Aircraft Overview

Snowbird Human-Powered Ornithopter

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1 General Overview

The project started in the fall of 2006 as a student group within the University of Toronto and as an offshoot of Prof. DeLaurier's Subsonics Lab. The goal was to be the first in the world to sustain flight with a human-powered ornithopter: an aircraft that generates thrust by flapping it's wings like a bird, rather than using a propeller. Over the summers of 2008 and 2009 the aircraft was built at Great Lakes Gliding Club in Tottenham, Ontario, Canada. Flight testing took place in October 2009, and July-August 2010, with the best sustained flight occurring on August 2nd, 2010 at 6:35AM.

The construction methods and materials are similar in nature to previous human-powered aircraft, using custom carbon fibre tubes for primary structural elements, and using foam, balsa and bass wood for ribs and other parts of the secondary structure. Where the design differs most is in the leg-press-based drive mechanism which pulls the wings downward with each press of the pilot's legs. The structural design of the spar is also a significant innovation in that its torsional stiffness and placement along the chordwise axis has been optimized such that the wing twists passively under aerodynamic loads at the proper magnitude and phase for efficient thrust production. Photographs of the aircraft and key performance figures are given below.

Empty weight:	$43.5kg$ ($95.9lbs$)
Gross weight:	$114.3kg$ ($251.9lbs$)
Span:	$32m$ ($105ft$)
Wing area:	$29.6m^2$ ($319ft^2$)
L/D:	20.9 at design airspeed
Required Power:	$620W$ ($0.83Hp$)
Flapping frequency:	$0.65Hz$

Figure 1: Photos of the project team and the Snowbird in flight.

Figure 2: Photos during construction, assembly and flight testing.

2 Flapping Mechanism

Using bike shoes the pilot clips into a sliding block designed for a Thys Rowingbike. The pilots legs transfer the leg-press motion to the wings with dyneema cable, through a 2:1 block and set of pulleys as shown in Figure 3. Each press translates into the downstroke of the wings. On the recovery the wings are drawn up by the aerodynamic forces and the elastic forces in the spar, requiring no power from the pilot. The frequency can be modulated slightly by adjusting the force on the downstroke, but the wings are tuned to perform best at a frequency of $0.65Hz$, which is what was observed in flight.

Figure 3: Drive system as seen from the bottom. The pedals attach to a Rowingbike foot-slider, which is connected to the yellow line. The yellow line goes through a 2:1 block with the two white lines turning around the pulleys and out to the attachment point on the wings.

A significant design feature is that the wing contains no hinge mechanism; the flapping motion is articulated through the flexibility of the spar itself. Static lines, shown in Figure 2 provide an additional elastic force to offset the lift of the wings. Figure 4 shows the nature of the motion, where it can be seen that the tip lags behind the rest of the wing on the downstroke. Though the tip lag reduces propulsive efficiency, it represents the optimum trade-off between spar stiffness and spar weight.

Figure 4: Wing motion during flight at various fractions of one stroke (0, 0.17, 0.41, 0.59, 0.71, 1).

3 Power Requirements

Using computational and experimental drag data, as well as extensive testing of sample structures, an accurate aero-structural simulation was used to design and analyze the Snowbird. The optimal force profile involves a gradual increase to a peak force, followed by a sudden reduction in force and period of repose (Figure 5). To sustain level flight, the computed maximum force is 3500 Newtons ($357kg$), with a required average power of 620 watts. This is confirmed with data taken on a leg-press machine in the gym, where the pilot was able to replicate, at least approximately, the forces predicted by the simulation. This power output is shown relative to other athletes in Figure 6, where it can is shown to be comparable to a "healthy man". The figure, however, represents a pedalling motion, which is more efficient than the low frequency leg press. In Figure 7 the required power is compared to that of other human-powered aircraft. For the first iteration of such an aircraft, the required power is relatively high, but design modifications in future aircraft could result in significantly more efficient flight vehicles.

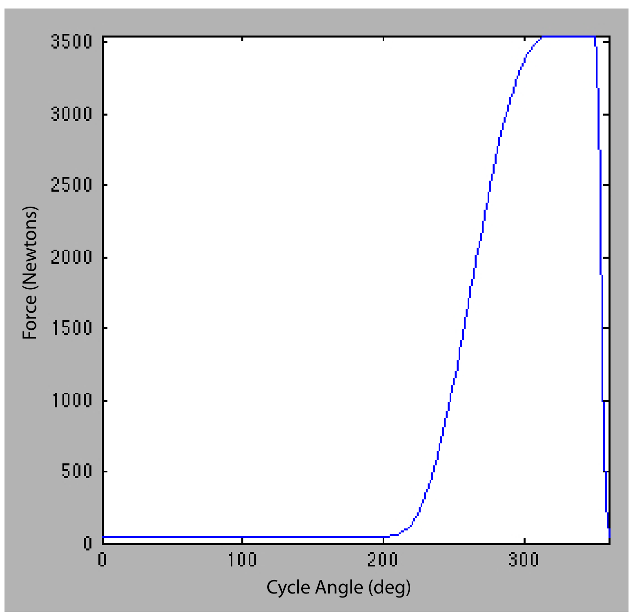

Figure 5: Optimal force profile over one cycle, as predicted through simulation, and roughly replicated by the pilot in gym tests.

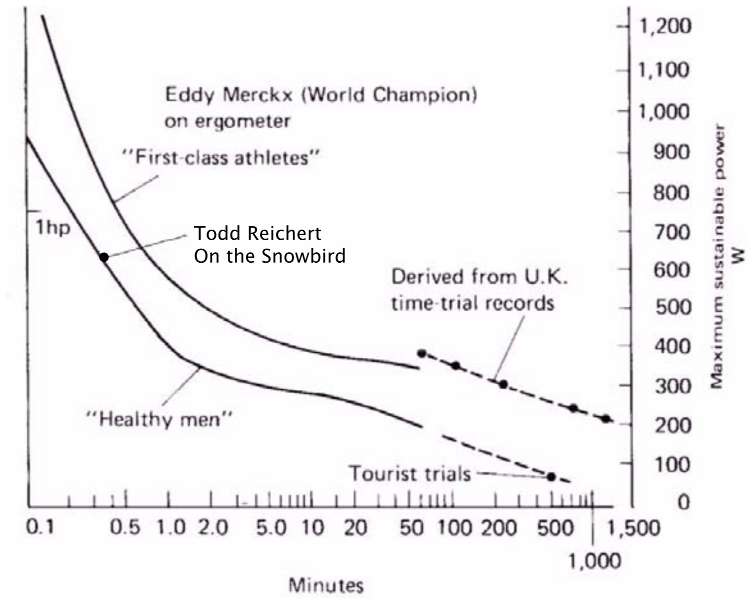

Figure 6: Typical human power output over different periods of required exertion (NASA Bioastronautics report, 1964).

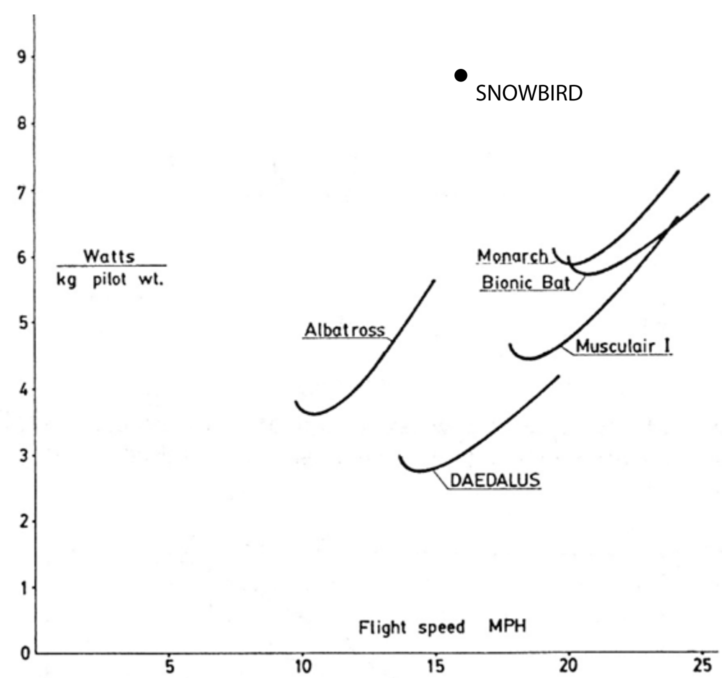

Figure 7: Power requirements for various human-powered aircraft (J. Langford, "The Deadalus Project", 1989).

4 Flight Team

The Snowbird was piloted by Todd Reichert:

Height:	$176cm$ ($5'9.5''$)
Flight weight:	$70.8kg$ ($156lbs$)
Place of birth:	Saskatoon, SK, Canada
Birth date:	Jan 30, 1982
FAI Sporting Licence:	10-096 (exp. Dec 31/2010)

Together, Todd Reichert and Cameron Robertson are the co-founders of the project. Todd is also the Chief Engineer and Project Manager, and Cameron is the Chief Structural Engineer. Prof. James DeLaurier is the Faculty advisor, whose research in flapping wings flight laid the groundwork for the project. Carson Dueck lent a great deal of insight and dedication to final construction and flight-testing phase, along with Rober Dueck who specialized in process engineering throughout construction. Since 2006, over 20 students from the University of Toronto and nearly 10 exchange students from Poitier University in France, and the Technical University of Delft in the Netherlands have been involved with the design and construction of the aircraft.