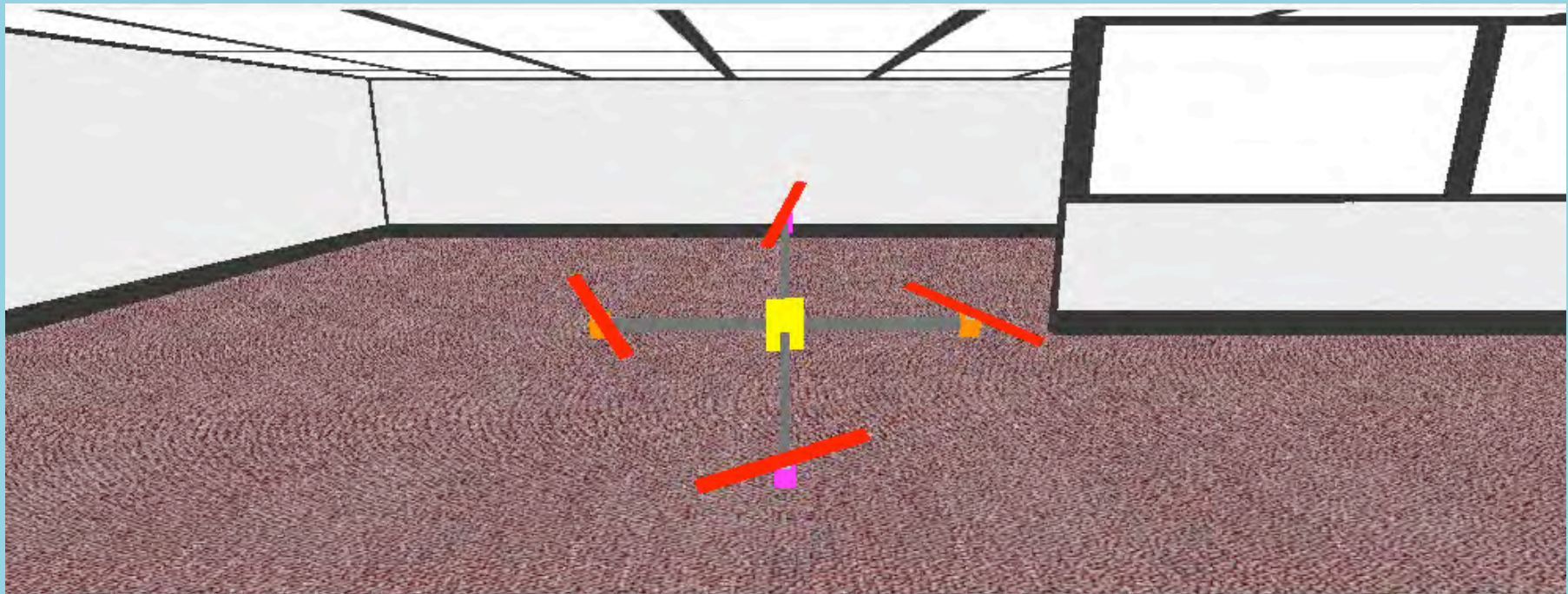
$$F_{drag} = \frac{\rho C_d U^2 S}{2} = K_d \omega_{mp}^2$$



ADG - Stanford

Simulator

- developed in GL for Java
- porting to JOGL



+Throttle (E)		+Pitch (I)		Input	RPM	Rotor Force (N)	Position	Rear View		
-Yaw (S)	+Yaw (F)	-Roll (J)	+Roll (L)	Throttle : 18000	Front : 361	Front : 134	X : 7.1747265	Lock Height		
-Throttle (D)		-Pitch (K)		Yaw : 0	Back : 460	Back : 217	Y : 1.3797226	Lock Screen		
				Pitch : -6000	Left : 419	Left : 180	Z : 2.1113658	Sensitive Mode		
				Roll : 1000	Right : 402	Right : 166	Visible Walls			
DF Velocity(m/s)	DF Acceleration(m/s)	F-Force (N)	B-Force (N)	L-Force (N)	R-Force (N)	Acceleration(m/s)	Speed (m/s)	Degree		
X	-1.4363338	-0.19788261	-59	-96	-80	-73	Yaw	-8.278424E-6	-4.1392119E-7	-9.727154E-5
Y	0.10687487	0.08067809	1	2	2	1	Pitch	-32.784775	-1.6392387	-26.57633
Z	0.0	1.977214	127	205	171	158	Roll	-100.860054	-5.0430026	-0.37726447

Acknowledgement

Images used in this talk were downloaded from:

- DM AeroPlatforms Ltd - <http://www.dmaerosafe.freesevers.com/index.html>
- University of Technology of Compiègne - <http://www.hds.utc.fr/~helico/>
- MFI Project - <http://robotics.eecs.berkeley.edu/~ronf/mfi.html>
- Urban Aeronautics Ltd. - http://www.urbanaero.com/Urban_Main.htm
- Moller International - <http://www.moller.com/>
- AeroVironment - <http://www.aerovironment.com/>
- Draganflyer - <http://www.rctoys.com/draganflyer3.php>
- J. Borenstein - Michigan - <http://www-personal.engin.umich.edu/~johannb/>
- EADs - <http://www.eads.com/>
- P. OH - Drexel - <http://www.pages.drexel.edu/~pyo22/index.html>
- Georgia Tech Aerial Robotics - <http://controls.ae.gatech.edu/gtar/>
- Lil Mo - <http://www.bumpygreen.co.uk/index.htm>
- ADG - Stanford - <http://aero.stanford.edu/mesicopter/>

