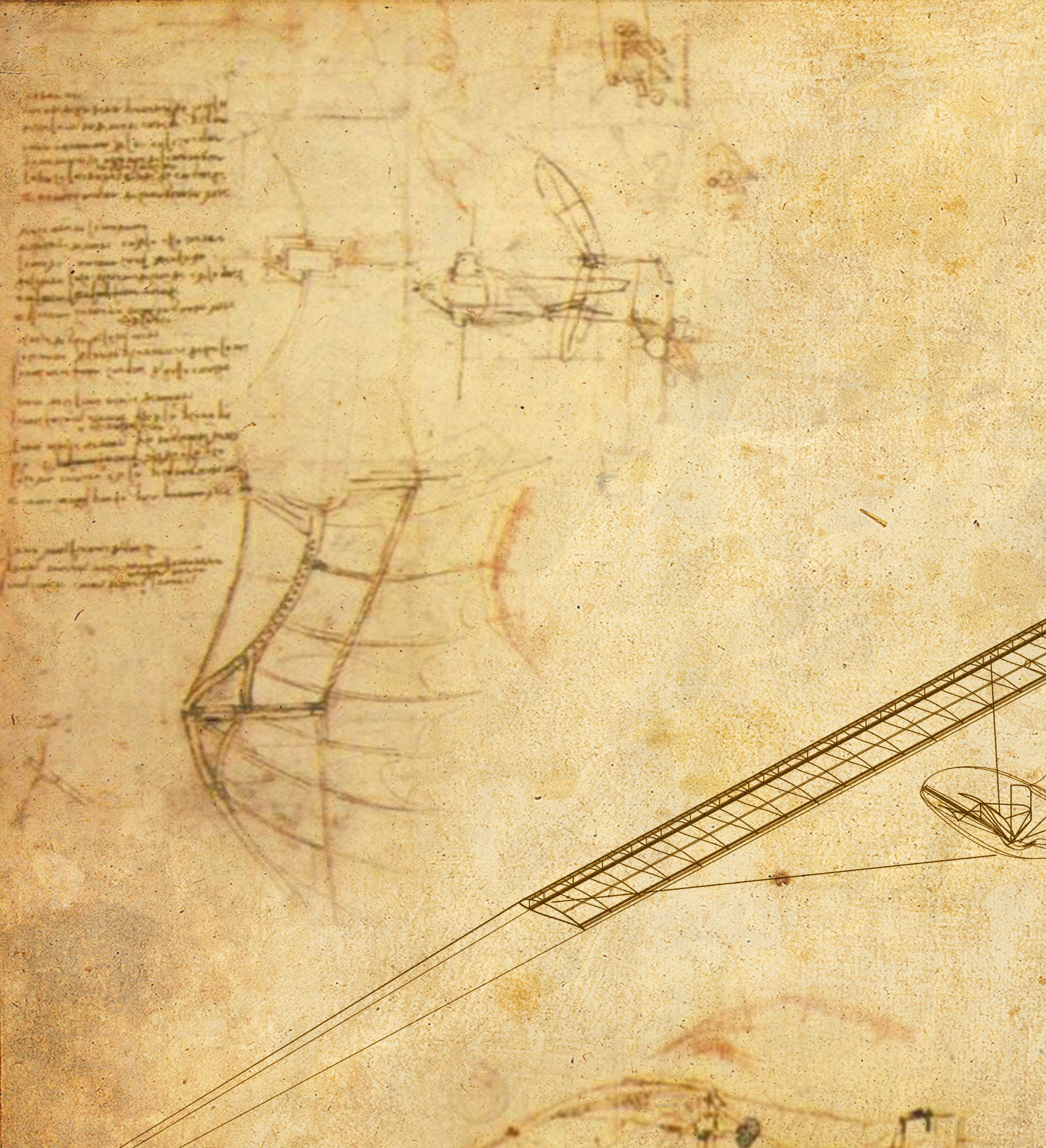
HPO SPONSORSHIP PACKAGE 2007-2008



Sketches for a Human-Powered Ornithopter, by Leonardo Da Vinci in 1490 and the U of T HPO Project in 2008.

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PROJECT OVERVIEW

The Human-Powered Ornithopter (HPO) team is part of a student organization at the University of Toronto that is focused on the design and construction of innovative, high-performance, human-powered vehicles. Our goal is to provide students with practical hands on experience in engineering design while at the same time promoting efficiency, sustainability and the use of human power as a means of reducing society's impact on the environment. Finally, the HPO team seeks to achieve one of humanity's oldest dreams with the successful flight of a human-powered, flapping-wing aircraft, the last of the aviation firsts.

The HPO project started in the summer of 2006 as a spin-off of the flapping-wing research being conducted at the University of Toronto. The team is made up of a dedicated, energetic group of graduate and undergraduate engineering students either working on a thesis project or volunteering their time outside of the classroom. An advisory board of experienced aerospace engineers, including successful ornithopter designer Prof. James DeLaurier, will also be lending their expertise to the project. Finally, the team is collaborating with Dutch rowingbike designer Derk Thys, who brings to the project more than twenty years of experience in the design of efficient rowing mechanisms, which will be used in the HPO to transmit power from the pilot to the wings.

The specific goal of the project is the successful flight of a human-powered ornithopter around the one-mile benchmark Kremer Figure-of-Eight course by the summer of 2009. As with the first successful propeller-driven human-powered aircraft in 1977, the completion of the figure-of-eight course will be sure to capture the hearts and minds of the international community. As an integral part of the project, the dedicated contributions of the sponsors will be duly recognized for the role they play in bringing this age-old dream into reality.

Armed with the tools and experience of those before us, our team is prepared for a successful development and construction program, positioned to return to the roots of human flight five centuries later with a human-powered ornithopter.

After its successful flight in 2006, the University of Toronto's Engine-Powered Ornithopter sits beside an RCAF CF-18A at the Toronto Aerospace Museum. Photo by Parr Yonemoto

HISTORICAL BACKGROUND

It is no surprise that humanity's first attempts at flight were in the form of birdlike, human-powered ornithopters. The great artist and engineer Leonardo Da Vinci is credited as the first to propose a reasonable flying machine in 1490: a giant bat-shaped craft that uses both the pilot's arms and legs to power the wings. Though the aircraft was never built, and we now know that it would not have flown, it was a remarkable achievement considering the knowledge of the day. At the turn of the 20th century, focus shifted both in the method of thrust production, from flapping wings to the propeller, and the method of power generation, from the human body to the internal combustion engine. With the aerodynamic problem greatly simplified, the impossibility of human flight was disproved by the Wright brother's flight in 1903 and the stage was set for the boom of aircraft developments in the decades to come. Though work on human-powered aircraft was still carried on from time to time by several groups in various countries, it would be three-quarters of a century before anyone mastered the art of human-powered flight, and a decade beyond that before the complex aerodynamics of flapping wings would be properly understood.

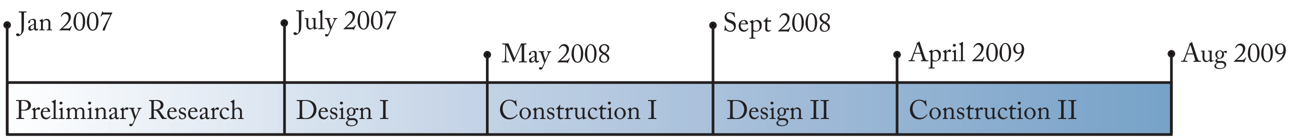
The first truly successful HPA came in 1977 when Paul MacCready's Gossamer Condor flew a one-mile figure-of-eight course in 7 ½ minutes to capture the £50,000 Kremer Prize. What followed was breakneck development in the field, and a mere two years later the Gossamer Albatross flew 36 km across the English Channel, earning the team the second Kremer Prize. To date, the greatest HPA accomplishment was by M.I.T.'s Daedalus, which in 1988 flew 119 km from Crete to Santorini, an incredible feat worthy of the aircraft's mythological name. These and many other HPA projects have pioneered methods of lightweight composite construction, power transmission, and multi-disciplinary aero-structural optimization, much of which has been published and made available to those eager to pursue the field.

The problem of flapping-wing flight has been tackled by countless engineers and craftsmen, but until recently only moderated success had been achieved. This was to change in 1991 when the University of Toronto was awarded the "Diplôme d'Honneur" by the FAI for having flown the world's first engine-powered remotely-piloted ornithopter. Theoretical and experimental research intensified in subsequent years, culminating in the successful flight of a full-scale piloted ornithopter on July 8th, 2006. A patented wing-twisting mechanism and extensive research in aeroelastic tailoring has kept the University of Toronto at the forefront of ornithopter innovation for the last 20 years. Most importantly, along with the experience gained through the design and construction of a variety of ornithopters, these projects have validated the accuracy of the design tools and provide confidence in our performance estimates for the human-powered ornithopter.

Paul MacCready's Gossamer Albatross, the HPA that in 1979 crossed the English Channel

TIMELINE

Initial feasibility studies over the past few years have shown that a human-powered ornithopter is indeed viable, and have led to the official start of the project in January 2007. From preliminary design to the end of flight testing, the project follows the two and a half year timeline shown below. Important project milestones are described in detail below.



PRELIMINARY RESEARCH AND DESIGN

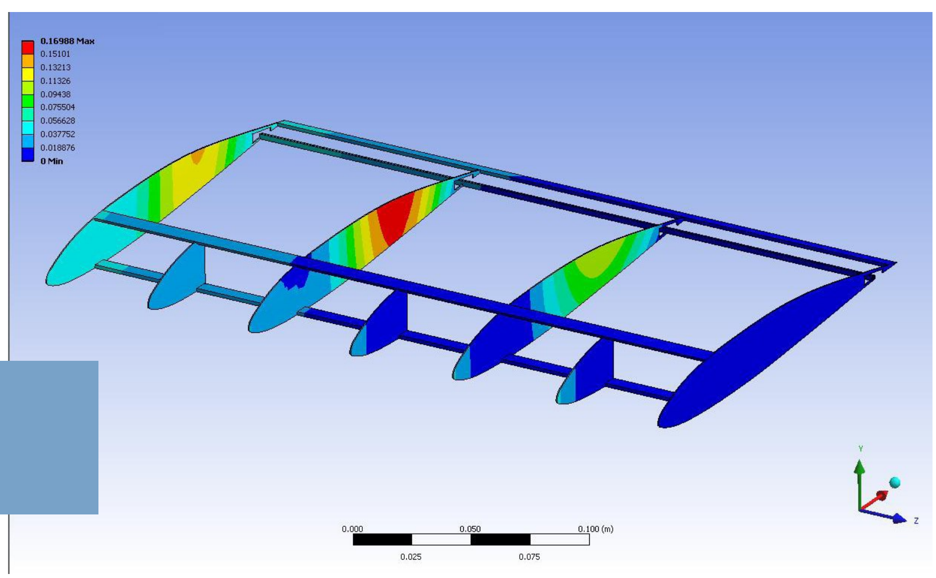
Completion: July 2007

The preliminary design phase included extensive research of past HPA designs, preliminary kinematic optimization using existing design tools and initial estimates of the structural configuration, materials, and weights.

1ST ITERATION: DESIGN

Completion: May 2008

More precise aerodynamic and structural models, as well as a full dynamic simulation model, are currently being developed as part of a related PhD and MASc theses. These theoretical models are being implemented in an aero-structural optimization program and are being used together with the results of physical testing on sample wing spars, ribs, and other structural elements to finalize the design. The relationships between component weight, strengths, and stiffnesses are being measured and employed in the iterative design optimization process.



FINITE-ELEMENT ANALYSIS OF THE HPO WING SPAR AND RIBS

1ST ITERATION: CONSTRUCTION AND FLIGHT TESTING

Completion: September 2008

Construction of the full-scale aircraft is underway at the Great Lakes Gliding Club airfield in Tottenham, Ontario. The objective of this phase is to better understand contruction limitations and the real-world dynamics of the aircraft through low-altitude, towed-launch test flights. This will enable the refinement of our aerodynamic and structural design tools for improved theoretical predictions.

2ND ITERATION: DESIGN

Completion: April 2009

Experience gained during the first iteration will be utilized to work out problem areas in the design and refine fabrication methods for faster and more robust construction. A second-iteration aircraft will be designed for improved performance and the successful completion of the original Kremer Prize figure-of-eight course.

2ND ITERATION: CONSTRUCTION AND FLIGHT TESTING

Completion: August 2009

The second summer will focus on extensive flight-testing and refinement, preparing the aircraft for the completion of its ultimate goal, a successful flight of the Figure-of-Eight Kremer course.

HPO left wing after completed rib assembly (Above)

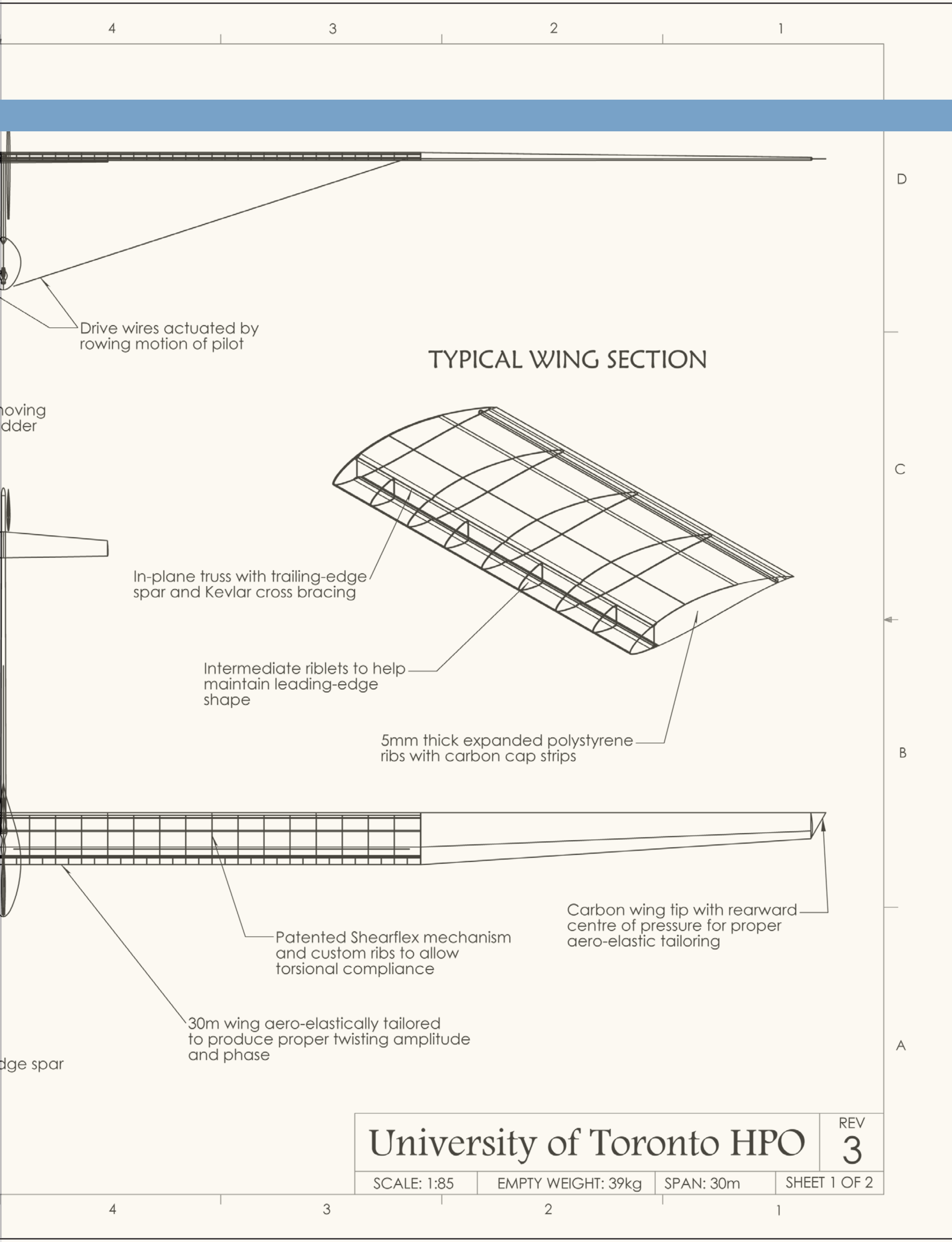
The 1:20 scale HPO model used to demonstrate and test the available configurations for stability and feasability (Left)

TECHNICAL SPECIFICATIONS

The in-depth feasibility study conducted in the summer of 2006 generated a preliminary set of specifications for a possible human-powered ornithopter. Existing design and optimization tools were used along with our knowledge of previous HPAs to generate more accurate and refined performance figures for the HPO. The current specifications and performance figures are as follows:

Wing Span	28 m
Root Chord	1.25 m
Mass (Empty)	36 Kg (79 lbs)
Estimated Pilot Mass	75 Kg (165 lbs)
Required Thrust (Parasite drag)	3 N
Flapping Frequency	0.65 Hz
Theoretical Flight Speed	7.5 m/s (27 Km/h)
Flapping Amplitude (Deflection at wing tip)	1.5 m
Tip Twist Amplitude	5°
Power Output Required (Human Engine)	241 Watts

The preliminary design and layout of the HPO are based on previously successful propeller-driven HPA configurations. The wings are attached to the top of the fuselage, and the tail is a conventional arrangement with perpendicular control surfaces in the rear position. The wings are driven via a rowing mechanism (whereas propeller-driven HPAs use pedaling), as our research shows that the optimal flapping frequency lies in the optimal range of rowing frequencies. The rowing mechanism uses wires to directly drive the downstroke of the wings and control the upstroke recovery. The patented Shearflex mechanism allows the wings to twist with the proper amplitude and phase for optimal thrust generation.



TYPICAL WING SECTION
Drive wires actuated by rowing motion of pilot
noving
dder
In-plane truss with trailing-edge spar and Kevlar cross bracing
Intermediate riblets to help maintain leading-edge shape
5mm thick expanded polystyrene ribs with carbon cap strips
Patented Shearflex mechanism and custom ribs to allow torsional compliance
Carbon wing tip with rearward centre of pressure for proper aero-elastic tailoring
30m wing aero-elastically tailored to produce proper twisting amplitude and phase
dge spar
University of Toronto HPO
REV
3
SCALE: 1:85
EMPTY WEIGHT: 39kg
SPAN: 30m
SHEET 1 OF 2

BUDGET

The budget is broken down into the four project phases described above. The cost of the materials reflects the market value, but it is our hope that much of this will be sponsored directly by the manufactures or their distributors. Almost all labour is volunteer with the exception of key summer internship positions and external consulting. The budget best reflects the team's current operations plan.

1ST ITERATION: DESIGN, CONSTRUCTION, AND FLIGHT TESTING

Sample spar segments, ribs, and other structural elements	
Polystyrene foam	$500.00
Pre-preg and wet-lay unidirectional carbon fibre	$2,000.00
Nomex honeycomb structural core	$200.00
Instrumentation	$1,000.00
Vacuum bagging materials	$1,500.00
Aeropoxy epoxy system	$500.00
Mylar covering material	$200.00
1st Iteration aircraft	
Polystyrene foam	$500.00
Wet-lay woven Kevlar fibre	$1,000.00
Pre-preg and wet-lay unidirectional carbon fibre	$3,000.00
Kevlar roving	$1,000.00
Structual foam core materials (Corecell, Airex)	$1,000.00
Nomex honeycomb structural core	$200.00
Aircraft-grade balsa wood	$500.00
Vacuum bagging materials	$1,500.00
Aeropoxy epoxy system	$500.00
Spectra drive lines	$500.00
Laser cutting	$500.00
Control electronics, circuitry, and wiring	$1,000.00
Cockpit instrumentation	$2,000.00
Mylar covering material	$200.00
Canopy material	$1,000.00
Force-feedback flight simulator	
Rowingbike frame, handlebars, seat, and foot slider	$2,000.00
Computer motor controller	$1,000.00
Servo motor and force sensor	$10,000.00
Miscellaneous	
Rowingbike and indoor trainer	$6,000.00
Miscellaneous supplies and tools	$6,000.00
Materials Subtotal	$45,300.00
Labour	
Summer internships (8)	$48,000.00
Consulting (400 hrs)	$20,000.00
Labour Subtotal	$68,000.00

Logistics	
Team vehicle costs	$6,000.00
Runway access and workspace rental	$8,000.00
Team office space	$5,000.00
Insurance	$2,000.00
Logistics Subtotal	$21,000.00
1st Iteration: Design, Construction, and Flight Testing, Total	$134,300.00

2ND ITERATION: DESIGN, CONSTRUCTION, AND FLIGHT TESTING

Sample spar segments, ribs, and other structural elements	
Polystyrene foam	$500.00
Pre-preg and wet-lay unidirectional carbon fibre	$2,000.00
Nomex honeycomb structural core	$200.00
Instrumentation	$1,000.00
Vacuum bagging materials	$1,500.00
Aeropoxy epoxy system	$500.00
Mylar covering material	$200.00
2nd iteration aircraft	
Polystyrene foam	$500.00
Wet-lay woven Kevlar fibre	$1,000.00
Pre-preg and wet-lay unidirectional carbon fibre	$3,000.00
Kevlar roving	$1,000.00
Structual foam core materials (Corecell, Airex)	$1,000.00
Nomex honeycomb structural core	$200.00
Aircraft-grade balsa wood	$500.00
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Aeropoxy epoxy system	$500.00
Spectra drive lines	$500.00
Laser cutting	$500.00
Control electronics, circuitry, and wiring	$1,000.00
Cockpit instrumentation	$2,000.00
Mylar covering material	$200.00
Canopy material	$1,000.00
Materials Subtotal	$20,300.00
Logistics	
Team vehicle costs	$6,000.00
Runway access and workspace rental	$8,000.00
Aircraft transportation	$5,000.00
Insurance	$2,000.00
Logistics Subtotal	$21,000.00
Labour	
Summer internships (12)	$72,000.00
Consulting (400 hrs)	$20,000.00
Labour Subtotal	$92,000.00
2nd Iteration: Design, Construction and Flight Testing, Total	$133,300.00

TOTAL PROJECT COSTS	$267,600.00
Total without labour	$107,600.00

SPONSOR BENEFITS

By approaching your organization, we are inviting you to become an active member of our team. In aiding the U of T Human-Powered Vehicles Design Team, you will be supporting our mutual goals and expressing a desire to effect change in the way we live. In addition, your company will gain the recognition and prestige associated with the success of a human-powered ornithopter.

Although the U of T HPVDT is a student organization, only a small portion of our funding is provided through the University. The success of our efforts is dependent upon your organization's contributions and generous support. In addition to financial support, donations in the form of composites materials and construction tools are also greatly appreciated, as these costs comprise a significant portion of the team's project budget. The value of these materials will be taken into account when determining sponsorship level.

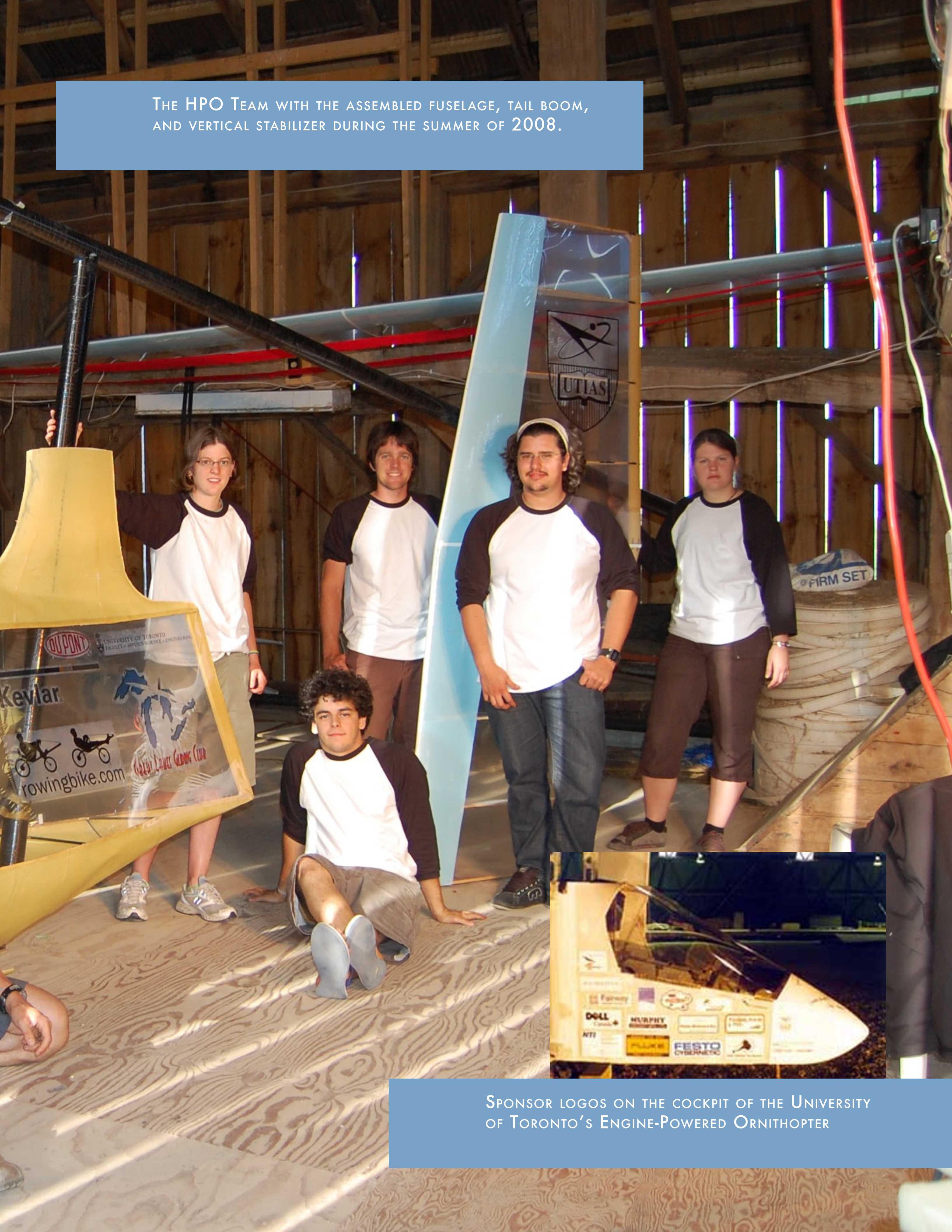
Levels of Sponsor Commitment and Benefits:

Bronze: Donation > $1,000
- Regular updates on project progress and invitation to historic flight
- Provision of the sponsor with videos and photos of construction and flight tests
- Sponsor Logo and mention on team website

Silver: Donation > $5,000
- All of the above benefits
- Sponsor logo on Information Pamphlet and Media Package
- Sponsor logo (small) on HPO aircraft

Gold: Donation > $20,000
- All of the above benefits
- Sponsor logo on Information Pamphlet and Media Package
- Sponsor logo (Large) on HPO aircraft
- Showcasing the HPO simulator at your establishment or event

Title Sponsor: Donation > $100,000
- All of the above benefits
- Additional negotiable benefits including media rights and aircraft proprietorship



The HPO Team with the assembled fuselage, tail boom, and vertical stabilizer during the summer of 2008.

Sponsor logos on the cockpit of the University of Toronto's Engine-Powered Ornithopter

HPO ADVISORY BOARD

Prof. James D. DeLaurier, University of Toronto

Dr. DeLaurier graduated from Stanford University with a Ph.D. in Aeronautics and Astronautics in 1970. His research and industry experience includes time at McDonnel Aircraft, NASA Ames Research Center, and Battelle Memorial Institute. Dr. DeLaurier's focus has been on lighter-than-air and mechanical flapping-wing aircraft. A remotely-piloted proof-of-concept ornithopter designed by Dr. DeLaurier and Jeremy Harris (a research associate) flew successfully in 1991, and their full-scale engine-powered ornithopter was the first to achieve fight on July 8th, 2006.

Patrick Zdunich, Advanced Subsonics Inc.

Patrick graduated with a B.A.Sc. from University of Alberta in 1999, and completed his M.A.Sc. at UTIAS in 2002 under Dr. DeLaurier developing a flapping-wing Micro Air Vehicle. Following his masters, Patrick co-founded Advanced Subsonics in 2002, now a world leader in small-scale flapping-wing flight. Patrick has worked on the engine-powered ornithopter since 1997, and was acting as chief field engineer during the aircraft's first successful flight in 2006.

Bruce Fenton, University of Toronto

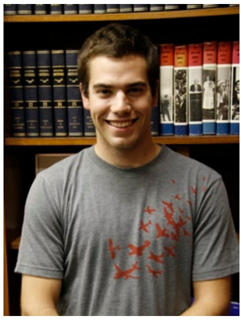
Bruce graduated University of Toronto with a B.A.Sc. in Mechanical Engineering in 1996, and with an M.A.Sc. (again from U of T) in Aerospace Engineering in 1999. Bruce has worked on the engine-powered ornithopter for 10 years, with 2 of those years as chief engineer. Bruce has also been involved in several lighter-than-air projects, and has extensive experience in experimental work.

The Daedalus HPA, constructed by students and staff at M.I.T. and flown across the Aegean Sea in 1988.

HPO EXECUTIVE TEAM

Todd Reichert, HPO Project Manager

Todd is entering the third year of his PhD at UTIAS, researching optimal kinematic strategies for flapping-wing propulsion. In addition to his B.A.Sc. in Engineering Science at the University of Toronto, Todd completed a minor in Cinema Studies and served as the president of the Engineering Society in 2004-2005. Todd has also worked at the National Research Council's Institute for Aerospace Research for several summers and has been a volunteer with the engine-powered ornithopter since 2004.



Cameron Robertson, Structures and Materials Team Leader

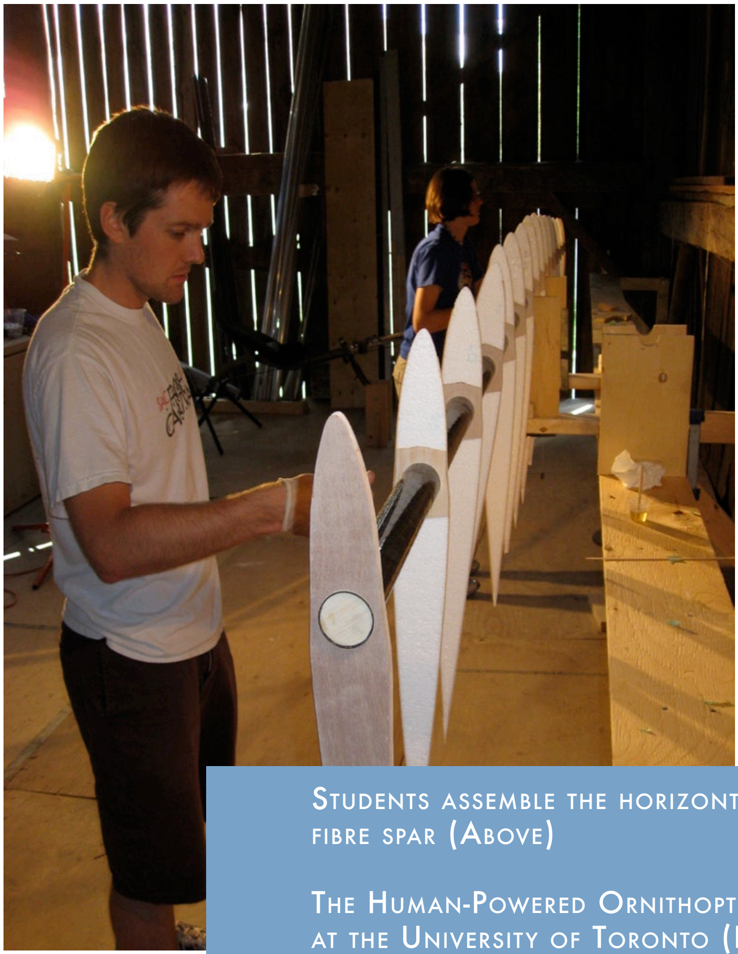
Cameron is beginning his M.A.Sc. at UTIAS, having recently completed his B.A.Sc. at University of Toronto in the Engineering Science program, Aerospace option. Having become a volunteer with the engine-powered ornithopter during his third year, Cameron is conducted research in the summer of 2007 on the HPO in the Subsonic Aerodynamics Lab at UTIAS under Dr. DeLaurier. Cameron's primary interests are in advanced composites, ultralight structures, and their fabrication methods.

Tom Veitch, Aerodynamics, Stability, and Control Team Leader

Tom is beginning his M.A.Sc. at UTIAS, having completed his B.A.Sc. at University of Toronto in the Engineering Science program, Aerospace option. After volunteering in third year on the engine-powered ornithopter, Thomas also conducted summer research on the HPO in the Subsonic Aerodynamics Lab at UTIAS under Dr. DeLaurier. Tom finds the interactions between aircraft structures and aerodynamic forces particularly interesting.

HPO TEAM MEMBERS

Laura Bradbury, Dyanmic Stability 4th Year, Engineering Science (Aerospace Option)
Rafik Chekiri, Simulator Visualization 4th Year, Engineering Science (Aerospace Option)
Tatiana Chiesa, Drivetrain 4th Year, Engineering Science (Aerospace Option)
Kyle Dyroff, Fly-By-Wire Controls, Webmaster 4th Year, Engineering Science (Aerospace Option)
Jennifer Elliott, Physiology and Pilot Training Alumni, Engineering Science (Aerospace Option)
Jessica Fockler, Simulator Mechanics 4th Year, Engineering Science (Aerospace Option)
Geoff Frost, Structural Mechanics On PEY after 3rd Year, Engineering Science (Aerospace Option)
Riley Monsour, Structural Testing On PEY after 3rd Year, Mechanical Engineering
Elena Stumm, Control Surfaces 4th Year, Engineering Science (Aerospace Option)
Dennis Trips, Airfoil Optimization 4th Year, Aerospace Engineering at T.U. Delft (in The Netherlands)



Students assemble the horizontal stabilizer from polystyrene ribs and a carbon-fibre spar (Above)

The Human-Powered Ornithopter Team with a Rowingbike (donated by Derk Thys) at the University of Toronto (Left to Right: Geoff Frost, Riley Monsour, Jenn Elliot, Jessica Fockler, Tom Veitch, Cameron Robertson, Kyle Dyroff, Laura Bradbury, Todd Reichert, and Dennis Trips. (Below)

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