

Human Powered Helicopters Rise Higher

By Benjamin Hein and Mike Hirschberg



The University of Maryland's Gamera II has reached a height of 9.4 ft (2.9 m) in the AHS Human Powered Helicopter Competition. The AHS banner can be seen in the background. Photo by Andrew Rivers, Essential Eye Photographics.

The year 2012 has proved more significant in the race for the AHS Igor I. Sikorsky Human Powered Helicopter prize than any year since its inception in 1980. Maryland has made leaps and bounds with their flights of the Gamera II, and two new competitors have entered the race from Canada and California, respectively. Team AeroVelo is fresh off success with a human-powered ornithopter, and the Neil Saiki-led NTS Works team has strived to have achieved both the first and the final successful flights in the AHS human powered helicopter competition.

Gamera Breaking Records

As described in the July/August 2012 Vertiflite, the University of Maryland unveiled their Gamera II aircraft and flew it over the course of several weeks in June. This aircraft set an NAA-certified record of 49.9 seconds of flight endurance, piloted by Kyle Gluesenkamp. In late August, Maryland was back testing with a new vehicle, now called Gamera II XR (for "extended radius"), with all new rotor blades and transmission system enhancements.

Each step of the way, from Gamera I to Gamera II and Gamera II XR, significant improvements have been made to the vehicle. This was in no small part due to the guidance and support given by the Aerospace Engineering

department at the UMD Glenn L. Martin School of Engineering. Ph.D. student William Staruk said that at every stage of the competition they knew that it was potentially the last chance they would get to fly. However, each time



Seconds after this photo was taken, Gamera II broke up in flight. Fortunately no one was injured. Ph.D. student Elizabeth Weiner's fingertip is 7 ft 2 inches (2.2 m) high. Photo by Earl Zubkoff, Essential Eye Photographics.

flight attempts were undertaken and such significant improvements in altitude and duration were made, that it was virtually impossible for students and faculty to say “no” to continued research and development of the Gamera vehicle.

What was the recipe for the latest round of record breaking flights? Science and cycling. The Maryland team has continued improvements in the drivetrain and optimization of the vehicle for the power-to-weight ratio of the pilot-vehicle-system, zeroing in on 140 lb (63.5 kg) individuals. These pilots are capable of generating approximately 8 Watts/kg, or an impressive 510 Watts (0.68 hp) for 60 seconds.

The basic foundation of the Gamera aircraft family began with testing of isolated rotor systems. This gave Maryland the insight into basic design changes to the rotors to minimize the power required for a large, low-Reynolds number rotor in extreme ground effect. The research surveyed different low-Re airfoils in order to find a combination of high stiffness and good performance for their rotor blades. The team has also conducted extensive research on several factors of human power generation that culminated in the refined hand-foot crank system on all the Gamera aircraft. This research set the stage for a string of success over the past two years. Further improvements were made to the Gamera II, for the August flights, based on extensive calculation, testing and refined manufacturing processes.

For the Gamera II, Maryland students revisited their multi-disciplinary optimization of airfoil and blade structure. These efforts have yielded in a lighter, stiffer and longer rotor blade. As indicated in Maryland’s published papers, the first flights in June of Gamera featured a rotor radius of 6.5 m (11.5 ft). However, the second round of testing included a major diameter increase to 7.2 m (23.6 ft). With the increasing size of the rotor system, the Gamera vehicle gained roughly 12 lb (5.4 kg) between the June and August Gamera II vehicles. These design changes predicted a net benefit for pilot workload: a 12% reduction in the power required to hover.



Neil Shah and Jiho Yeom are part of the rotor fabrication team. Seven additional spare blades were stockpiled next to them.

Maryland’s engineering effort has obviously paid off. After only a few flights, the vehicle hover endurance was increased dramatically to 65 seconds. Following the endurance expansion flights, the team quickly moved on to breaking altitude records, culminating in a not-yet official altitude of over 9 ft. Measurements showed the pilot’s seat was at 9.4 ft, while the vehicle was rolling slightly so that one of the landing posts might have been slightly lower. The longest flights so far have been held by student pilots Colin Gore and Kyle Gluesenkamp. The altitude record has been captured by Henry Enerson. AHS members were on-site to witness the event. Unfortunately, the vehicle sustained significant damage from several hard landings; fortunately, no one was hurt.

As of October, these are the pilot statistics for Gamera II flights, courtesy of Ph.D. candidate Ben Berry:

Colin Gore: totals of 39 flights, 903 seconds and 8.6 ft (2.6 m) maximum altitude. The pilot of the unofficial 65 second endurance flight.

Kyle Gluesenkamp: 24 flights, 673 seconds, 7 ft (2.1 m) max. Kyle holds the official record of 49.9 seconds from June. Kyle also performed a 70 second tethered flight in early August, the longest flight to date.

Henry Enerson: 21 flights, 405 seconds, >9 ft max. Henry’s best endurance flight is 55 seconds.

Dennis Bodewits: 13 flights, 259 seconds, 2.5 ft (0.8 m) max.

Maryland student Judy Wexler was the sole pilot who achieved flight with Gamera I. During 2011, she had made a total of 6 flights totaling 37.8 seconds in the air, reaching a maximum altitude of about 12 inches (0.3 m).

While they have nearly the right combination flight parameters to win the prize, it will take further refinements to simultaneously achieve the 3 m altitude and 60 sec endurance flight. To date, the team has accomplished all this without a control system. As a result, drift remains the major challenge for the Maryland team. With both the hands and feet employed by the pilot, it will be tricky for the Gamera team to develop a control system that allows the pilot to control the vehicle. Maryland has gone back to the drawing-board and plans to fly again in November. The rotorcraft and human powered vehicle community must wait for follow-on flight testing to see the next round of upgrades to Gamera.

Atlas First Flight

Most followers will know that another serious team has entered the fray to compete for the AHS Igor I. Sikorsky HPHC prize. AeroVelo (“flying bike”) is led by two individuals, carried by a team of volunteers, engineers and others, and supported by friends and family. The team also has a long list of supporters that have donated hardware and money to their cause, including through a fundraising campaign through Kickstarter.com.

Unlike most other human-powered helicopter teams, AeroVelo’s pilot Todd Reichert is also one of its chief engineers. Cameron Robertson is the other chief engineer, an indispensable asset when Todd is piloting the aircraft. With many lessons learned from their successful design, build and flight of a human-powered ornithopter AeroVelo exemplifies a tightly knit, efficient team of engineers and mechanics. In 2011, the AeroVelo team also smashed the



AeroVelo's Atlas is the largest human powered helicopter to have ever flown and the first one in Canada. AHS photo.

collegiate human-powered bicycle speed record, achieving 72.6 mph (116.9 km/hr).

Like the Nihon University Yuri I tested in the 1990s and the University of Maryland Gamera, AeroVelo is working on a quad-rotor HPH. AeroVelo's vehicle has been appropriately named Atlas, as its dimensions are impressive. Each rotor is 20.4 m (66.9 ft) in diameter, with a maximum dimension of 58 m (190 ft) on a diagonal. Their circular spars are both impossibly long and at the same time unexpectedly light. The blades have a non-linear taper that arguably give the rotor an enhanced efficiency over those with linearly tapered blades. The airframe system is also an incredibly light carbon tube and polymer line truss. Todd pedals on a heavily modified Cervelo carbon bike frame suspended with the same polymer at the center of the truss. The transmission is driven by polymer line to four custom Kevlar-wound spoke wheels at the center of each rotor.

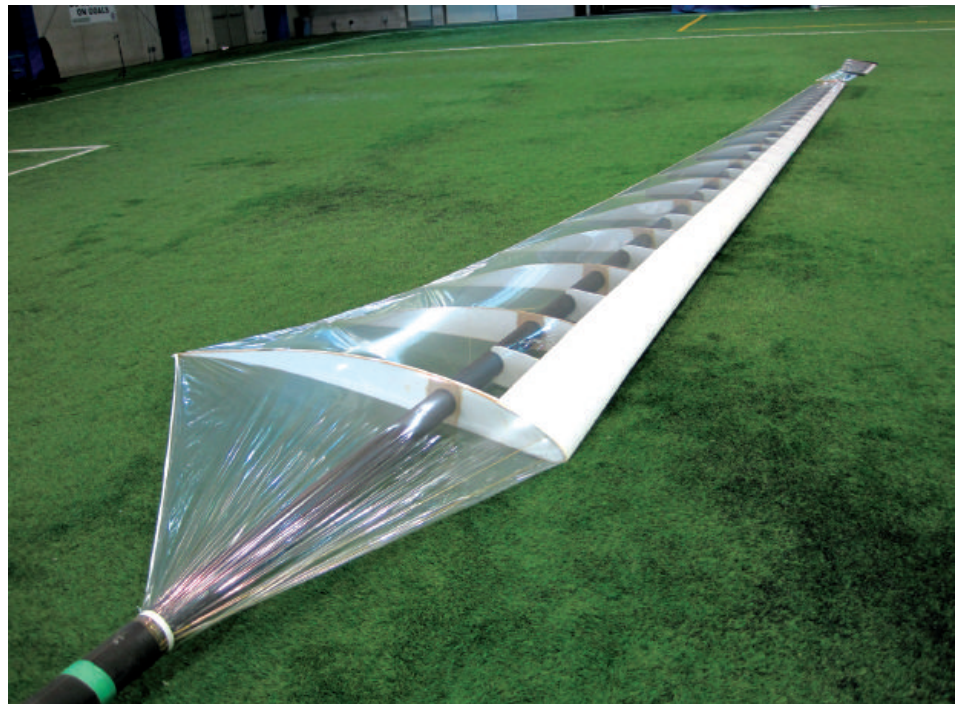
The AeroVelo engineers also conducted extensive analysis on their design. A multi-disciplinary optimization of structural weight, geometry, and aerodynamic performance was conducted with many design variables. Cameron indicated that a lifting-line and wake model was used to study the rotor aerodynamics with details of the root and tip flow considered in their

design. At 120 lb (54.4 kb), the Atlas is nearly in line with Gamera I's empty weight. Ultimately, the power required by the pilot to hover is a combination of weight and disk loading, as well as mechanical and aerodynamic efficiency. Based on measurements from the foot-only pedal system, Todd has demonstrated an incredible 770 Watts (1 hp) of power output for over one minute, which is theoretically enough to

meet the endurance specification of the competition.

Testing of AeroVelo's Atlas HPH was conducted inside the Ontario Soccer Centre in late August/early September. At the end of each flight day, however, the entire aircraft was disassembled and stored in their trailer around back. This feat was accomplished in as few as 20 minutes, when flights went late into the afternoon. The Gamera is similarly designed for modular deconstruction, a painful compromise for vehicles so sensitive to the performance-weight-strength balance.

The AeroVelo team has dared to think big, and the results speak for themselves. After a few days of shaking out their design, the Atlas flew for an estimated 15 seconds. This statistic puts the Atlas in the top three teams of unofficial endurance records in the history of human-powered helicopter flight. The first being University of Maryland, with its current record of 65 seconds. To put this in perspective, the second best endurance time by any HPH team was the Nihon University flight of the Yuri I at 24 sec (unofficial). This achievement only occurred after years of research and development, and in the second round of testing. However, credit must be given to the Japanese



AeroVelo rotor blade. The taper is not an illusion of the perspective. The wingtip canard is a control surface connected to levels on the handlebars of the bike. Photo by the author.



Todd Reichert (left) and Cameron Robertson are both the brains, and Reichert is the brawn in AeroVelo's human powered vehicle efforts. The team has made extensive use of polymer line for strength, rigidity and even for control lines. AHS photo.

team for laying the groundwork for the success of teams to follow. Similarly, the official flight endurance during the first round of testing for the Maryland – with Gamera I – was 11.4 sec.

AeroVelo does have one distinct advantage over the competition at this point in time. Their vehicle has amenities for a mechanical differential pitch and roll system. The rotor blades have a variable pitch flap, integrated into a canard style wing-tip. This system is expected to enable the aircraft to stay inside a 10 m by 10 m (32.8 ft) square box when significant heights are achieved. While this team has also had their fair share of mechanical failures and fixes on the vehicle, AHS anticipates another round of testing in the following months, with likely a significant improvement in performance.

Upturn First Flight and Passing of the Torch

The other major news in the race to win the AHS Sikorsky prize, also described in the July/August Vertiflite, was the first flight of the Upturn. The aircraft and pilot Robert Pasco achieved an impressive unofficial 10 sec flight, at 2 ft (0.6 m) of altitude on



During one of several late August tests, Atlas takes flight. Aeroelasticity, trimming the four rotor systems and gyroscopic precession were all interesting challenges. AHS photo.

June 24, 2012. The flight was terminated when he became exhausted and the aircraft was caught by a safety line attached to the ceiling above. Robert had competed in a bicycle race earlier in the day in addition to three other flight attempts.

Neal Saiki had been part of the 1989 student team at California State Polytechnic University (Cal Poly) in San Luis Obispo, California that built the first human powered helicopters to lift off the ground, culminating in "Da Vinci IV" – it flew for a record 8.6 seconds and a height of 8 inches (20 cm). Saiki's team had achieved the first successful flight in the AHS Sikorsky Competition and hoped that the Upturn would also capture the AHS HPH Prize. However, NTS Works has now turned its focus back to its core business. Nonetheless, the company has generously donated the Upturn to the California Polytechnic State University (Cal Poly) in San Luis Obispo, California for continued development, so Saiki's Upturn may still achieve that goal. Under the guidance

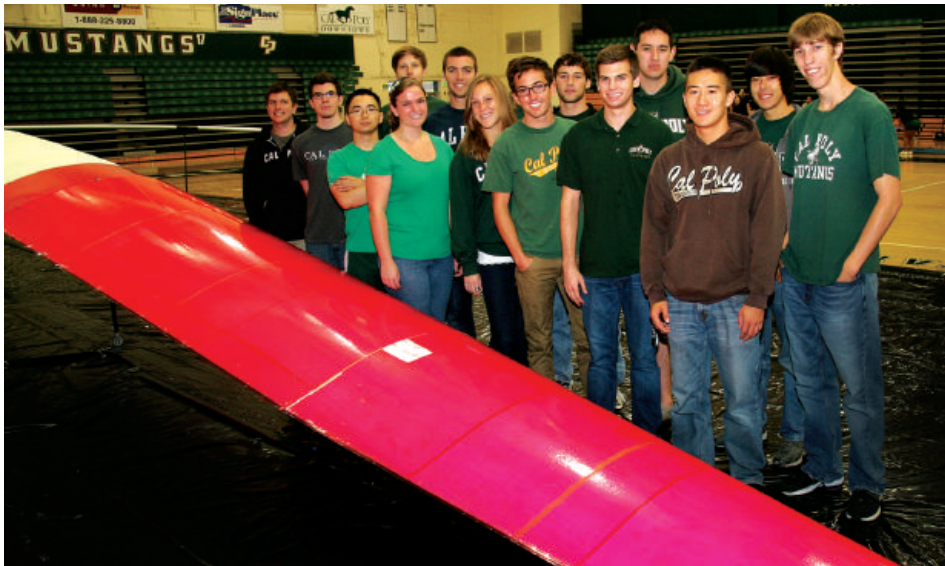
of Prof. Kurt Colvin, the new team has begun to consider the tremendous challenges of the AHS competition and approaches to tackle them. The unique propeller-driven Upturn promises to show even better endurance in the future in the hands of the university. It will be interesting to see if they can get the weight out, increase efficiency and/or increase their diameter to beat the quad-rotors to the prize.

2012 – The Year of the HPH

Three human powered vehicle teams have flown in the past year, and the boundary of human-powered VTOL flight has been pushed beyond the 60 second mark. But even with the incredible advancements seen in human powered helicopter technology in the past year, the challenge of the AHS Igor I. Sikorsky Human Powered Helicopter prize still remains unclaimed after 32 years. However, unlike years past, it is safe to say that it will not stay that way forever.



Upturn in the air with pilot Robert Pasco.



Cal Poly has taken over the Upturn. An organization meeting was held in September. Cal Poly Photo.

Significant Challenges Remain

Much as in the early years of the development of the combustion-powered helicopter, weight and control remain significant challenges to human-powered helicopters. With the harsh limitation on power-available to the vehicle by a single human for 60 seconds, the HPH designers must refine their designs even further to eliminate weight, while maintaining stiffness and strength. In hover, conventional helicopters are driven by induced power, which is a function of weight and rotor disk area. If you consult helicopter performance references, you will find that the relationship is more strongly weighted by weight than disk area. So designers must find and expand the limit of practical rotor radius, while

maintaining or even lowering the vehicle weight, which is the more powerful parameter when it comes to power-required-to-hover. As we have seen from the historical design solutions, this limit is governed by blades stiffness, airframe strength and the size of the facility in which it can be tested.

The spirit of the competition is to design, build and fly a vehicle powered and controlled purely by a human. Governing the use of controls is strongly limited by the regulation of stored-energy. Past committee chairs were consulted during negotiations with active HPH teams as to whether stored battery power is permissible. It was concluded that use of chemical energy would violate the spirit of the rules, as they were originally written. While clarifications to the rules allow the use of batteries, in systems not contributing

to the rotor system power available, these will be prohibited following August 2013. If needed, competitors will have to find a way to generate electrical power derived from the human pilot.

It was fairly obvious from video footage of Gamera's flights that any small disturbance leads to uncontrolled drift, especially as the vehicle gained altitude. Credit must go to the AeroVelo team for pioneering a unique system to control the vehicle's pitch and roll during flight without the use of batteries. Similarly, systems are being developed for Gamera and Upturn to control the vehicles' attitude. It is unlikely that the 10x10 m flight envelope can be maintained without a control system. AHS looks forward to seeing how novel systems can be employed to add the final leg of the trio of core regulations.

About the Authors

Ben Hein is a senior engineer at Sikorsky Aircraft Corporation, currently investigating active rotor technology. Ben holds patents in helicopter design and rotor system design. He has been the AHS Igor I. Sikorsky Human Powered Helicopter Committee chair since May 2012.

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Successful Human Powered Helicopters in the AHS HPH Competition

Vehicle	Da Vinci III / IV	Yuri I	Gamera I	Gamera II	Gamera II XR	Upturn	Atlas
Team	Cal Poly U.	Nihon U.	U. Maryland	U. Maryland	U. Maryland	NTS Works	AeroVelo
RotorType (# Blades/Rotor)	Single MR, Propeller (2)	Quadrotor (2)	Quadrotor (2)	Quadrotor (2)	Quadrotor (2)	Single MR, Propeller (4)	Quadrotor (2)
First flight	Dec 1989	Dec 1993	May 2011	June 2012	Aug 2012	Jun 2012	Aug 2012
Rotor diameter	100 ft / 30.5 m	33 ft / 10 m	42.6 ft / 13 m	42.6 ft / 13 m	47.2 ft / 14.4 m	85 ft / 25.9 m	66.9 ft / 20.4 m
Max dimension	100 ft / 30.5 m	~ 80 ft / 24.5 m	105 ft / 32 m	105 ft / 32 m	115 ft / 35 m	85 ft / 25.9 m	190 ft / 58 m
Empty weight	97 lb / 44 kg	83 lb / 38 kg	106 lb / 48 kg	76 lb / 34 kg	82 lb / 37 kg	95 lb / 43 kg	120 lb / 54.4 kg
Max endurance	8.6 sec	19.46 sec	11.4 sec	50 sec	65 sec	10 sec	15 sec
Max altitude	8 in / 20 cm	8 in / 20 cm	1 ft / 30 cm	3.5 ft / 1.1 m	9 ft / 2.7 m	2 ft / 0.6 m	1.6 ft / 0.5 m

n/a = not available