A NOVEL SYSTEM FOR HIGH ALTITUDE WIND POWER EXTRACTION (iPG)

AIRBORNE 2010 WIND ENERGY CONFERENCE

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OUTLINE

- Motivation, Wind Power Sources
- Flapping-Wing Thrust and Power Generation
- Review of Oscillating-Wing Power Generation Systems
- A Solar Powered Oscillating-Wing Power Generator : intelligent Power Generator (iPG)
- Performance and Power Output
- Potential Applications Conclusions

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OUR MOTIVATION

- The climate change problem is at least equal in magnitude to World War II
- Statement by Dr. Steven Chu, Secretary of Energy
- Quoted by “Time” Magazine, 1 June 2009 page 34

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Renewable Energy Sources

- Current consensus: Available renewable energy sources are insufficient to replace carbon-based power generation (James Hansen, Al Gore, Jay Inslee and Bracken Hendricks)
- Categorize renewable energy sources by availability, accessibility and power density

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Renewable Energy Sources

- Solar, geothermal, biomass/biofuel, wind energy, tidal/river flow energy
- Surface wind energy density: 1.2 kW/m^2
- Tidal/river flow energy density: 1.89 kW/m^2 at 3 knots

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U.S. Energy Production

- In 2007 renewable energy constituted only 7% of total energy production
- Wind energy is projected to provide at most 20% of total need in 2020
- If a war is to be won, all possible resources need to be mobilized !

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Jet-stream Wind Power

- Brian Richards 1979
- Current Projects as presented at this conference:

  Sky Wind Power Corporation

  Makani Corporation

  Joby Inc

  others

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Unexplored Wind Power

- Jet-stream wind power
- energy density: 16 kW/m^2

- Ocean-surface wind power
- 70% of globe is covered by oceans

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Objective

- Develop a power generation system suitable for low and high-altitude wind power generation
- Demonstrate a novel oscillating-wing power generator

A new concept for a flying electric generator with a tethered flying wing and an attached oscillating-wing power generator for the extraction of energy from high-altitude airstreams is presented. The operating principle of the oscillating-wing power generator is explained and Navier-Stokes computational study and experiments are summarized which have been performed to estimate the operating characteristics, power output and efficiency of the generator. Furthermore, the proposed flying wing & power generator configuration and the expected structural and flight mechanical characteristics will be outlined.

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Power Generators

- Traditional Rotary Power Generators

  and
- Novel Oscillating-Wing Power Generators

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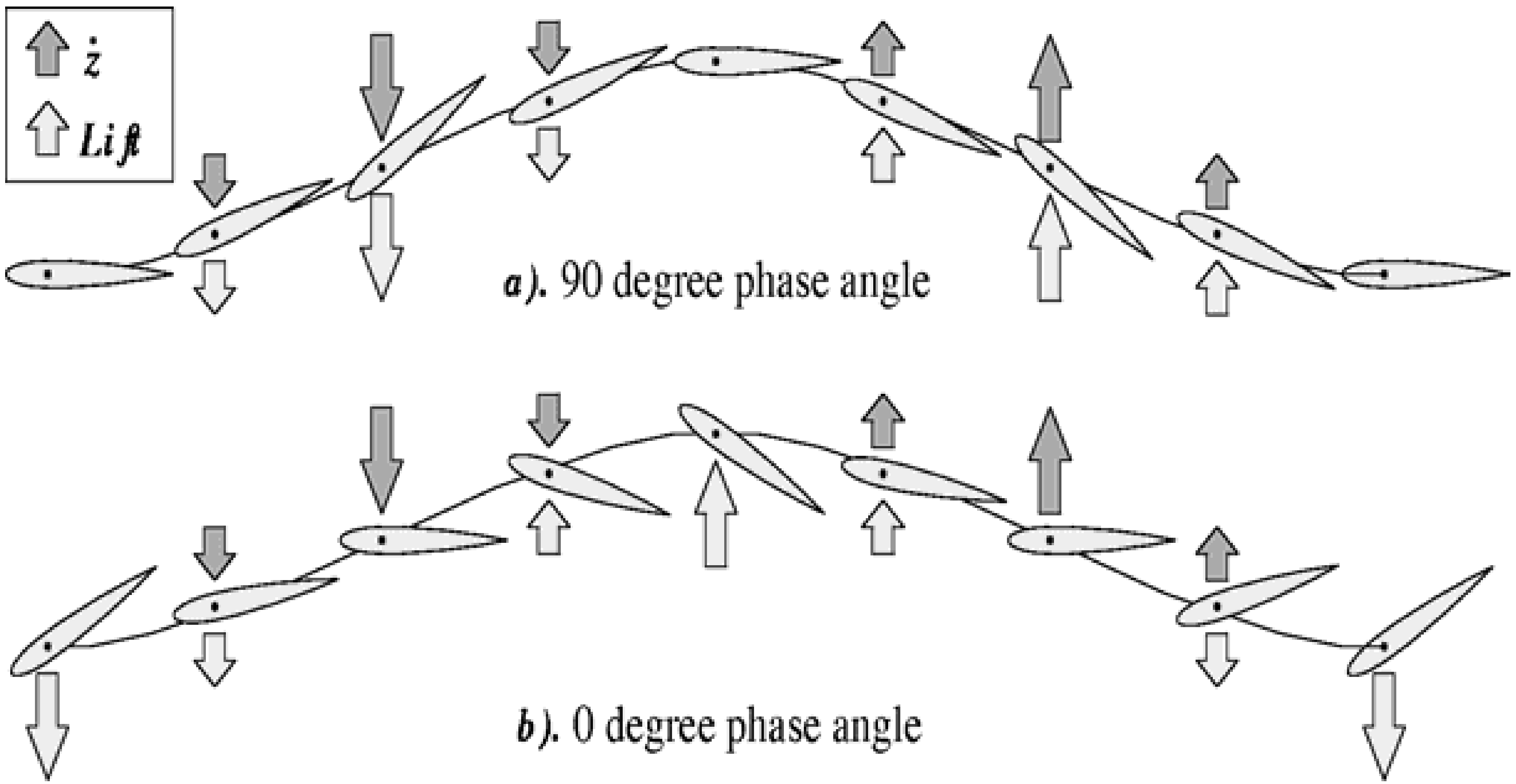
Bending-Torsion Airfoil Flutter



Slide 11

New Oscillating-Foil Power Generator

- Phasing between pitch and plunge is fluid-dynamically controlled
- This produces a simpler and sturdier device

Reference:

Platzer, M.F. and Sarigul-Klijin, Nesrin, *A Novel Approach to Extract Power from Free-Flowing Water and High Altitude Jet Streams,* 3rd ASME Energy Sustainability Conference, San Francisco, 19-23 July, 2009. *(American Society of Mechanical Engineers Advanced Energy Systems Division 2009 Energy Best Paper Award, presented in May 2010 Phoenix, AZ, USA)*

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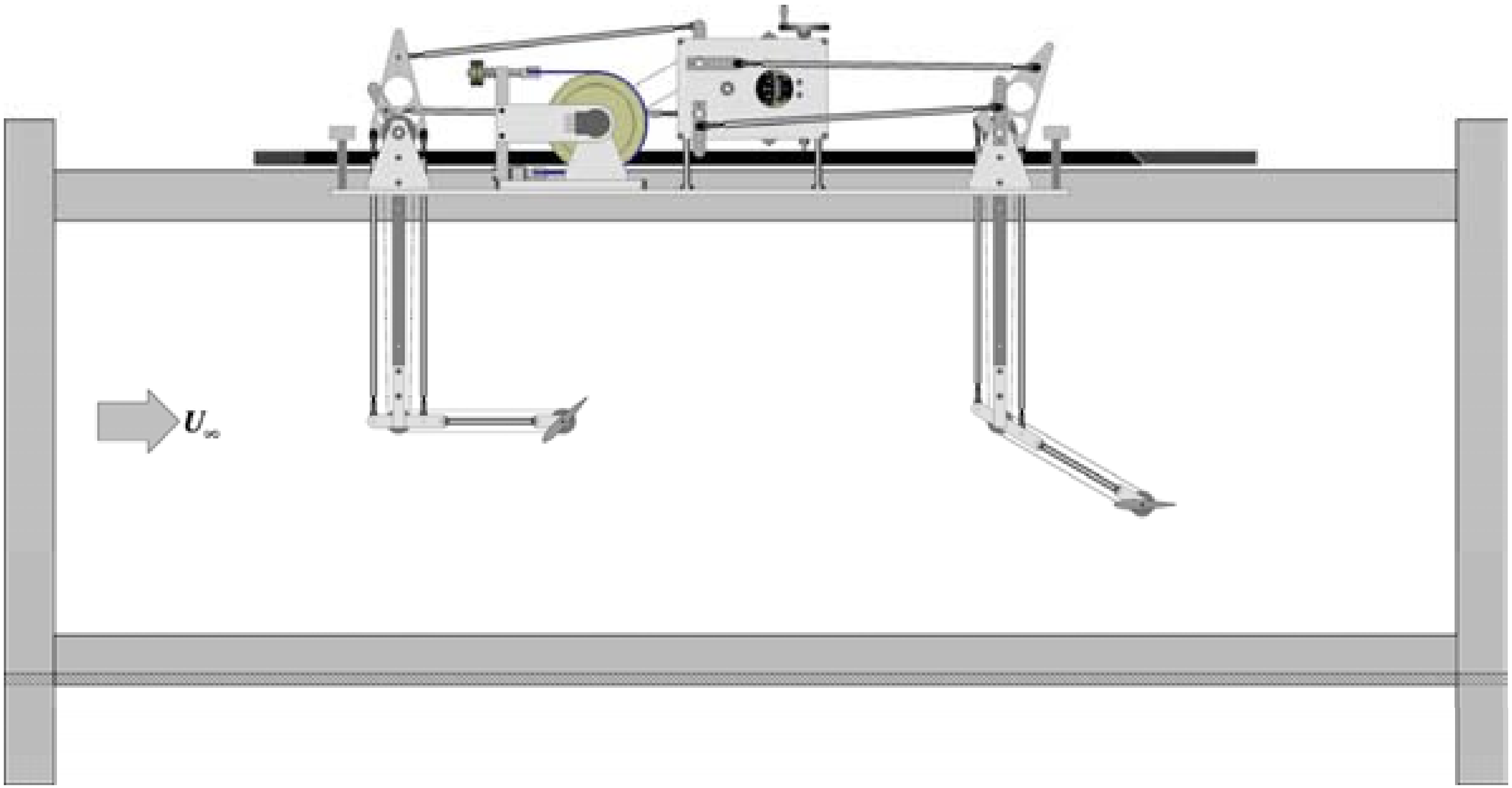
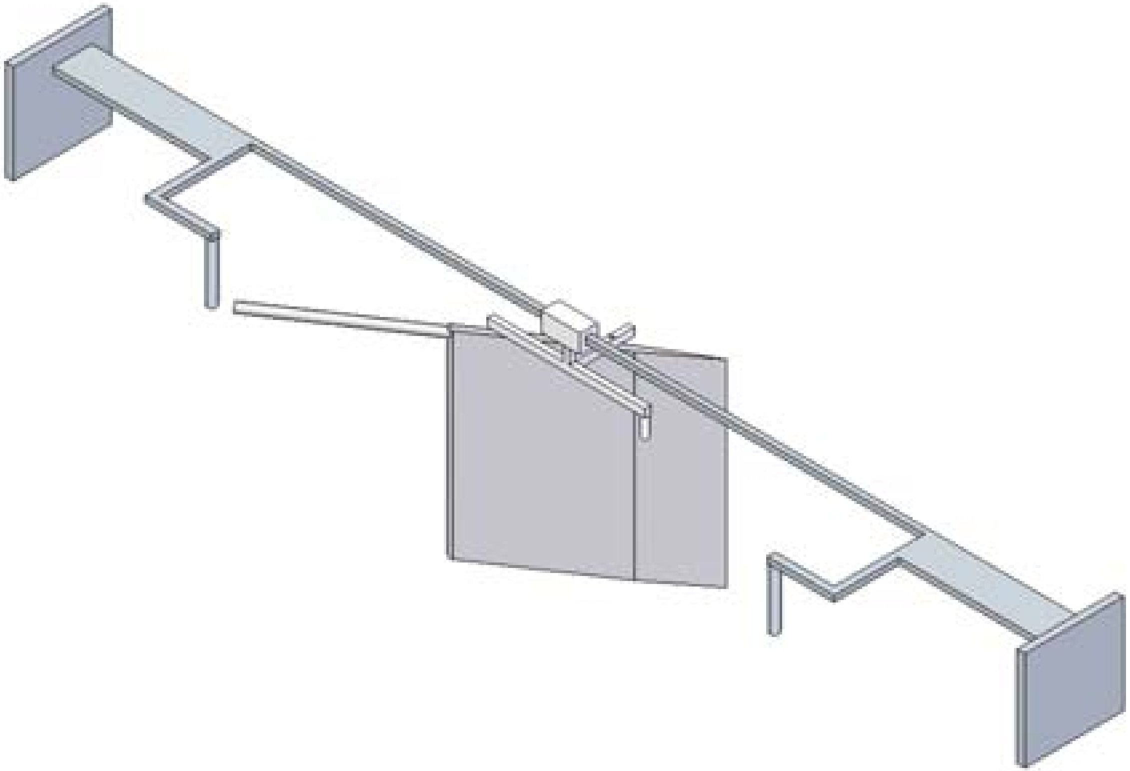
Oscillating-Wing Power Generator



Proposed Aerodynamically Controlled Oscillating-Wing Power Generator



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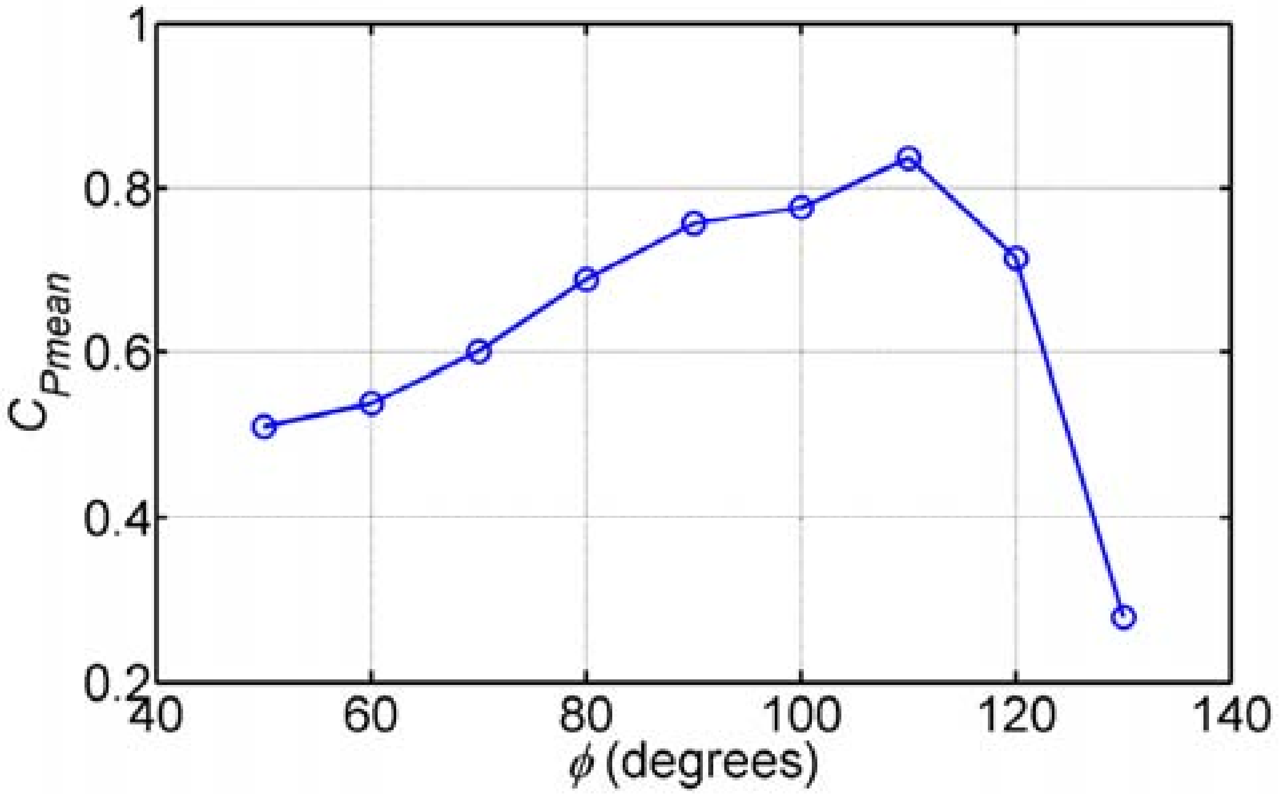
Predicted Output Power

- Sinusoidal Pitch-Plunge Oscillation



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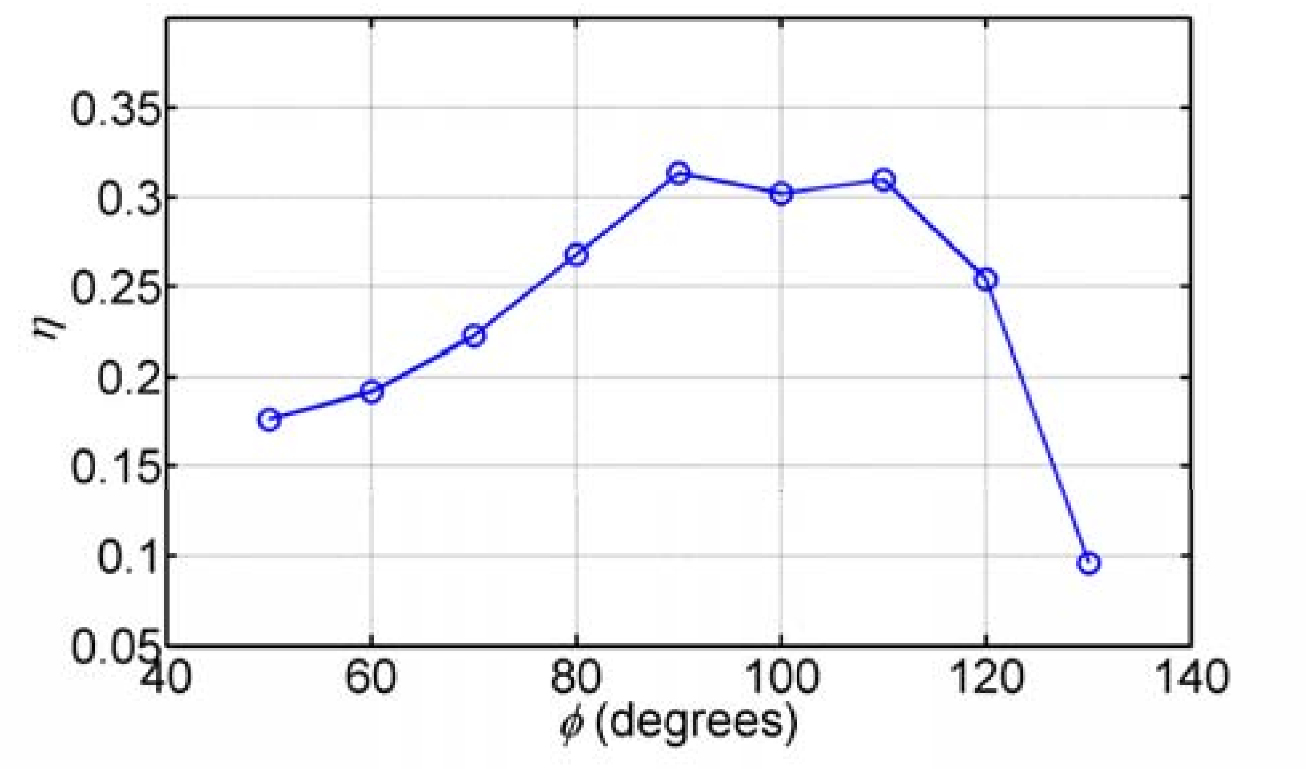
Predicted Efficiency

- Sinusoidal Pitch-Plunge Oscillation



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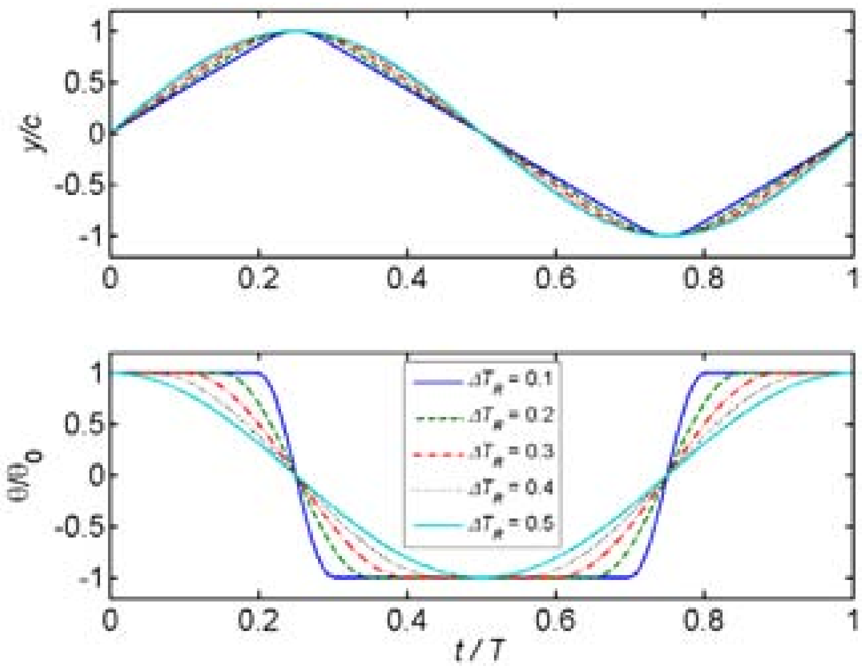
New Power Generator

- Square-wave type oscillation
- Aerohydrodynamic Control



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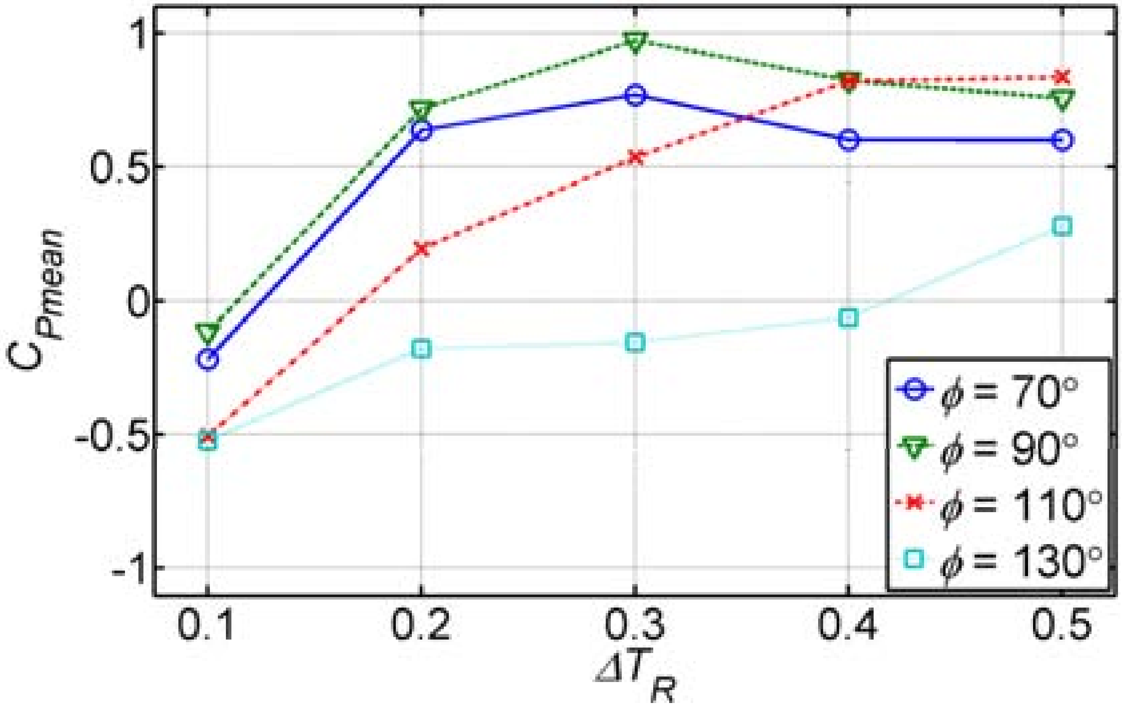
Predicted Output Power

- Square-wave type oscillation



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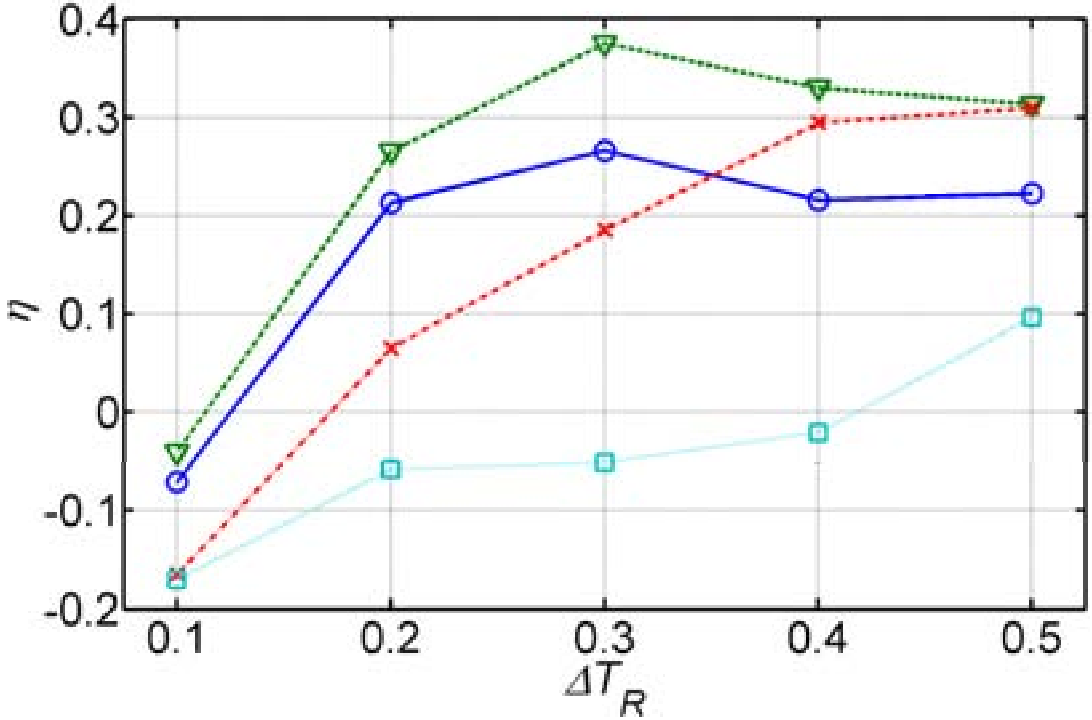
Predicted Efficiency

- Square-wave type oscillation



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New Power Generator

Solar-Powered Aircraft with Oscillating-Wing Power Generator

The following requirements need to be met in order to demonstrate a vehicle which can stay in the air at a particular point without having to rely on a strong tether cable:

a) the propulsion system must be able to generate a thrust which equals the total vehicle drag
b) Lift must equal total vehicle weight
c) longitudinal static stability must be achieved
c) the generation of oscillatory forces and moments must be minimized
d) stall sensitivity must be minimized

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NEW CONCEPT

It stands to reason that the performance of our new power generator, Fig 5 can be enhanced if the aerodynamic lift is augmented by a gravitational component during the oscillation. This can be done if the guide rails are induced into a (properly phased) roll oscillation. This suggests to mount the generator on a flapping wing. However, to comply with requirement (d), two generators need to be used with airfoils which oscillate in counterphase so that their joint center of gravity remains in the longitudinal axis of the vehicle. Therefore, the two generators need to be attached to two wings which are forced into symmetric roll oscillations about the longitudinal axis (similar to the flapping of bird wings). While enhancing the generator performance the flapping wings are used at the same time as thrust generators. This dual use is beneficial for minimizing the total vehicle weight. The basic arrangement is shown in Figure 6. The vertical generator wings are mounted on guide rails so that they can oscillate in the spanwise direction of the two flapping wings. The two vertical generator wings extend both upwards and downwards so that the total drag of these wings coincides with the longitudinal vehicle axis and hence generates a zero moment about the center of gravity, in compliance with requirement (c). The two flapping wings are held at an angle of attack so that they generate both lift and thrust. Downstream, but very close to the trailing edges of the flapping wings, a flapping biplane propulsor (similar to the one used on the micro air vehicle) is attached.

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The design and manufacture used basic principles to minimize structural weight. During the flight test it demonstrated 45 pounds of payload with only nine pounds of structural weight. Its wing span is 14 feet.

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Proposed Jet-stream Power Generator

- Mount oscillating-wing power generator on tethered high-aspect ratio wing

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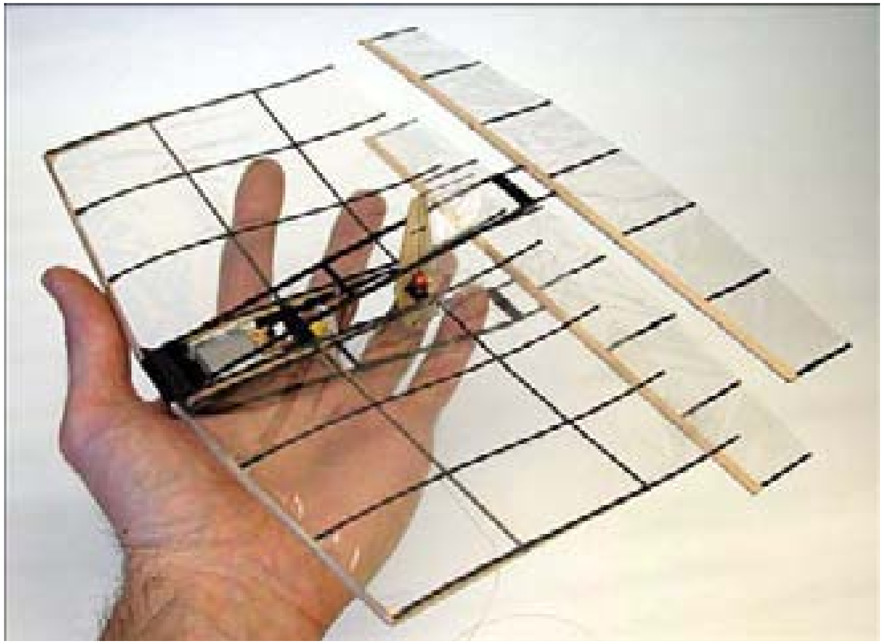
Flapping Wing Thrust Generator



As demonstrated on the flapping-wing propelled micro air vehicle shown in Figure, an additional benefit accrues from the fact that the flapping wings of the biplane propulsor entrain the boundary layer and wake of the forward wing. This effect reduces the drag of the forward wing and delays wing stall.

The two swing arms are driven by a crankshaft so that the two wings are flapping in counter-phase. This arrangement has the advantage of keeping the joint center of gravity constant, thus eliminating undesirable vehicle oscillation.

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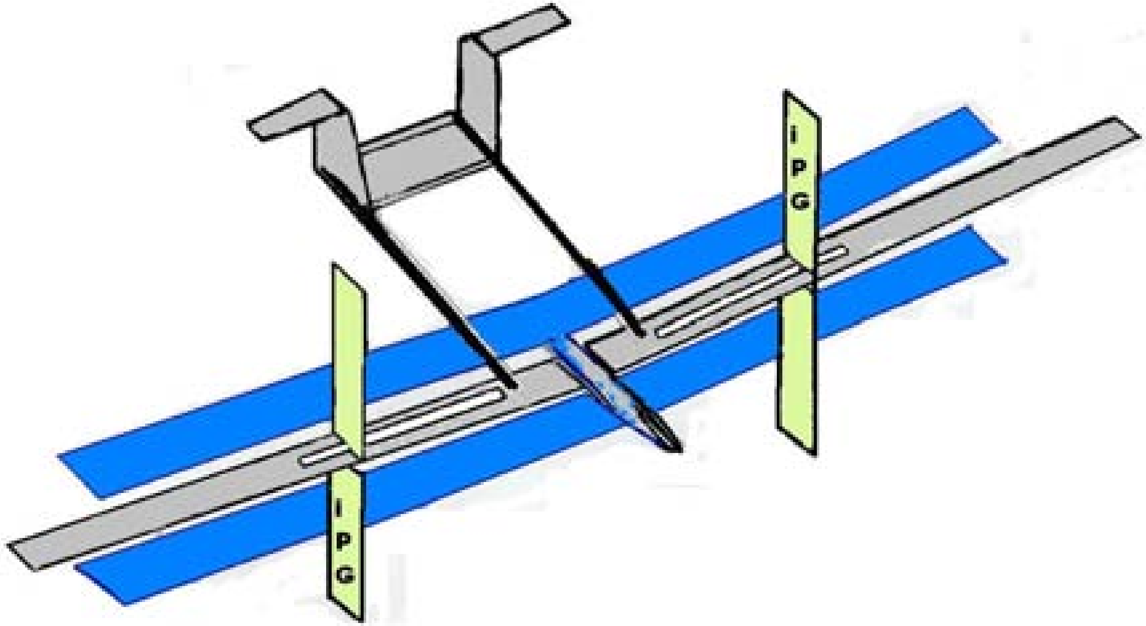
Innovative Power Generator (iPG)



Dual use flapping wings for minimizing the total vehicle weight.

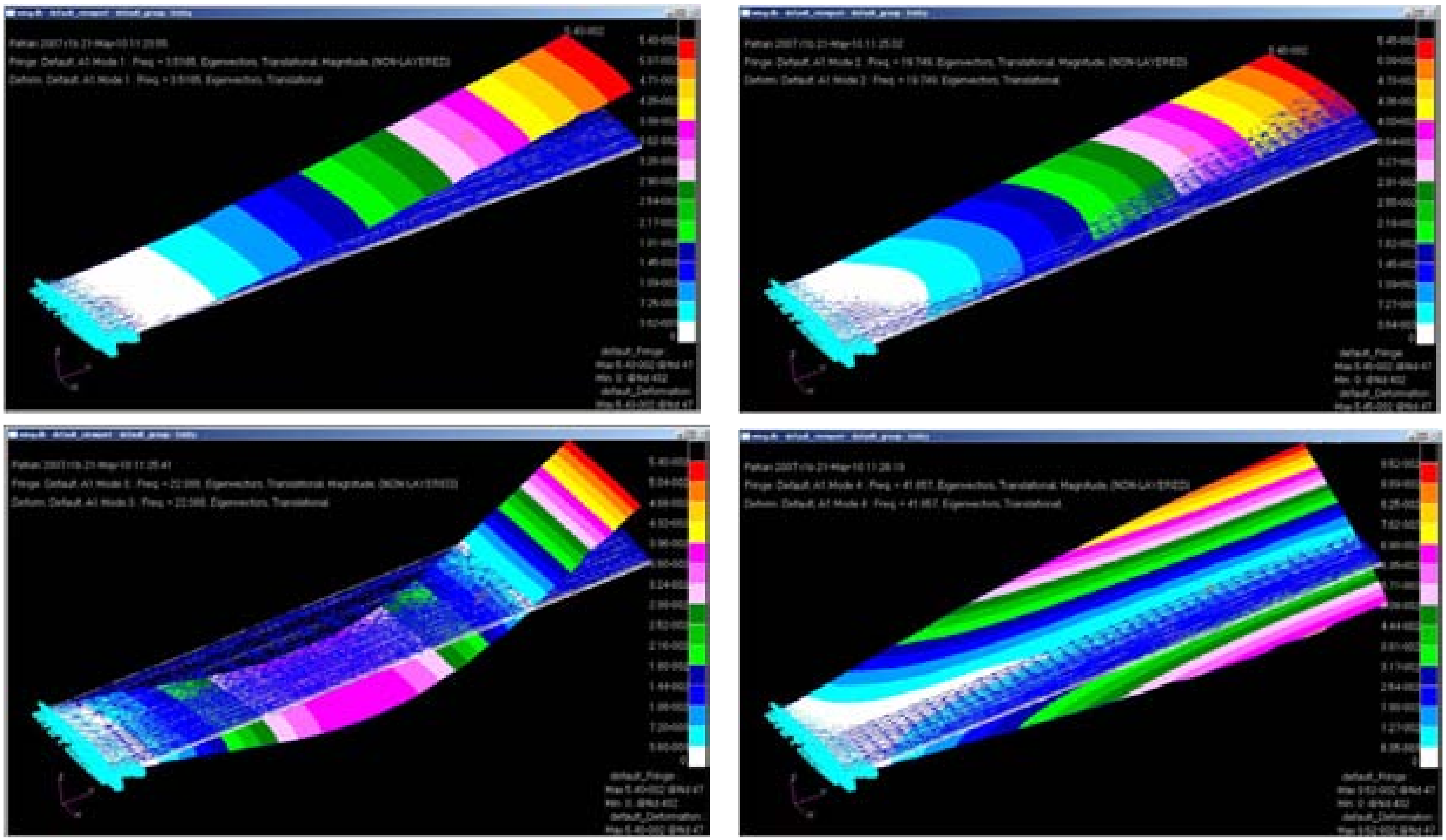
The vertical generator wings are mounted on guide rails so that they can oscillate in the spanwise direction of the two flapping wings.

The two vertical generator wings extend both upwards and downwards

A flapping biplane propulsor (similar to the one used on the micro air vehicle) is attached.

[18] Platzer, Max and Sarigul-Klijn, Nesrin *Gravity-Assisted Oscillating-Wing Power Generator with Flow-induced Pitch-Plunge Phasing,* patent application filed on 27 September, 2010.

Free Vibration Analysis: 10 Normal Modes



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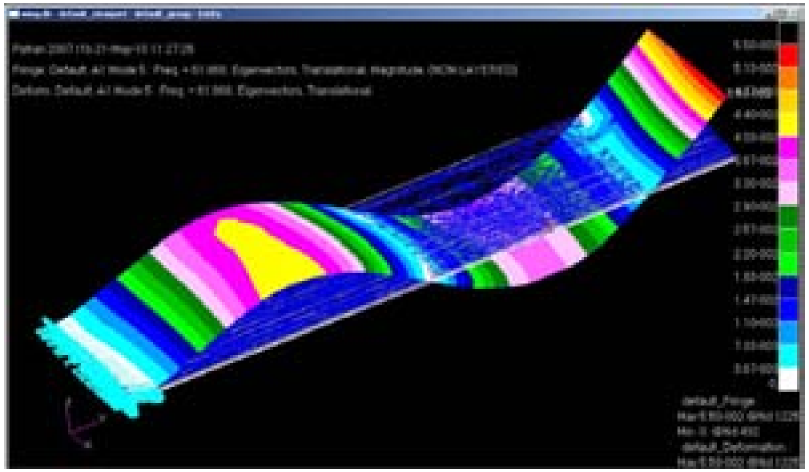
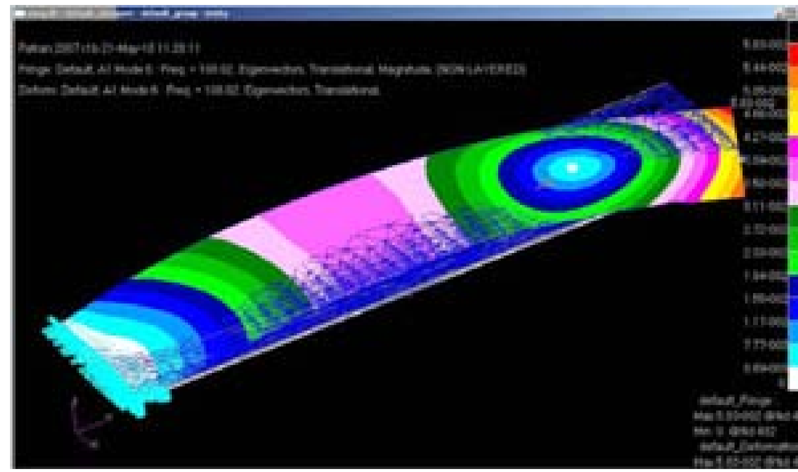
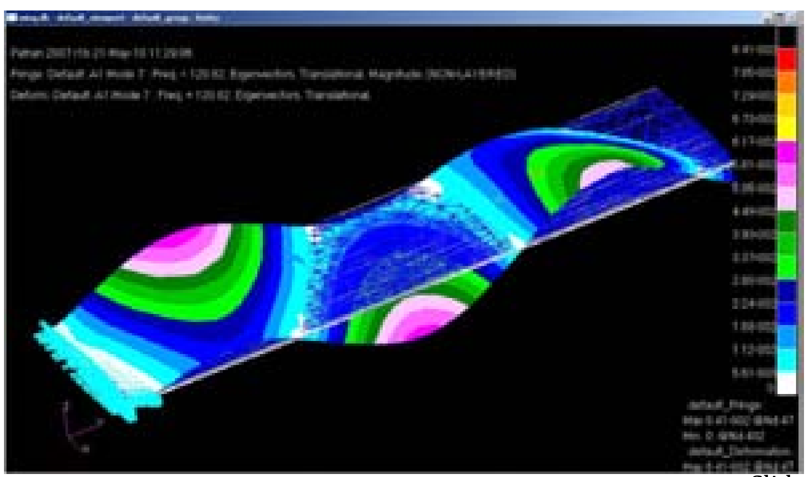
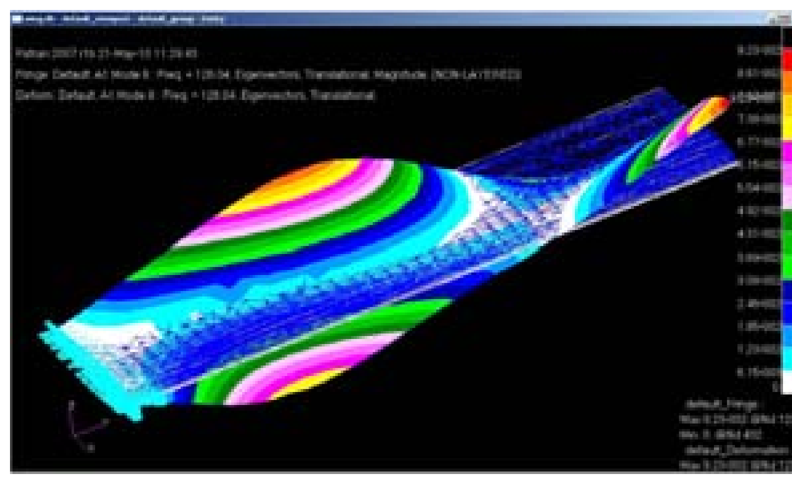
Free Vibration Analysis: 10 Normal Modes (Cont.)









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Estimate of Output Power

- In the absence of experimental data we estimate the power output and the aerodynamic drag generated by an oscillating-wing power generator based on our Navier-Stokes computations for two-dimensional flow over oscillating airfoils
- We denote the average power output per oscillation cycle and per unit of span as
- $P = Cp \frac{1}{2} \rho V^3 c$

- The computations yield power coefficients between 0.8 to 1.0 at optimum operating conditions. Hence at a wind speed of V = 25 m/s one obtains for a wing of 1 m chord length at sea level air density with a power coefficient of 0.9
- $$P = 0.9 (1.225/2) (253) = 8613 W$$
- Therefore the power output per unit span and unit chord is roughly 8.5 kW.
- At a wind speed of V = 30 m/s one obtains 14.9 kW.
- At altitudes of 6.5 km and 10 km the air densities are 50% and 34% of the sea-level density. The power outputs per unit span and unit chord therefore are 4.25 kW at 6.5 km altitude and V = 25 m/s and 5 kW at 10 km altitude and V = 30 m/s .
- The combined power output from two wings with 1 m chord and 5 m span therefore is 43 kW at 6.5 km altitude and 50 kW at 10 km altitude.

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Lift Estimate

The lift generated by the fixed wing of 1 m chord and 20 m span flying at a lift coefficient of 2.0 is 7656 N at 6.5 km altitude and 7497 N at 10 km altitude. The two flapping wings will also generate a certain amount of lift, but their contribution is omitted for simplicity.

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Drag &Thrust Estimate

- The drag generated by the flapping-wing power generators can only be estimated from Navier-Stokes computations. A drag coefficient of 2.0 appears to be the best estimate at this time. Hence, at 6.5 km altitude the total drag is 3828 N and at 10 km altitude it is 3750 N.

- A considerable amount of experimental information was obtained on the thrust generated by flapping wings during the wind tunnel and flight tests of the flapping-wing propelled micro air vehicle described Several other investigators also contributed experimental information which could be used for validation of Navier-Stokes computations Assuming a wing span of 10 m for each wing and a chord length of 1 m a thrust of 3828 N is obtained at 6.5 km altitude and a thrust of 3749 N at 10 km altitude.

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Conclusion

The estimates show that the above described vehicle generates enough thrust to compensate for the drag. Given the fact that the Zephyr aircraft weighs only 30 kg and SMARTLAB 04 carries 5.5 times its structural weight as payload it is likely that our vehicle will weigh no more than 100 kg. Hence there remains plenty of lift to accommodate the additional weight of the tethering cable and of the electric generator.

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