Flapping wing aerodynamics for insect-size drones

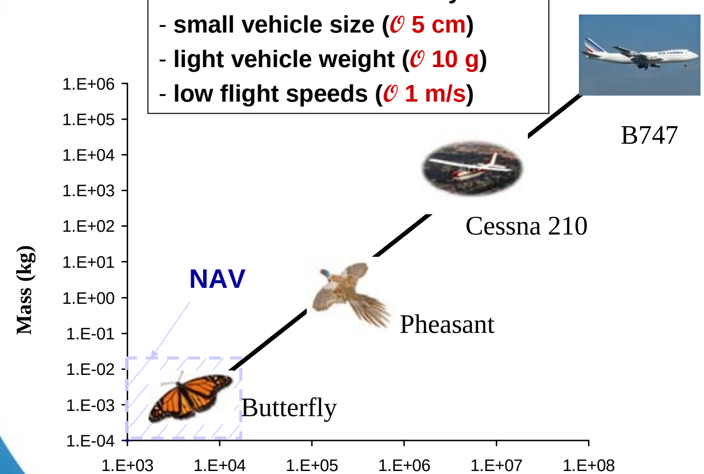
Soldier Systems Vision and Future Capabilities Workshop
Gatineau, 16 June 2009

Defence Research and Development Canada | Recherche et développement pour la défense Canada

Canada

Insect-size drones = Nano Air Vehicle (NAV)

NAVs are characterized by:
- **small vehicle size ($\mathcal{O}$ 5 cm)**
- **light vehicle weight ($\mathcal{O}$ 10 g)**
- **low flight speeds ($\mathcal{O}$ 1 m/s)**



Reynolds number = $\frac{\rho V l}{\mu}$

From Micro Air Vehicle (MAV) to Nano Air Vehicle (NAV)


Mentor


Black Widow


Seiko-Epson Robot


Picoflyer


Harvard University

Strong evidence that for very small crafts (less than 5 cm), flapping-wing performance is superior to rotors due to dynamic effects that create much higher average lift coefficients at low Reynolds numbers

NAV Future Capabilities

It is a new class of military system

Information superiority in urban operation
- low visibility, covertness
- precision
- low cost, low weight,
- little to no logistical footprint,
- mission versatility

Flight envelope: hover, perching, and other high agility manoeuvres

Mission niche : indoor where there is currently no reconnaissance asset

DARPA Nano air vehicle program

- Develop and demonstrate extremely small, ultra-lightweight air vehicle (7.5 cm; 10 g)
  - 20 minutes of fligth time
  - 2.5 m/s wind gusts
  - inside buildings
  - one kilometer command and control range
- Four contractors for phase 1 (2006-2008)
- One contractor for phase 2 (AeroVironment)
- Flapping wing concept

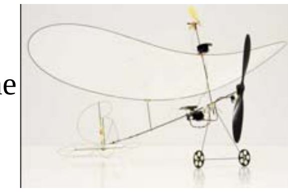
DARPA's top10 NAV challenges

- Navigation w/o GPS for small vehicles in urban and building areas
- **Efficient aerodynamic design and analysis tools**
- Power/propulsion efficiency conversion
- Monolithic structures with multi-functionality (power/aero/structure/electronics/sensors)
- Robust command, communication and control
- Efficient sensors/actuators at small scale
- Cost effective rapid prototyping manufacturing capability
- Low signature vehicles (visual, infrared, acoustic)
- Autonomous operation
- CONOPS – how will they operate and be made useful

Recent progress

- Harvard

- École Polytechnique Fédérale de Lausanne



- Berkeley

- Georgia Tech
- Delft University

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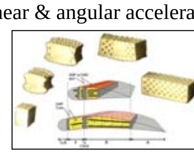
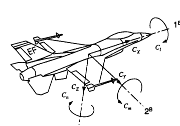
Aerodynamic / flight mechamic challenges

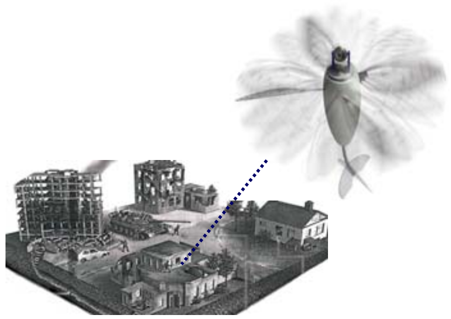
- Flapping wing aerodynamics
  - Complex 3D motion (flapping, lagging, feathering)
  - Unsteady aerodynamics
  - Testing: small size and high flapping frequency (80 Hz)
  - Unsteady aerodynamic mechanisms (used by insects) for enhanced lift
- Low Reynolds number aerodynamics
  - Flow separation region on the order (or larger) than vehicle
  - Vastly different airfoil designs
  - Transition from laminar to turbulent flow

- Flexible structures
  - Closely coupled structural dynamics and aerodynamics
  - Flexibility desirable to absorb gust loading
- Flight mechanics/dynamics
  - Validity of force/moment coefficients & stability derivatives?
  - Invariant mass properties?

- Low speed flight regime
  - NAV vehicle velocities on the order of (or smaller) than gust
- Guidance navigation, & control
  - Short reaction times
  - Reliance on linear & angular accelerations







Flapping wing for nano air vehicles

Participants:

DRDC Valcartier
NRC / IAR
Advanced Subsonics
Université Laval

2006-2010

Objective:
To increase our understanding of the issues concerning the flight of very small UAVs using flapping wings.
Focus on the development of modelling and experimental capabilities, and investigations as to the appropriate sizes and performance parameters with considerations of system integration requirements and mission.

Challenges / Risks
The complex unsteady motion required to produce high lift and the low Reynolds number of flow.

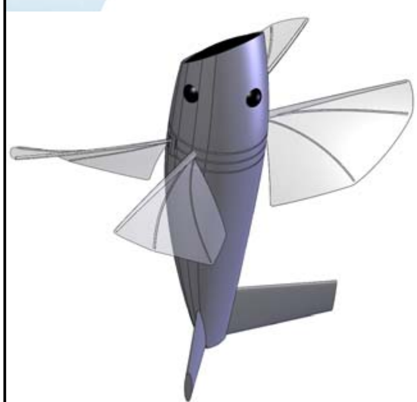
Deliverables / Milestones

1. Navier-Stokes simulation of low-Reynolds-number insect-like wings in complex unsteady motions
2. Experimental study in water tunnel
3. Accurate three-dimensional engineering model of the important unsteady aerodynamic behaviour
4. System Considerations

Desired Outcome:

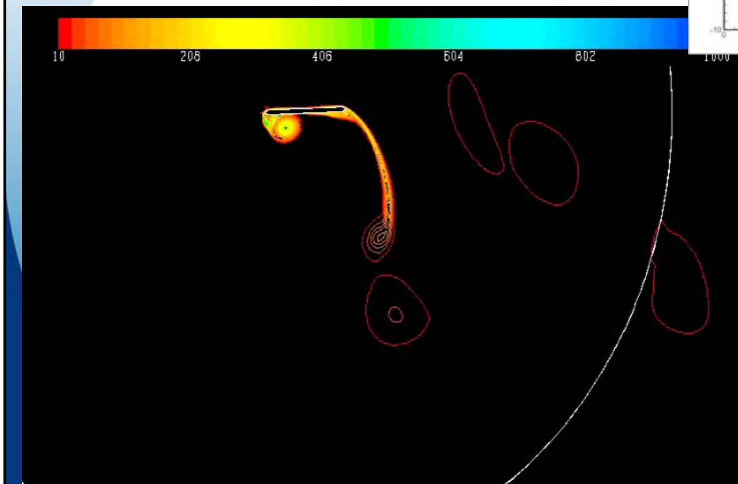
Design and analysis capability for nano air vehicles;
nano air vehicles are expected to contribute to information superiority in urban operations, particularly indoor

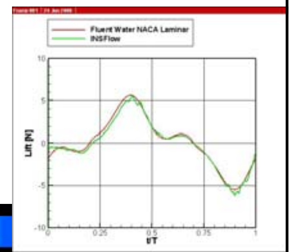
Target vehicle



mass (m)	10 g = 0.01 kg
weight (W)	~0.1 N
span (b)	7.5 cm = 0.075 m
semi-span (b/2)	3.75 cm = 0.0375 m
chord (c)	0.019 m
frequency (f)	80 Hz (best estimate of req'd freq)
peak plunge amplitude angle (γ)	75 deg (= 1.31 rad)
angle by which pitching lags plunging (δ)	90 deg.
peak rotational amplitude (Θ)	~ 50 deg.
Freestream velocity for hover flight	3 m/s
disk loading	23.9 N/m^2

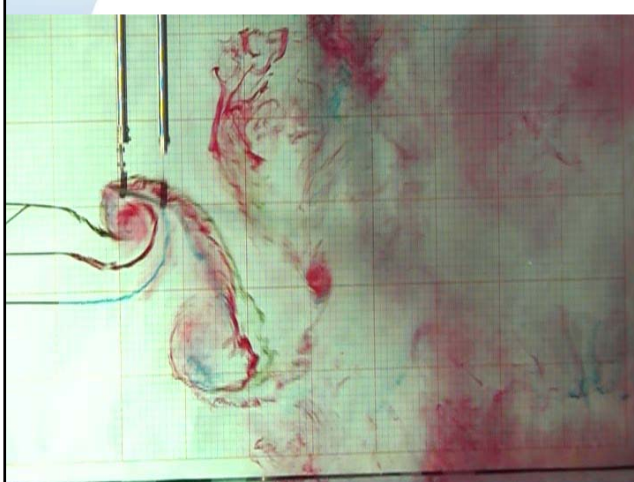
CFD: INSFlow and Fluent





Water tunnel

7 cm wing at a frequency of 1 Hz



- 2D rig
- 3D rig
- load sensors
- micro-scale PIV
- dye

-Match:

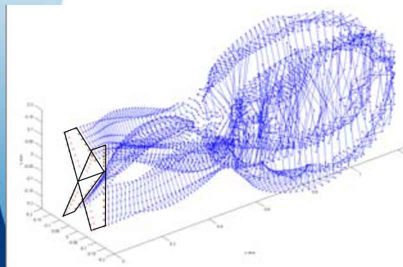
Reynolds number - $U_{ref} \cdot c / \nu$

Reduced frequency – $\pi fc/U_{ref}$

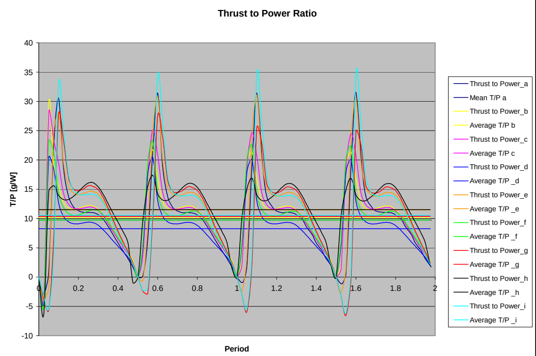
Amplitude to chord ratio

Engineering Model (Vortex lattice model)

- Discrete vortex elements and control points to model bound circulation
- Discrete wake elements to model continuous sheet of LE and TE wake vorticity



One complete flap cycle



Thrust to Power ratio
for different parameters of design space

Conclusions

- Operational NAVs do not exist yet
- NAVs will contribute to information superiority in urban operations
- Many technical challenges:
  - Aero
  - Navigation w/o GPS
  - Power/propulsion efficiency
  - Structures with multi-functions
  - Command, communication et control
  - Miniature sensors
  - Manufacturing
  - Autonomous operation
- DRDC project on flapping wing aerodynamics

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