DEFENCE ACADEMY
OF THE UNITED KINGDOM

Cranfield UNIVERSITY

Defence College of Management and Technology

Micro Air Vehicle Design Studies

Dr Kevin Knowles

Department of Aerospace, Power and Sensors
Cranfield University
Defence Academy of the UK
Shrivenham, England

EWADE 2005, Toulouse

Outline

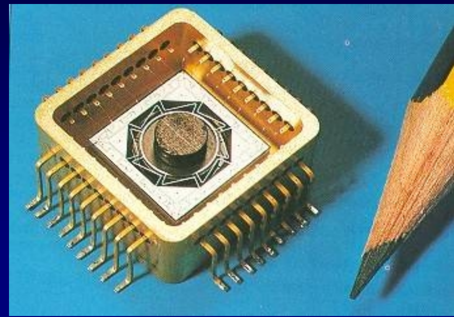
- Introduction
- Flapping-wing MAV Design
  - Flapping-Wing Problem
  - Aerodynamic Model
  - Parametric Study
- Fixed-wing MAV Design
- Summary

- Acknowledgements:
- Dr Rafal Zbikowski (FMAV project co-ordinator)
- Dr Salman Ansari (FMAV wing design and algorithm)
- Peter Wilkins (FMAV presentation)
- Elizabeth Hanbury-Chatten (Fixed-wing MAV presentation)

Introduction

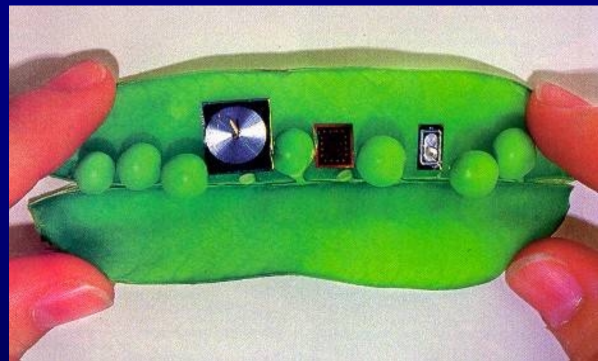
Micro Air Vehicles

- Defined as small flying vehicles with
  - Size: 150-230mm
  - Weight: 50–100g
  - Endurance: 20–60min



Microgyro

- Reasons for **U**AVs:
  - D^3 – 'Dull, Dirty, or Dangerous'
  - Cost – Initial cost & operating costs



Microsensors

- Reasons for MAVs:
  - Existing UAVs limited by large size
  - Niche exists for MAVs – e.g. indoor flight, low altitude, man-portable

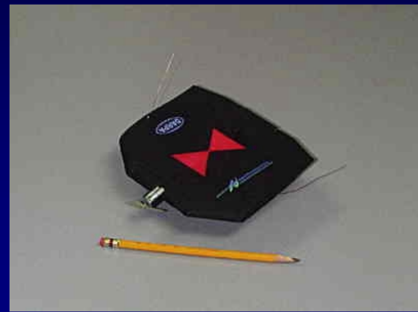
MAV Attributes

- Essential:
  - High Efficiency
  - Ability to carry at least one sensor
  - High manoeuvrability at low speeds (~5 m/s)
  - High autonomy
  - (Vertical flight & hover capability)
- Desirable:
  - Low aural/visual signature
  - durability

MAV Options

Fixed wing:

- ✓ Simple, lightweight
- ✗ Efficiency – best at cruise
- ✗ Manoeuvrability – poor at low speeds
- ✗ Efficient hover – no



Black Widow

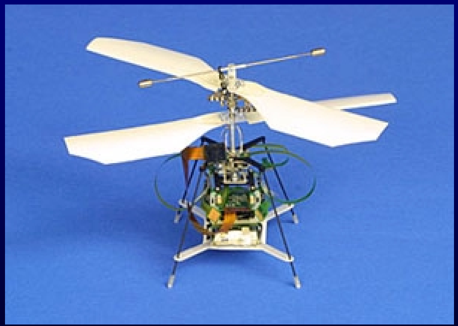
Wasp

Black Widow

MAV Options

Rotary wing:

- ✓ Manoeuvrability – good at low speeds
- ✘ Efficiency – poor
- ✘ Efficient hover – not at small scales
- ✘ Noisy
- ✘ Instability effects when close to walls
- ✘ Adverse Reynolds number effects at small scales



Epson μFR-II

Pixelito (courtesy A. Van de Rostyne)

MAV Options

Lighter than air:

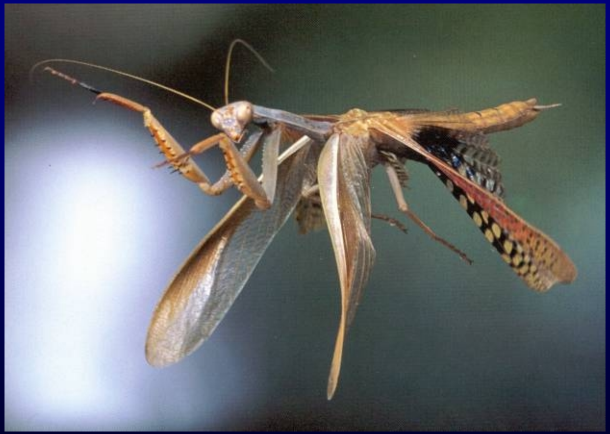
- ✓ Efficiency – lift efficiency good
- ✓ Efficient hover – yes
- ✓ Acoustic signature – good
- ✘ Manoeuvrability – poor
- ✘ Durability – poor
- ✘ Smallest lighter than air vehicle ~ 20" diameter

Plantraco Microblimp

MAV Options

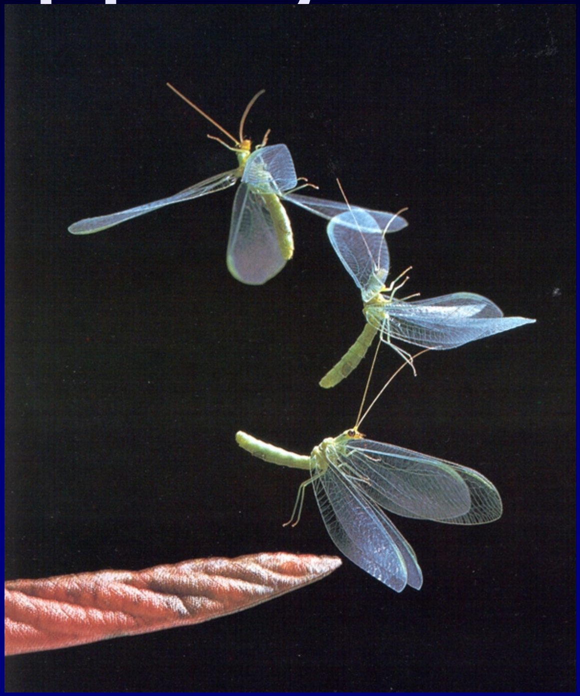
Flapping wing:

- ✓ Efficiency – very good
- ✓ Manoeuvrability – very good, even at low speeds
- ✓ Efficient hover – yes
- ✓ Zero acoustic signature if flapping frequency below 20 Hz



Why insect-like flapping?

- Insects are more manoeuvrable
- Power requirement:
  - Insect – 70 W/kg **maximum**
  - Bird – 80 W/kg **minimum**
  - Aeroplane – 150 W/kg
- Speeds:
  - Insects ~ 7mph
  - Birds ~ 15mph



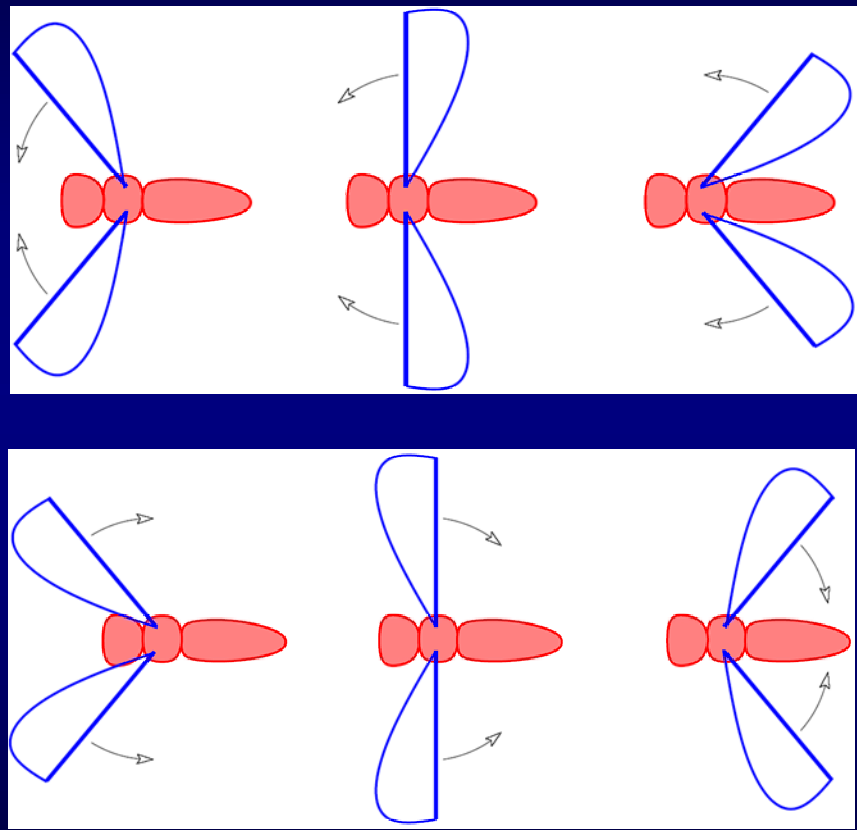
DEFENCE ACADEMY
OF THE UNITED KINGDOM
Cranfield UNIVERSITY
Defence College of Management and Technology

Flapping-Wing Problem

DEFENCE ACADEMY OF THE UNITED KINGDOM
Cranfield UNIVERSITY
Defence College of Management and Technology

Wing Kinematics – 1

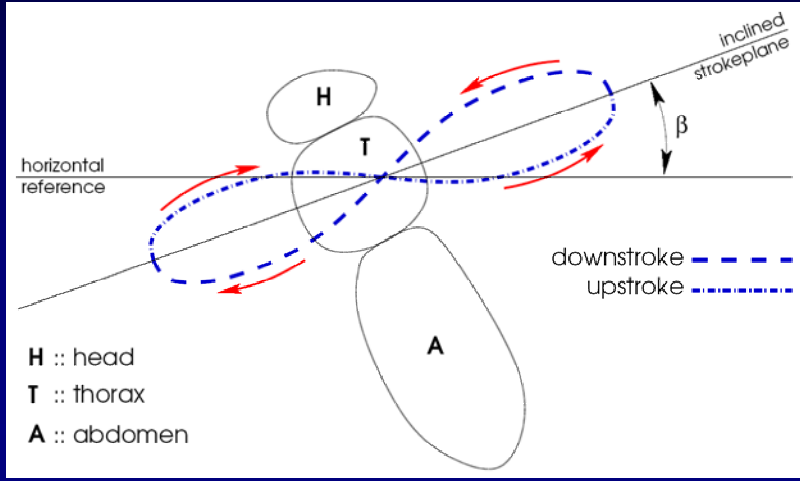
- Flapping Motion
  - sweeping
  - heaving
  - pitching
- Key Phases
  - Translational
    - downstroke
    - upstroke

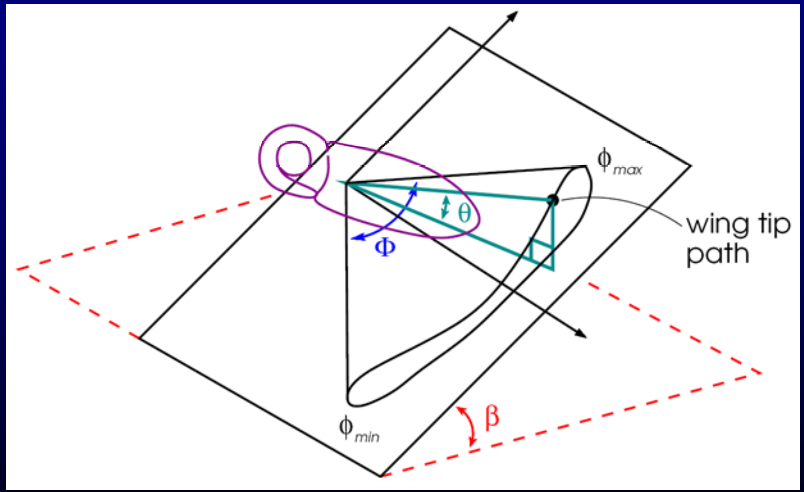


Wing Kinematics – 1

- Flapping Motion
  - sweeping
  - heaving
  - pitching

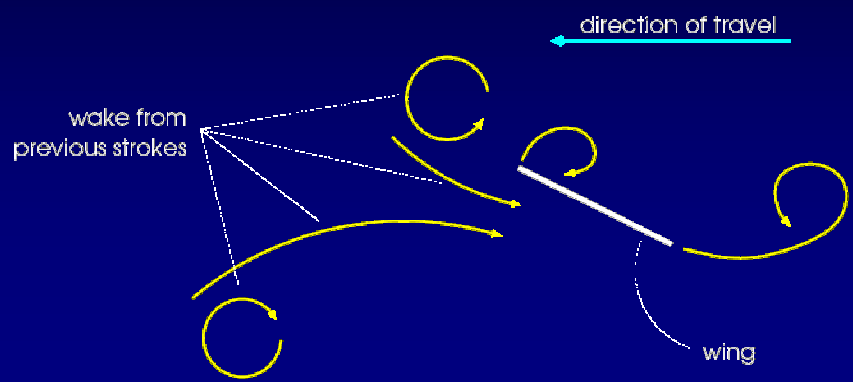
- Key Phases
  - Translational
    - downstroke
    - upstroke
  - Rotational
    - stroke reversal
    - high angle of attack

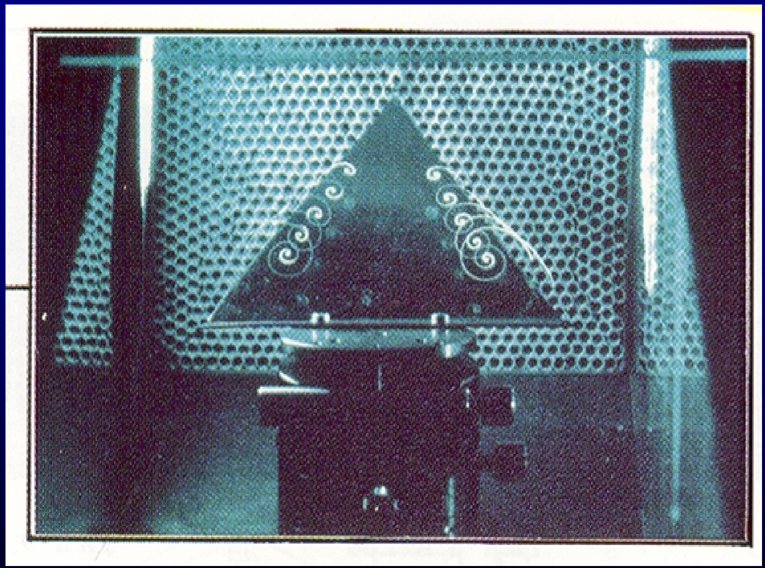




Aerodynamics

- Key phenomena
  - unsteady aerodynamics
    - apparent mass
    - Wagner effect
    - returning wake
  - leading-edge vortex



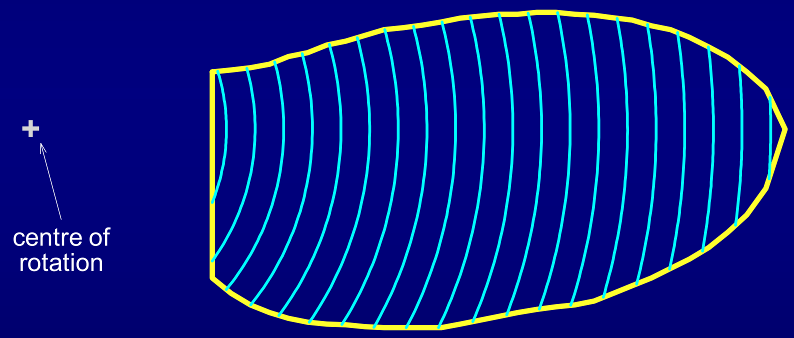


[Photo: Prenel *et al* 1997]

Aerodynamic Model

Aerodynamic Modelling – 1

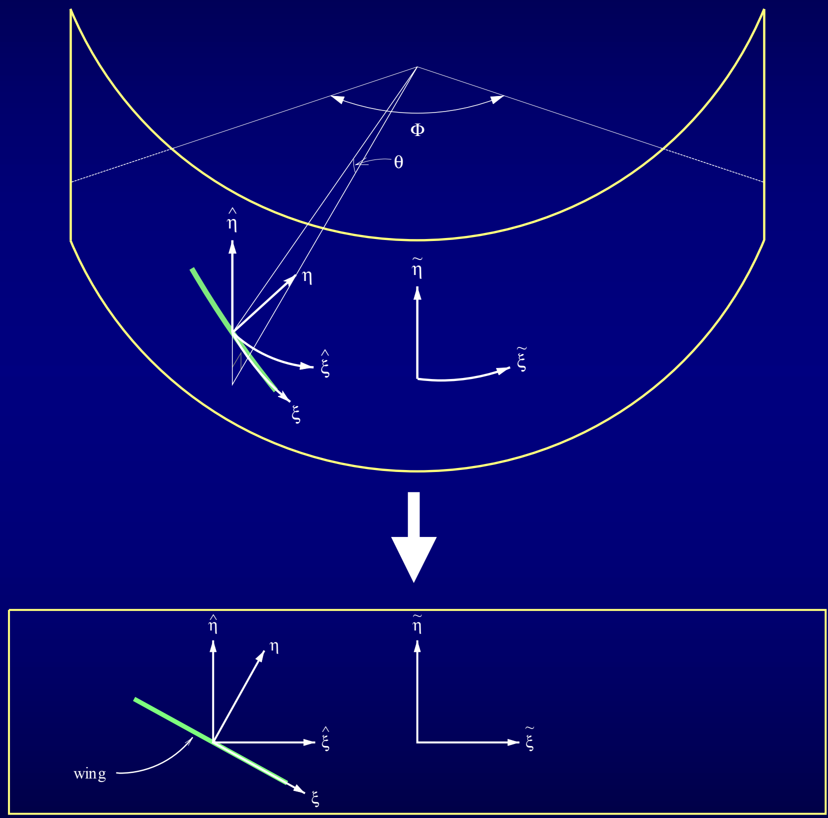
- Quasi-3D Model
- 2-D blade elements with
  - attached flow
  - separated flow
    - leading-edge vortex
    - trailing-edge wake
- Convert to 3-D
  - radial chords



Robofly wing

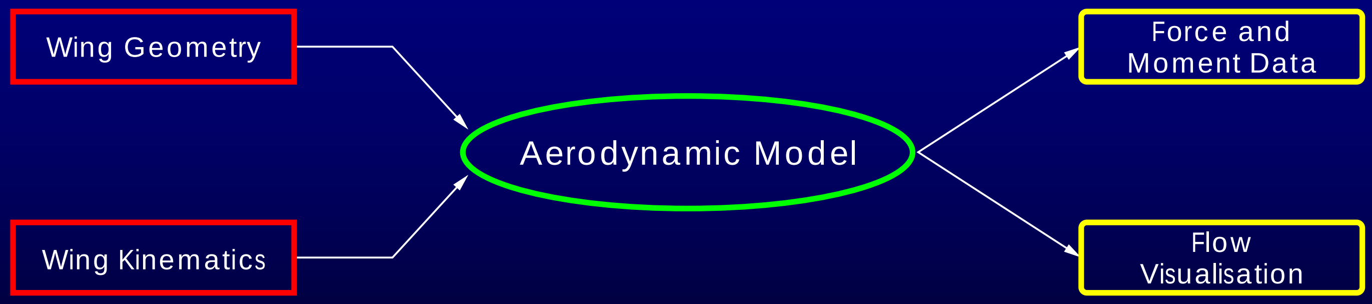
Aerodynamic Modelling – 1

- Quasi-3D Model
- 2-D blade elements with
  - attached flow
  - separated flow
    - leading-edge vortex
    - trailing-edge wake
- Convert to 3-D
  - radial chords
  - cylindrical cross-planes
  - integrate along wing span

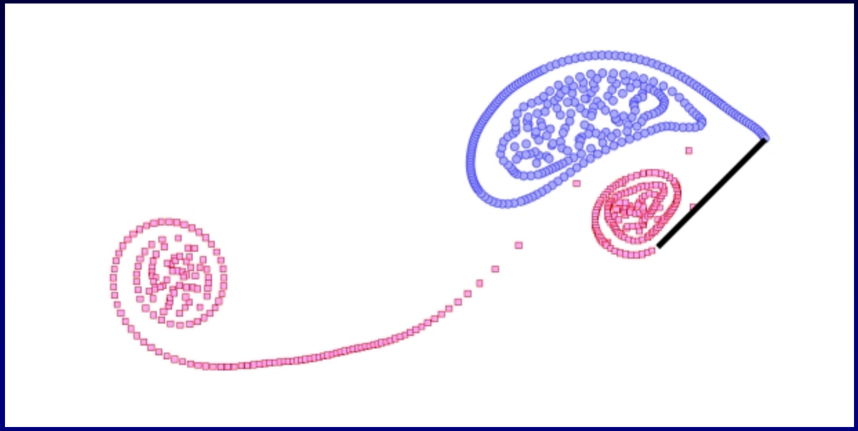


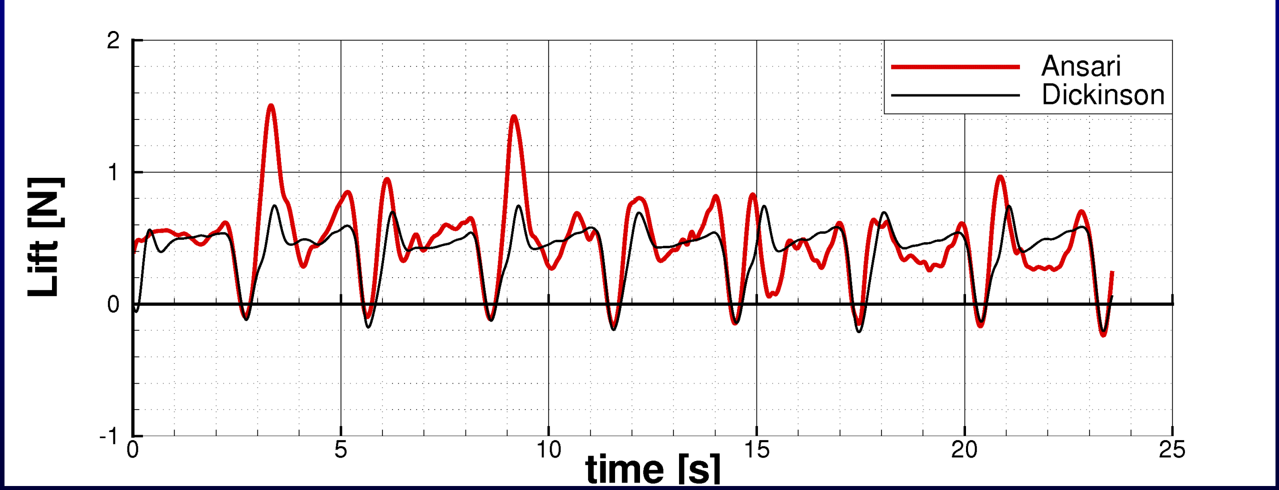
Aerodynamic Modelling – 2

- Model Summary
  - 6 DOF kinematics
  - circulation-based approach
  - inviscid model with viscosity introduced indirectly
  - numerical implementation by discrete vortex method
  - validated against experimental data



Validation of Model



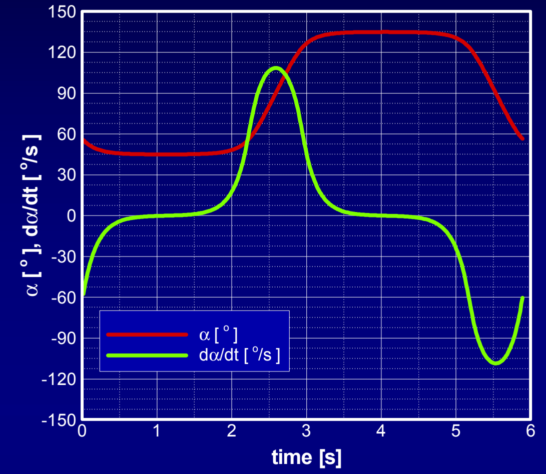


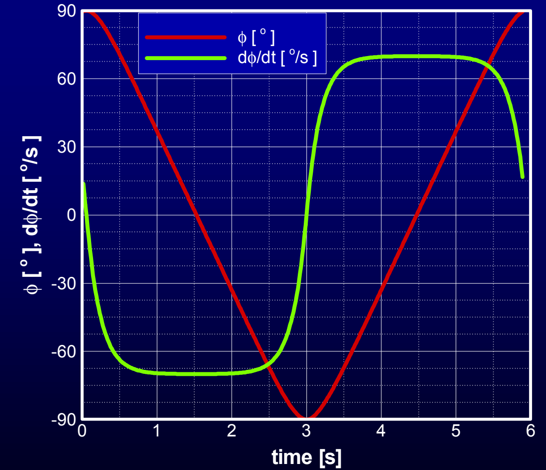
Parametric Study

Wing Kinematics Parameters

- One parameter varied at a time
  - flapping frequency
  - stroke amplitude
  - rotation lead/lag

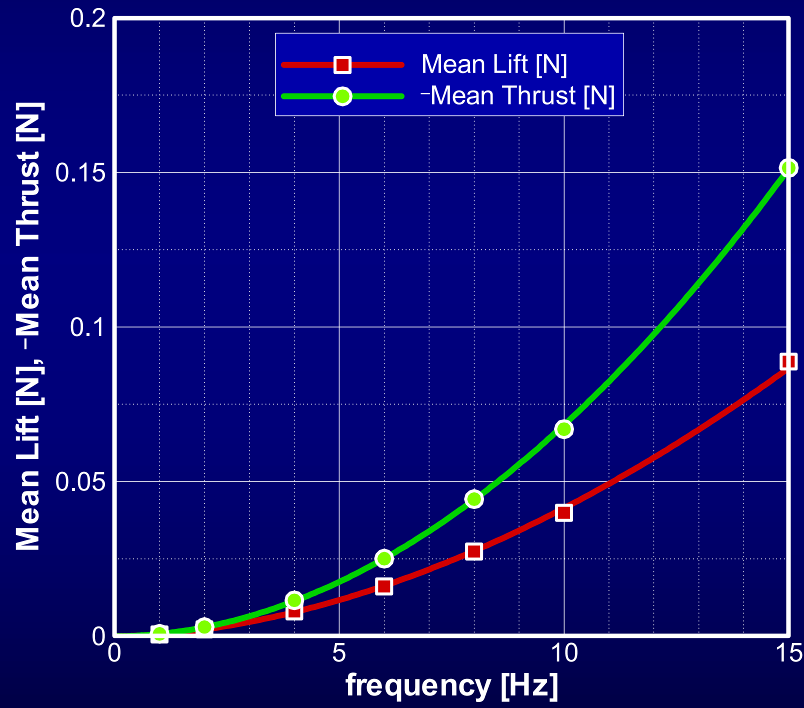
- Simulation `constants'
  - flapping frequency 2Hz
  - simulation time 1.0s
  - stroke amplitude 101.7°
  - kinematics Dickinson
  - wing shape Robofly





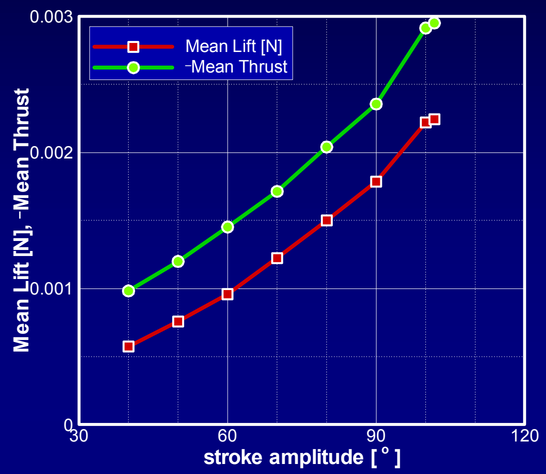
Flapping Frequency

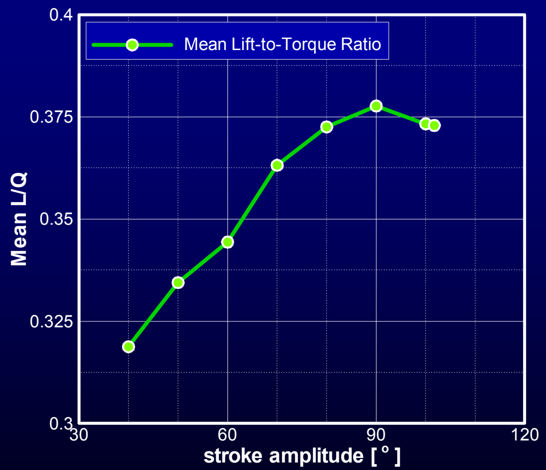
- Forces scale roughly with square of flapping frequency
- Increase in lift obtained without change in lift-to-torque ratio
- Limited by noise and hysteresis issues



Stroke Amplitude

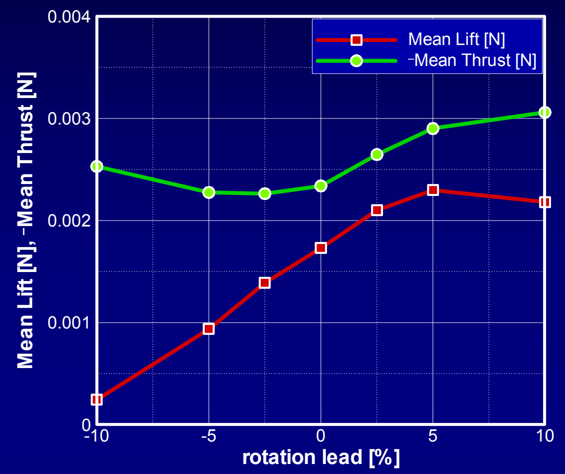
- Forces increase with stroke amplitude
- Lift-to-torque ratio peaks and drops
- Two opposing effects in operation
  - increased lift due to higher flapping velocities as stroke amplitude increases
  - increased flow breakdown as larger stroke amplitudes are swept

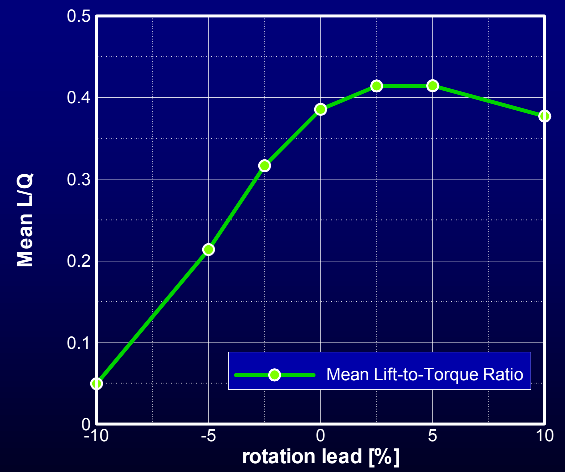




Rotation Lead

- Forces generally increase with advancing rotation
- Lift-to-torque ratio peaks and drops
- Two opposing effects in operation:
  - advanced rotation means higher angles of attack reached while translational speeds are significant, giving higher quasi-steady lift
  - larger pitch changes give rise to large starting vortices which impede lift

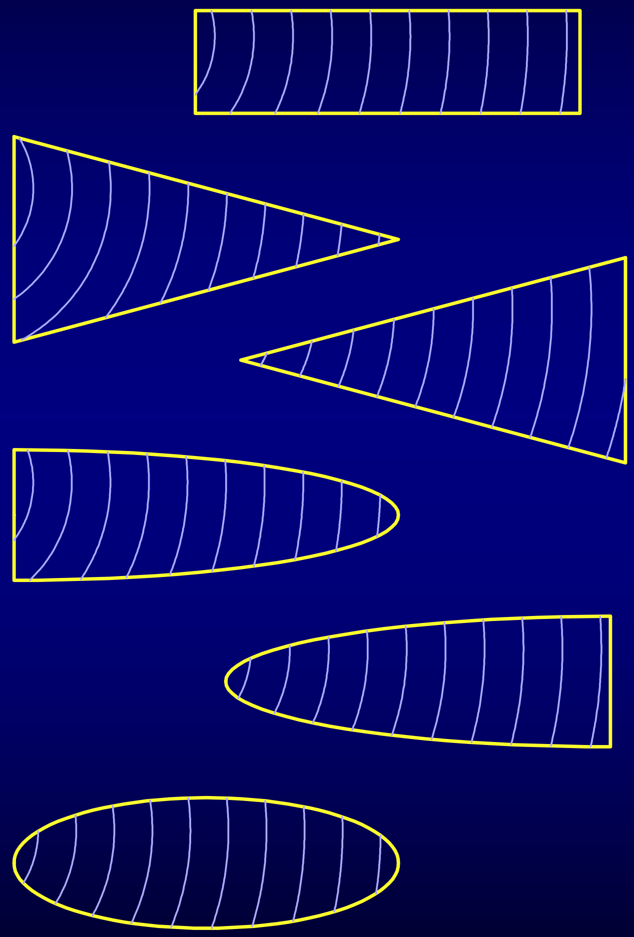




Wing Shape Parameters

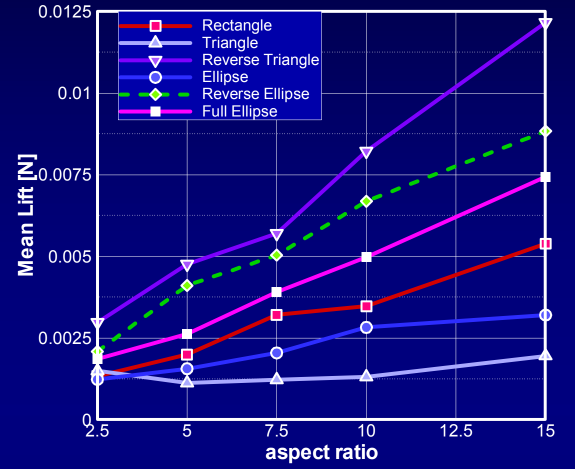
- 6 wing shapes
- One parameter varied at a time
  - aspect ratio
  - wing length
  - wing area
  - planform shape
- Simulation `constants'

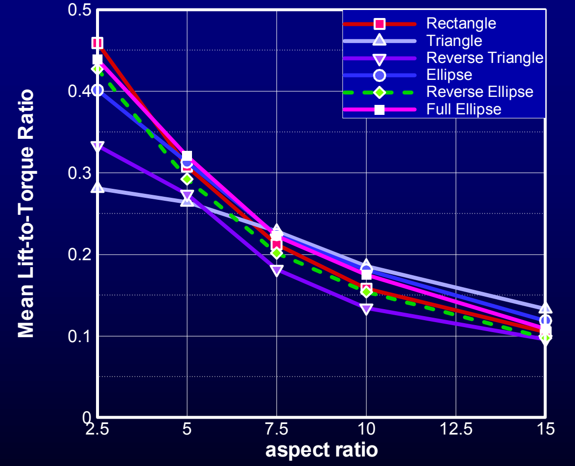
wing length	125mm
mean chord	66.7mm
wing area	4167mm²
aspect ratio	7.5
pitch-axis location	¼-chord
wing offset	25mm



Aspect Ratio

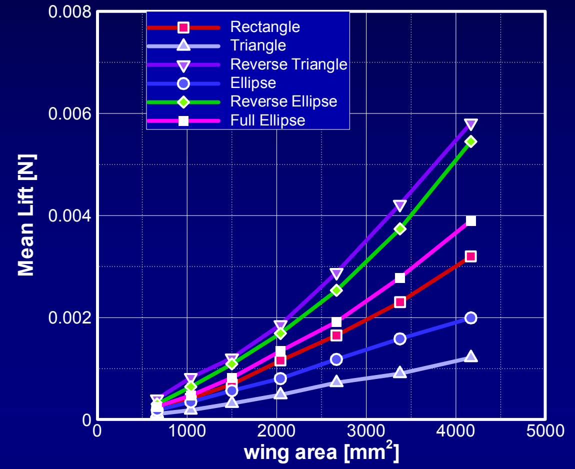
- Forces generally increase with aspect ratio
- Two main effects in operation
  - large aspect ratios mean narrower wings, implying smaller wing chords travel greater distances
  - flow is older in terms of 'chord-lengths travelled', hence more vortex breakdown and lower lift

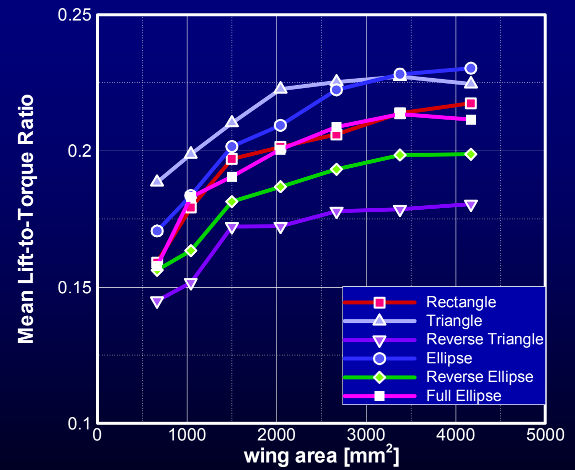




Wing Area

- Forces increase rapidly with wing area
- Lift-to-torque ratio plateaus, hence, not beneficial to increase wing area beyond certain value
- Practical constraints of wing loading against size





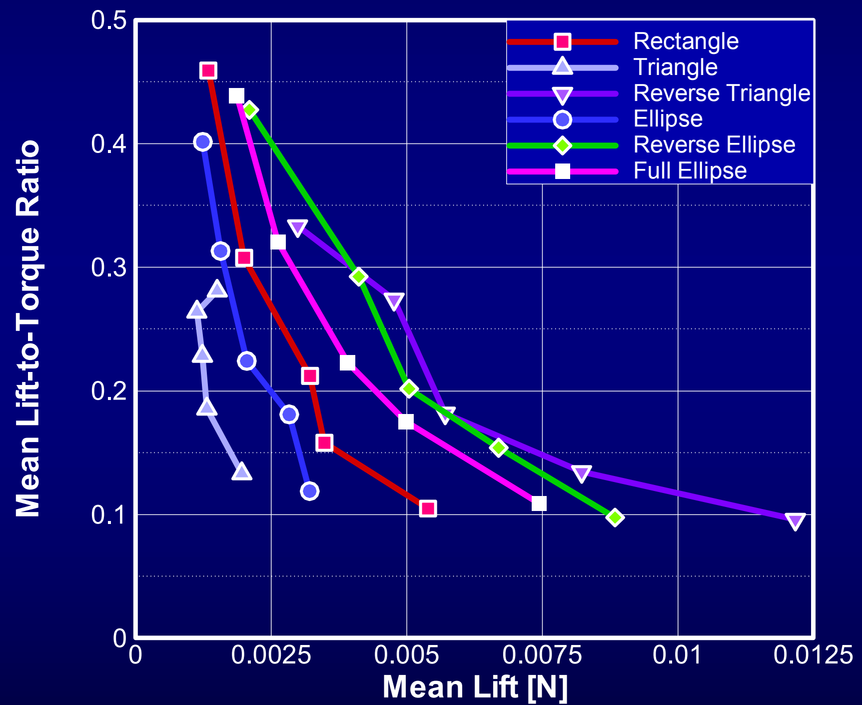
DEFENCE ACADEMY OF THE UNITED KINGDOM

Cranfield UNIVERSITY

Defence College of Management and Technology

Planform Shape

- Lift greater for more wing area outboard
- Lift-to-torque ratio decreases with increasing lift
- Practical considerations
  - High lift
  - High lift-to-torque ratio for low power
  - Low wing-root bending moment



Main Findings

- Favourable Wing Kinematics
  - high flapping frequency
  - large stroke amplitude
  - advanced wing rotation
- Favourable Wing Shape
  - high aspect ratio and wing length
  - large wing area
  - more outboard wing area
- Practical Considerations
  - low acoustic signature
  - hysteresis
  - low wing-root bending moment
  - small size and low wing loading

DEFENCE ACADEMY OF THE UNITED KINGDOM
Cranfield UNIVERSITY
Defence College of Management and Technology

Fixed-wing MAV Design

Aim

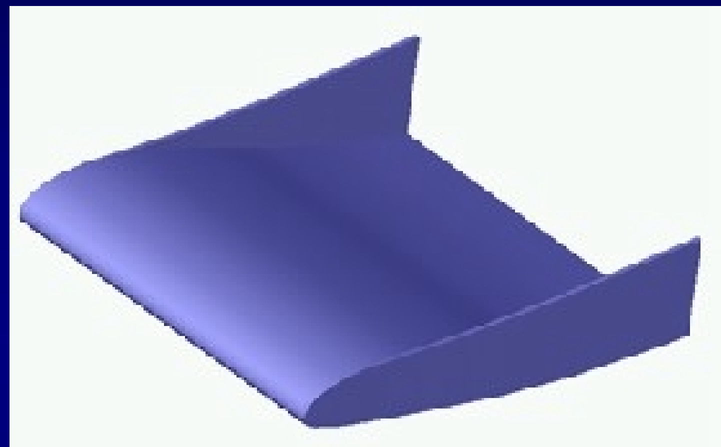
- To design an MAV to be used as a flying test platform for future systems
- The MAV should be suitable for military surveillance use
- The cost must be kept to a minimum

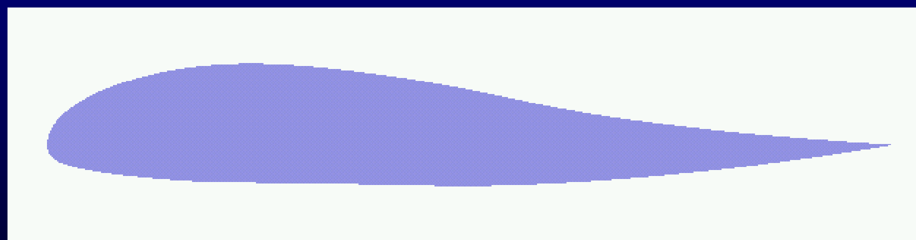
Approach

- Use off-the-shelf components
- Minimise manufacturing costs
- Durable airframe
- Radio controlled

Configuration and Airframe

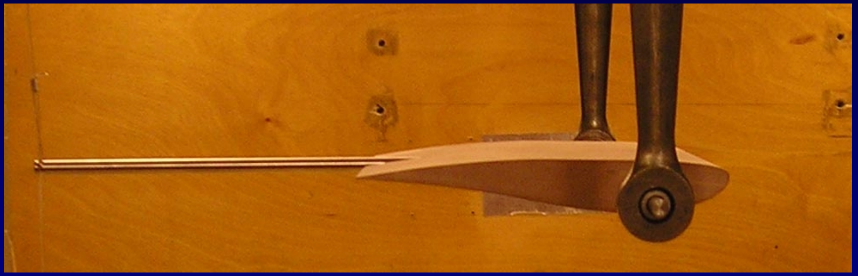
- Square wing with vertical wingtip fins
- Fauvel 14% t/c reflex aerofoil
- Hot wire cut EPP foam
- Powered by an electric motor and 860mAh lithium polymer 2 cell pack
- Elevon control surfaces

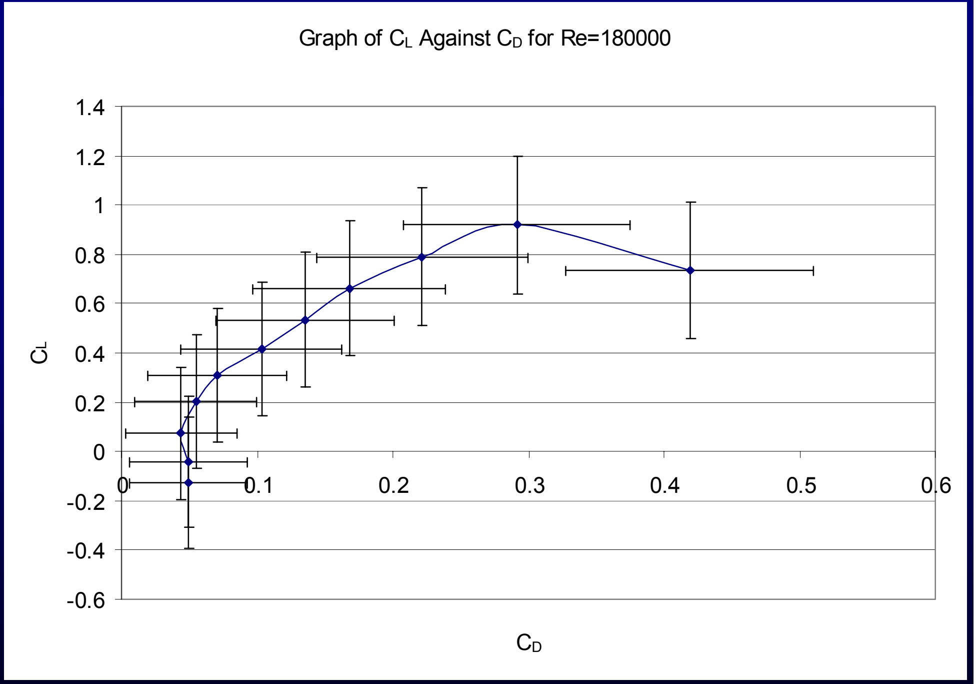




Wind Tunnel Testing

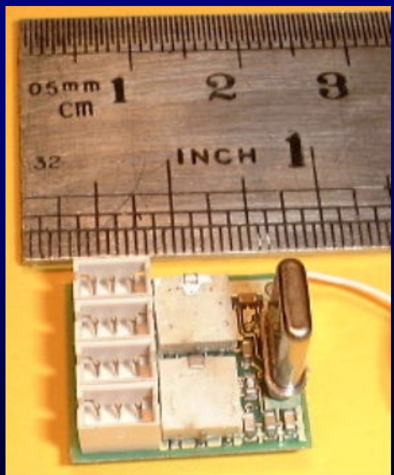
- Tests run at 80000≤Re≤180000
- Angle of attack varied from -3° to 27°
- Force balance not designed for forces of this magnitude
- Re has no clearly significant effects on the aerofoil characteristics
- Min flight speed 11m/s based on wind tunnel tests (max α=27°)

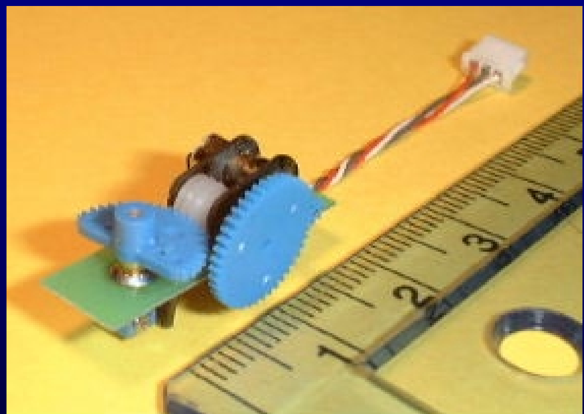




Radio Control System

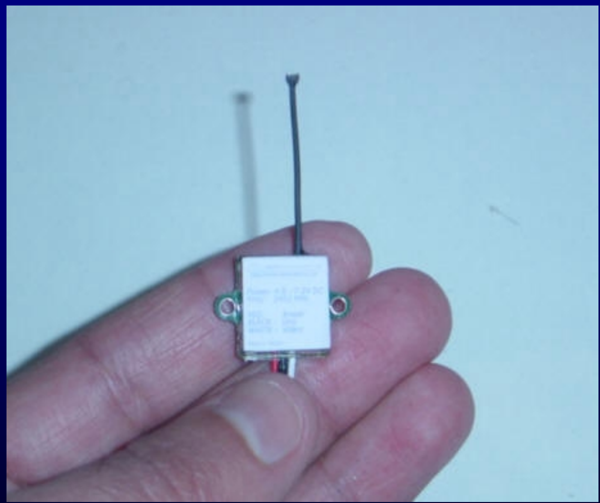
- Conventional radio control system
- Off-the-shelf components designed for indoor model aircraft
- Servos weigh 1.7g each, cost £32 (€48) each
- Receiver weighs 3.8g, cost £28 (€42)
- Speed controller weighs 1g, cost £12 (€18)

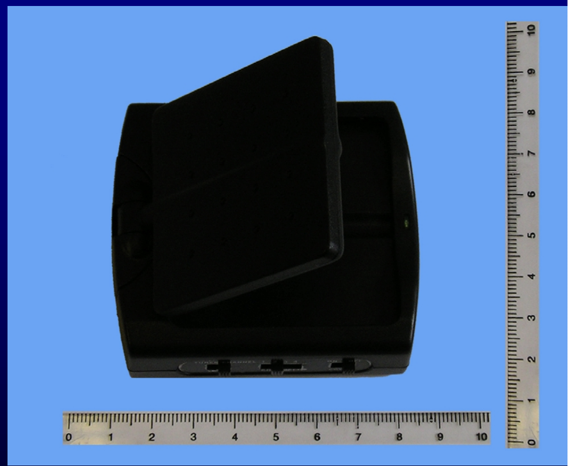




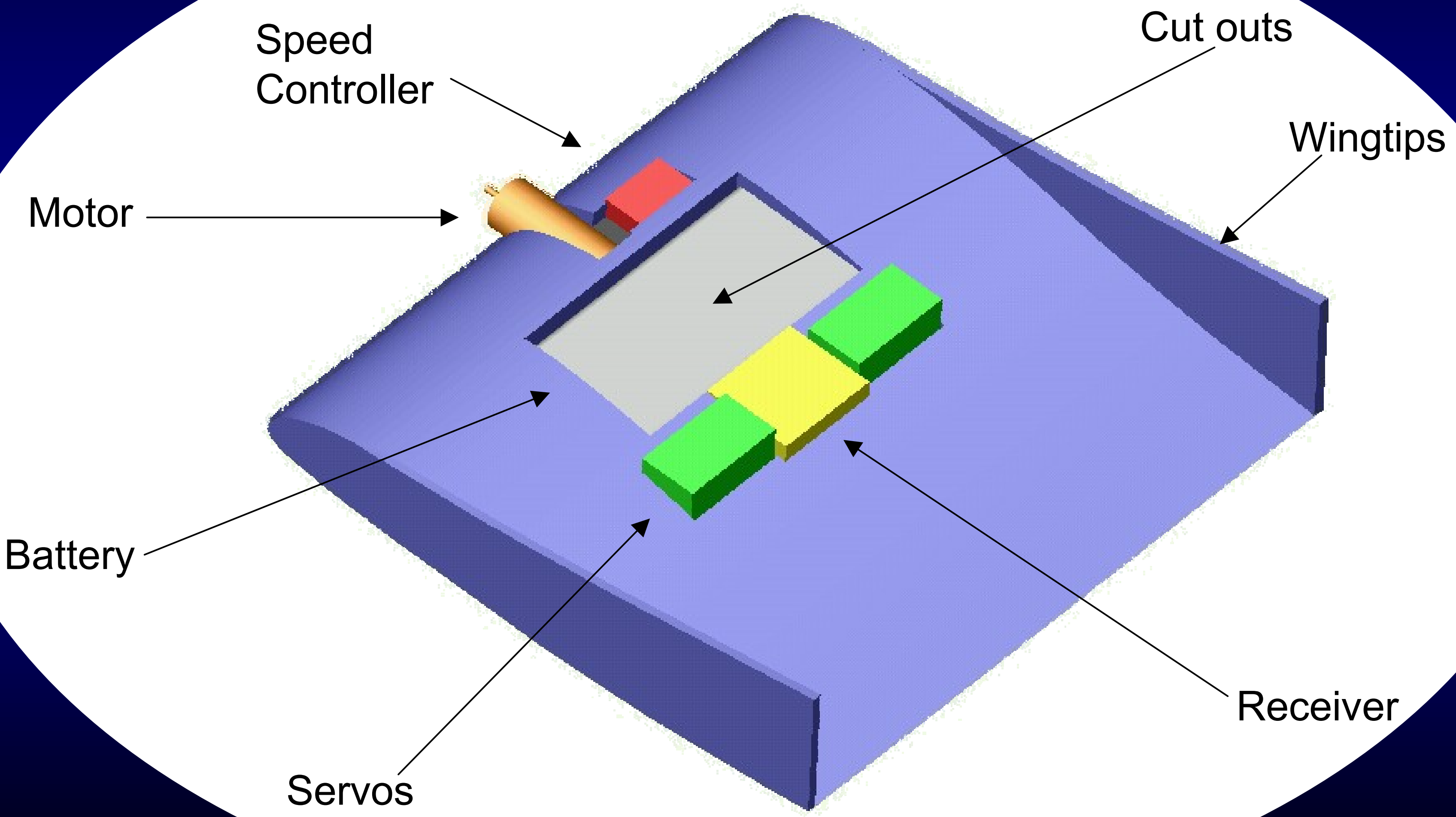
Camera System

- 0.365M Pixel colour CMOS video camera
- 2.4GHz transmitter and receiver
- 300m range
- Kit costs £130 (≈ €195)



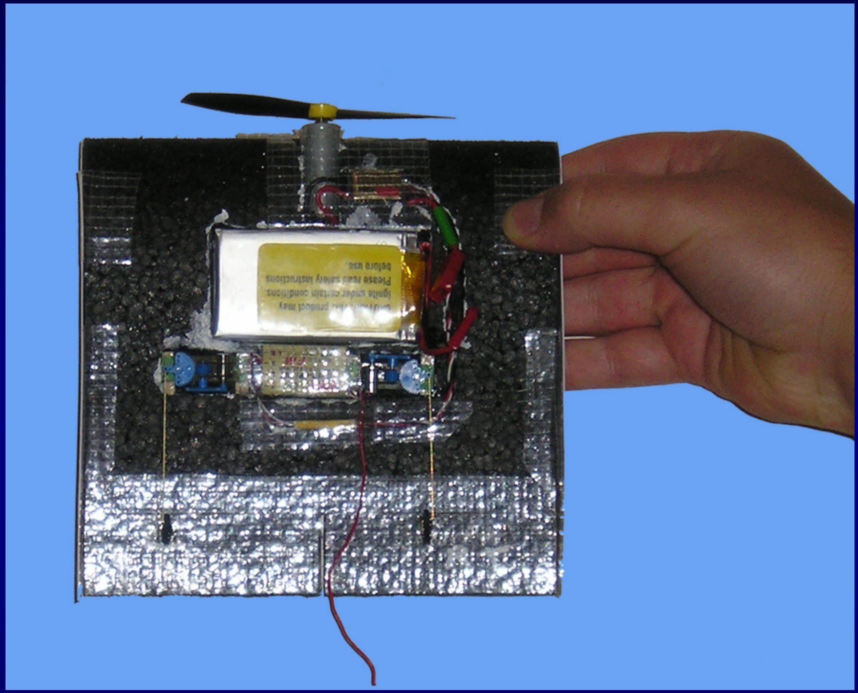


R/C System Integration



Current Status

- First prototype built
- Radio control system fitted and tested
- Finalising balance and C of G location
- Developing launch system
- Overall cost of the MAV is £300 (€450)



Summary

- Cost minimised by use of off-the-shelf components and simple manufacturing methods
- Simplicity of the design enhances the durability
- Work continuing on balance, C of G location and launch system

Conclusions

- MAVs are currently very popular subjects for design studies and research
- Flapping-wing MAVs offer unique capabilities
  - FMAV design is particularly challenging
  - Progress is being made through advanced research
- Fixed-wing MAVs offer limited capabilities
  - Design is still challenging at the 150mm scale
  - Care needs to be taken with wind tunnel testing at this scale
    - Low Reynolds Number effects need elucidating
    - Flow turbulence issues
    - Force balance resolution issues
- Novel designs and/or materials needed for successful MAVs

Questions?