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HUMAN POWER

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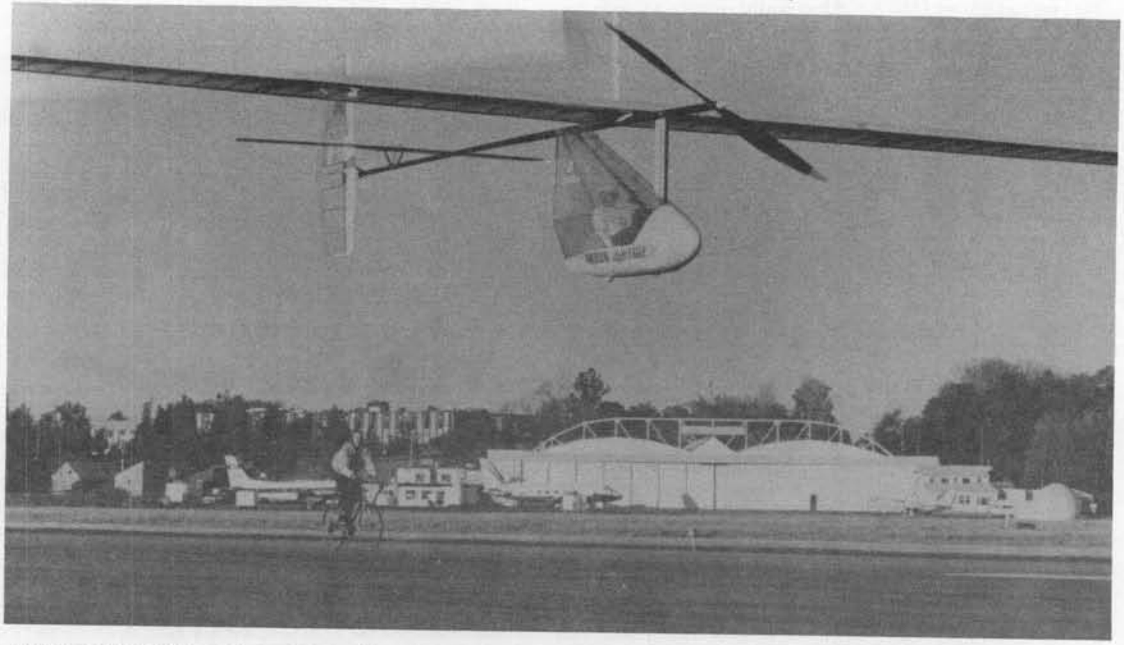

TEST FLIGHT - Steve Bussolari, director of flight operations for the Daedalus team, takes a test flight in the Michelob Light Eagle prototype. PHOTO BY Frank Siteman

DAEDALUS Project Milestone

First Test Flights for Michelob Light Eagle

The first test flights of a new human-powered aircraft have been successfully performed, setting the stage for an attempt at a new world distance record in early 1987.

John Langford, director of the Daedalus Human-Powered-Flight Team, said the Michelob Light Eagle, developed by engineers and students at the Massachusetts Institute of Technology, performed successfully during recent testing at Hanscom Field in Concord, Mass.

The ultralight plane will attempt to break the current world record for human-powered flight of 37 km, 23 miles, established by the Gossamer Albatross across the English Channel in 1979.

The Michelob Light Eagle will be attempting a two-hour flight of approximately 48 km, 30 miles, in January, 1987, at NASA's Dryden Flight Research Facility on Edwards Air Force Base near Lancaster, Calif., site of the U.S. Space-Shuttle landings.

Construction of the plane began at MIT on June 2, 1986, and the first flight occurred on Oct. 3. During that 123-day period, approximately 14,500 hours were devoted to construction of the aircraft and its associated tooling, simulator and trailer. Another 1,500 hours were spent on physiological research, pilot selection and training. Direct costs during this period amounted to $130,000.

The framework of the Michelob Light Eagle is made of Thornel^{R} carbon fibers, provided by Union Carbide. The carbon fibers are bonded with epoxy into a unique structural design, developed at MIT, that is extremely strong and stiff, yet very lightweight. The aerodynamic shape is formed by 120 ribs made of lightweight foam and aircraft plywood.

Mylar^{R}, a thin plastic film developed by Dupont, covers the wings and other surfaces. The trailing edges and fuselage fairing are made of Kevlar^{R}, a synthetic cloth also made by Dupont.

continued on page 4

HUMAN POWER - THE TECHNICAL JOURNAL OF THE
INTERNATIONAL HUMAN-POWERED-VEHICLE ASSOCIATION
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Volume 5, no. 4, winter 1986-7

The IHPVA - a Three-Media Movement

The three media are, of course, air, land and water, but the news media also have gotten fully involved and have treated us royally. All IHPVA hearts must have swelled with pride at the many reports of the triumph of GOLD RUSH, Freddie Markham and Gardner Martin over the 65-mph Du Pont hurdle; and over the portrayal of Allan Abbott, Alec Brooks and Parker MacCready, in particular, as light-hearted but superbly effective conquerors of the waves through hydrofoils in the public-TV science program Discover. As I write this, Allan is on the front cover of Scientific American on the Flying Fish. Gunter Rochelt and Wayne Bliesner with their magnificent flying machines have had excellent coverage in their home areas, but not as much as they deserve internationally. It looks as though the news media's interest is being intrigued by the plans of the Daedalus team to fly from Crete to the mainland of Greece.

So one way or another, we've gotten one category of media covered, and the other type of media are covering us. How can we still have a membership of only around 1500?

A striking series of quarter-page advertisements in the Boston Globe in November and December from a sailplane club proposed the ultimate gift: a sailplane ride for two for about eighty dollars. Maybe that's the approach we need. We are good enough that we get lots of publicity without asking for it. But we're bashful about asking people to join the IHPVA to support all these worthwhile activities. Maybe we should advertise. We can all do a little individual advertising, and maybe the IHPVA could put out some very short funds to start a modest national campaign. What do you think?

CONTENTS

This issue of HP was typed by Sabina Rataj and David Wilson; set-up by Dave Wilson and Tom Healy. Printed at Apple Press by Tom Healy. Distributed by Marti Daily & cast of thousands.

Letters

. . not only was the (Vancouver) event wonderful; the place and people were wonderful also. I have written to Tom (McDonald) telling him off for letting me leave. . . . A lot of people asked about my as-yet failed "Cyclops". If there is room in HP you might include photos and what passes for a drawing of the chassis. The rear track has now been increased to 15" (380 mm) from 12" (305 mm) which I hope will cure the problem of falling over at 30 mph. I am off to see the Dutch this weekend (end of September) to give them the good news.

Mike (Burrows) - Windcheetah HPVs
Green Lane West, Rackheath, Norwich, NR13 6LW, UK

I greatly enjoyed the Fall'86 issue of HP, and sincerely hope that you will be able to keep up this high standard.

As a result of it I wrote to Allan Abbott and Einar Jakobsen because we up in the Alps now have 3.5 HPB-addicts who intend to get going on a wing-flapping HP-hydrofoil project. If successful we shall call it "Mutiny of the Swiss Navy".

I also got a kick out of Fred Willkie's Bangladesh article . . . in fact, his account reminds me of my own ten years spent in Asia: long-nosed missionary disembarking with blossom-white drawings, but finding the field barren/irresponsive to our cartesian approach. This should not be taken as a dejected lament. I am quite confident about HPV progress. All we need is on top of Cherno-Byl and Cherno-Bale: a cherno-mobile indigestion senza benzina, as in 1974, in order to break the ice.

Meanwhile our Swiss EXPO-86 roamers have all come back home . . . I am sending you a concept copy of a recumbent project which I conceived some time back. It comes close to your own ideas regarding wheelbase and weather protection. The rear suspension is by trailing fork, supplemented by gas-damper struts. Front telescopic fork has a packet of rubber compression springs.

Here we are just about to hold our third technical workshop with the specific theme of fairing construction. Some fifteen active members are taking part. Our membership has now passed 200, out of which about 10% are also paying IHPVA members. Our next objective: a top-notch HPV booth at the next IFMA-Zurich at the end of February '87. . .

"Velauf", as we say here!

Peter Ernst, pres., FUTURE-BIKE club
15 rue Moser, 2503 Bienne, Switzerland.

As a long-time subscriber to Human Power, I would like to say it is a very good journal, and getting better with each issue. I want to express my thanks to . . all the fine people who take the time and trouble to put it together. . . In accordance with the editorial in the summer, 1986, issue, I want to give two gift subscriptions to friends of mine . .

Andy Ross, Ross Experimental Inc.
1660 W. Henderson Road, Columbus OH 43220 USA

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more letters on page 3

. . . re the losing but necessary battle against the excesses of the motorcar. In Switzerland we have it a bit easier now because of the widespread dying of the forests: it has become possible, and even fashionable, to launch tirades against cars. Indeed even the government is officially committed to reduce the effects of driving (all because of the trees - no one cares about people). Unfortunately it all remains theory. Except for a few mild speed reductions and the introduction of catalytic converters all remains as before even though many experts maintain that only gasoline rationing would have any serious effect. However, the majority of people remain egotistical, and even the $15 yearly fee for using the motorways is highly unpopular. . .

I assume that Peter Ernst has sent you a report of the Tour de Sol. What he may not have told you was that he managed to build quite a good vehicle in an incredibly short time, almost single-handedly but with some financial help from a Texan. The vehicle was built in the shape of a grand piano in order to attract attention but actually worked better than several entries with more aerodynamic shapes.

Tour de Sol 87 is going ahead next June. The last two Tours have done wonders publicity-wise. Only two years after the start of the movement we already have a multi-million-franc solar installation being built as a result of the publicity, and large firms talking about hundreds-of-millions investments into manufacturing such vehicles, perhaps in the style of a high-quality "cheapie", like the Swiss wrist watch. Unfortunately the human-power side gets left out completely, and I fear the solar part may be forgotten too, eventually, but it is better than nothing.

My Channel crossing (by bike plus pontoons) is now rescheduled for July-August 1987.

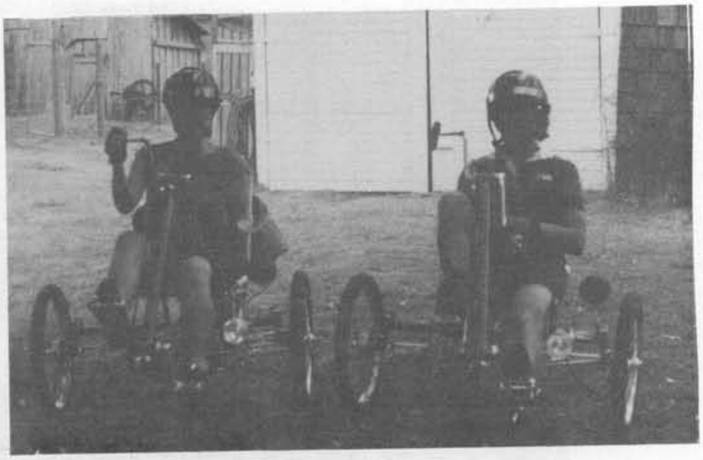
Theodor Schmidt, Rebackerweg 19, 4402 Frenkendorf
Switzerland.

. . I found one minor flaw in your article [on HPV history, reprinted in the super EXPO HPV program - ed.]: you credited the invention of the tension wheel to the French, around 1870. I believe that it should be credited to Sir George Cayley, 1773-1857, who needed light-weight landing gear for his man- (his reluctant chauffeur, I believe) -carrying aircraft, circa 1852-3.

Also, I would have liked to see a word or two about Alex Moulton (the bike on my letterhead is a Moulton Speed Six. I owned one once). . .

Harold Wooster, fellow, European Institute of Cycle Engineering, 8807 Mead St., Bethesda MD 20817.

[Harold Wooster gives me the opportunity here, as I have done in AMERICAN SCIENTIST in response to another letter, to acknowledge the wonderful Moultons. I have owned five, including a Speed Six. I used them for commuting and some touring and for lugging extraordinary weights of freight - for instance, a five-gallon drum of roof asphalt. Try that on a ten-speed. At the other end of the scale, the performance of the Aero-Moultons in the speed trials has been magnificent - ed.]



Larry and Marge Warning and their Hale Trikes.

We enjoyed the fall issue very much. Having attended HPV week at EXPO'86, the review of the vehicles and events there was especially interesting. The resource directory is helpful in our efforts to build a pedal-driven watercraft. Keep up the good work! We're getting our money's worth.

We do not own motorcars (the misnomer "automobile" is avoided deliberately) and we avoid riding in them. Cycling provides most of our transportation. Recently we completed a pair of hand-and-foot-cranked recumbent trikes, which we ride daily. They are great! The designer is Gary Hale of Eugene Oregon, an unsung hero of cycling innovation. Out Cateye cyclocomputers reveal a slightly faster cruising speed compared with our Schwinn ATBs: 14 vs 12 mph. But the comfort, handling, visibility in traffic and sex appeal are far greater: we're very happy with them.

Larry and Marge Warning, POB 43, Nahcotta, WA 98637

The Thunderer

THE TIMES of London was given this name decades ago because when it thundered out in an editorial against the government the effect could sometimes be dramatic. Campaigns often were, and are, started by one letter published in The Times' correspondence column. Governments occasionally fell as a result.

Another aspect of the power of letters in Britain came to me a couple of months ago when a friend and I had a paper on some obscure topic published in a British engineering-society journal. The editor sent us six-or-so long letters of comment. Some were almost small papers in themselves. We were encouraged to reply in almost as much length as we wanted. All the letters and our responses will be published. We can correct our errors and acknowledge valuable additions from others. The readers will, I hope, be well served.

The purpose of these reminiscences is to encourage letters to HUMAN POWER. Write letters about topics that interest or concern you, and letters criticizing or applauding or adding to published papers. We don't want to topple any regimes, but we could develop discussions that could reveal new truth.

DAEDALUS TEAM - John S. Langford, program manager and Lois McCallin, pilot stand with Michelob Light Eagle prototype in background. PHOTO BY Frank Siteman

continued from page 1

The pilot powers the craft by pedaling a set of bicycle cranks connected through two gear boxes and a drive shaft to a propeller of 3.4-m, 11-foot, diameter. The pilot can manually adjust the propeller's pitch to vary pedaling cadence, much as a bicycle rider can shift gears.

A joystick maneuvered by the pilot's right hand controls the aircraft's elevator and rudder, while the left hand controls the aileron and radio. The aircraft's instruments include an airspeed indicator, an altimeter and an artificial-horizon system.

The Michelob Light Eagle was designed by Juan Cruz, Mark Drela, John Langford and Bob Parks. The aircraft's electronics were developed by Steve Finberg and Bryan Sullivan.

Approximately a dozen students, led by Jim Alman and Jim Wilkerson, assisted in the aircraft's construction.

Tests to date have established the soundness of the basic design. Future tests will focus on accurately measuring the power required to fly the aircraft, its stability and handling characteristics.

Langford said because of the need for calm wind conditions, flight testing is conducted in the early morning hours, after dawn. Trial flights will continue at Hanscom Field until early November, as weather conditions permit, he said. In late December, the Daedalus team will move the operations to NASA facilities on Edwards Air Force Base.

The aircraft is a prototype for a second plane, to be called the Daedalus, that will be designed to attempt a flight later in the year from the island of Crete to the mainland of Greece.

That flight would recreate the myth of the ancient craftsman and engineer, Daedalus, who according to legend made the 111 km, 69-mile, flight using wings he fashioned from wax and feathers.

Langford said that, in addition to setting a world record, the Daedalus project has numerous scientific objectives. These include stimulating improvement in aircraft structures, aerodynamics and vehicle design; advancing understanding of the limits of human performance; and increasing awareness of the connections between art and science, and between technology and Western culture.

A feasibility study of the project was completed earlier this year, sponsored by MIT and the Smithsonian's National Air and Space Museum. Anheuser-Busch provided funding to build and test the prototype plane.

It will build on the experience gained by the department's previous human-powered aircraft, which included the 1979 Chrysalis and the 1984 Monarch B, which was awarded first prize in the Royal Aeronautical Society's Kremer World Speed Competition for a record-setting speed flight on May 11, 1984.

MICHELOB LIGHT EAGLE FACT SHEET

Type: Human-powered aircraft. The pilot powers the craft by pedaling a set of bicycle cranks which turn the airplane's propeller.

Length: 9m, 29.6 feet

Weight: 40 kg, 88 pounds, (without pilot)

Wingspan: 31 m, 102 feet (roughly equivalent to DC-9 jet)

Speed: The plane will fly at an average speed of 6.7 m/s, 15 m.p.h. about 3 m, 10 feet, above the ground.

Rickshaws in Bangladesh

By H. Frederick Willkie II

part two

(This is the concluding part of Fred Willkie's article, the first part of which appeared in HP vol.5 no.3, fall '86. He discussed the sociological background to the use of rickshaws, in particular who owns them and who operates them. He pointed out that the standard rickshaw weighs about 100 kg empty, and may weigh over 700 kg loaded, and has only one high gear. It is high so that the operator can return fast to the source of the business. It generally has only one brake, on the front wheel, which when used on a loaded machine can snap off the front forks. Rickshaw drivers are trapped into a situation of using unsafe and body-breaking machines because they do not own their own vehicles. Fred spent many months in Bangladesh looking for solutions).

In the small city of Jessore, I walked the clay street of the rickshaw shops. They were little lean-tos of cut-and-woven bamboo and corrugated-steel sheet. In front of one, a mishtri (mechanic) was building a frame. He had a little Chinese centrifugal blower that he drove with a rim strip passed around a bicycle wheel fitted with a hand crank and set in a wooden frame to act as a pulley. The blower forced air into a little clay oven whose mouth was no larger than your palm, crossed by a wire grate. The front triangle he was building was propped on a stick, so that its bottom bracket sat on the oven's mouth, covered over with charcoals that the mishtri occasionally dribbled water on to keep the heat in. The brass was wire, wound around the tubes just outside the sockets of the bracket shell. He drove his blower with the bicycle-wheel pulley until the coals got hot enough to melt the brass, which flowed down the tubes and into the joint. I would never have believed his apparatus would work if I hadn't seen it happen right there, and the brazing-alloy wire he made himself, melting and drawing, over the heat of his tiny mud-oven, old rivets, belt-buckles, buttons, and brass chips swept by old women from the floor of little machine shops. Ingenuity is abundant among the mishtris of Bangladesh; materials are scarce. Alloys are seldom pure or strong. You must keep that in mind when you're trying to design something for their use. It needs to be robust, cheap and simple.

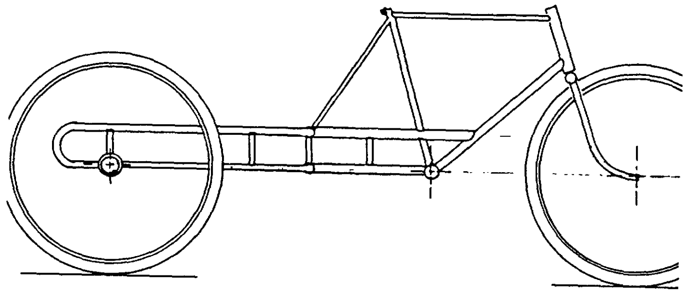
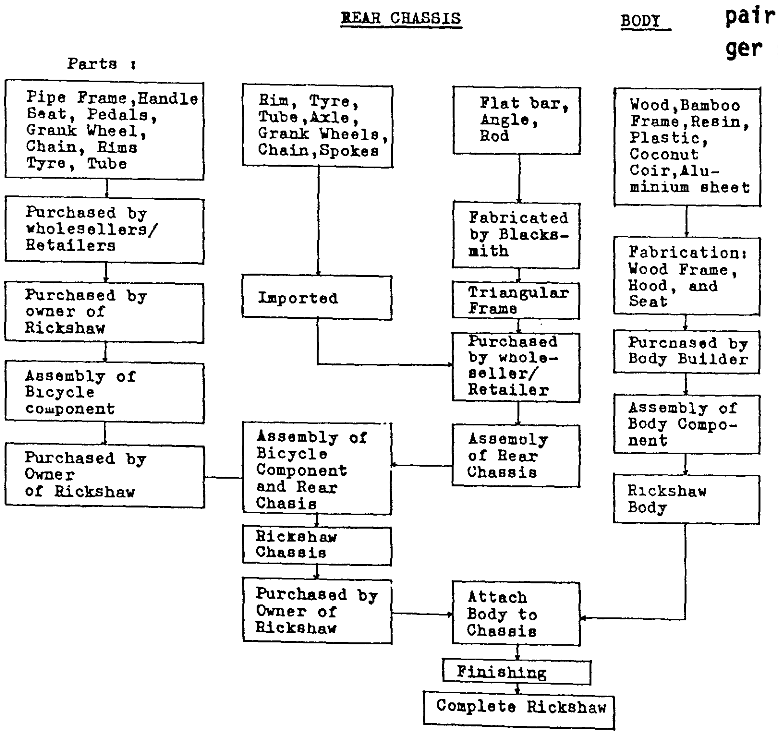


DIAGRAM 2

MANUFACTURING AND ASSEMBLY PROCESS OF THE RICKSHAW



Source : "Small scale Manufacturing : Case studies of Urban enterprises in Dhaka Metropolitan area". UNCHS: July 1979.

We managed to get a workable design together. It was of tubular construction, though tubes weren't available and we had to incorporate waterpipe. It had a foot-operated drum brake working on the rear axle, a pair of conical rubber shock absorbers for the passenger seat, an optional three-speed shifter requiring no

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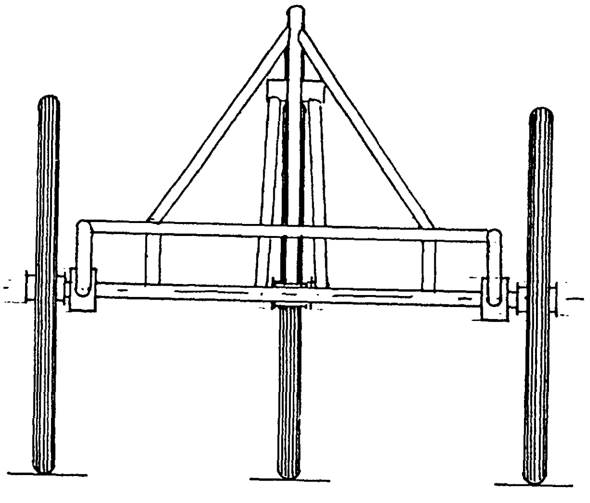

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parallelograms, no cables, no pinion, no hardened parts, and only hand labor for most of its manufacture. The front fork had no trail, so it didn't fight the wallah every time the rickshaw went over a bump. The stability came from a geometry that required the steering head to rise as the fork turned to either side, so it didn't, unless the wallah wanted it to. The first wallah to test it increased his gross daily earnings by 35% right away. He said, too, that he felt better and slept better at the end of a day; he had less pain. We had managed to decrease the resistances.

Inter Pares, a Canadian-based international development service, sent me to Bangladesh. It gave me a chance to reduce resistance. It is working to increase power, too. The new rickshaws are being built by two different co-operative workshops. Canada is providing starting-up money for plant, materials, and labor. The finished vehicles are sold only to the people who will actually drive them. They are sold on a hire-purchase plan with payments comparable to typical rents, at only one to a customer right now. That way a wallah doesn't pay for one and get another while he exploits another man in renting out the first. When the rickshaw is paid for, the wallah can keep all his earnings, rather than forking over a big share to a malik. There's more money left for the family to live on. Inter Pares is a good, thoughtful outfit, supported by private donations matched by the Canadian International Development Agency. Its address is:

Inter Pares, 58 Arthur, Ottawa, Canada K1R 7B9

Edward T. Hall, an American anthropologist, wrote "The Silent Language" about cross-cultural communication, different cultures' concepts and use of time, space, and gesture. I didn't read the book before going to Bangladesh. I should have. The title alone shows that learning the local spoken language is only part of the job of understanding and being understood by people of a very different culture. The pressure of much to do, little time, and much to learn made my eight months very hard. It's a tough place. I learned a lot. We can be useful to poor people in the world if we get over proposing technofixes from a comfortable distance. The nations of the third world suffer greatly from the present rules of trade with the industrialized countries. They sell raw materials and labor too cheap, buy manufactures for too much, and are hobbled by debt. If we want really to help, it looks as though we'll have to study, understand, and support the "new international economic order" that third-world countries have repeatedly called for.

Fred Willkie, 204 LeBreton St. N, OTTAWA K1R 7J1,
CANADA.

International Conference On Appropriate Transportation

This will be held in conjunction with the International Bicycle Show and in collaboration with the IHPVA, on Friday - Sunday February 6-8, 1987 in New York City. (Some of our valiant volunteers will be putting on an IHPVA booth). The conference fee is $25.00, or $35.00 including two breakfasts and lunches. It's nominally too late to book rooms at the Sloan Y, but it might be worth trying. Send checks payable to ICAT to 49 East Houston Street, NY NY 10012. Phone 212 925 8505.

Transcanada Pedicab

The small-ad sounded like an unusual commercial offshoot of Fred Willkie's work in Bangladesh. But it turned out to be a very straightforward Vancouver company (52 East Cordova Street) whose products were everywhere in evidence at EXPO-86. What impressed me about the material sent was the thoroughness in guiding people who might want to set up a pedicab operation, from making a feasibility survey, to covering insurance and applying to the city for an operating license. The basic Pedicab price is under $2000 (US) with several options including an AM-FM tape cassette with speakers. (If this has an "off" knob within reach of the passengers it would score high over taxis with me). We wish TCP good fortune.

The Cornell Bicycle Project

Jim Papadopoulos, recent PhD graduate from MIT, and Andy Ruina, Brown PhD and on the applied mechanics faculty at Cornell since 1980, have launched a bicycle-research project there. They have an impressive agenda of research on topics that may be specific to bicycles (including recumbents) but impact on HPVs generally. Their aim is to attract low-level sponsorship from a large number of companies. In effect, they want to accomplish privately what organizations like the Electric Power Research Institute do publicly: to spread the costs of high-quality concentrated research around so large a number of users that the added costs to the users are imperceptible. The bicycle industry needs this kind of research support. We wish them an enthusiastic response from industry and from the public.

Bike Tech, Winter 1986

Frank Berto, master evaluator of bicycle systems such as gears, wrote an insightful article on the 1986 IHPVA championships in which he examined the details of many of the high-speed machines and extracted general rules for success, in addition to comments on particular machines. I recommend his piece. Peter Van Handel writes on new methods of training in the first of a series, and David Sanderson discusses the biomechanics of pedalling. Technical editor Bob Flower looks at the US patent system and gives novices some guidelines.

Letter/Report

[The following letter is from Calvin Gongwer, a pioneer on oscillating-wing propulsion. I had asked him if he could write an article for us on any of his developments, including his revolutionary AQUEON swimming foils, which his company was selling in the sixties - ed.]

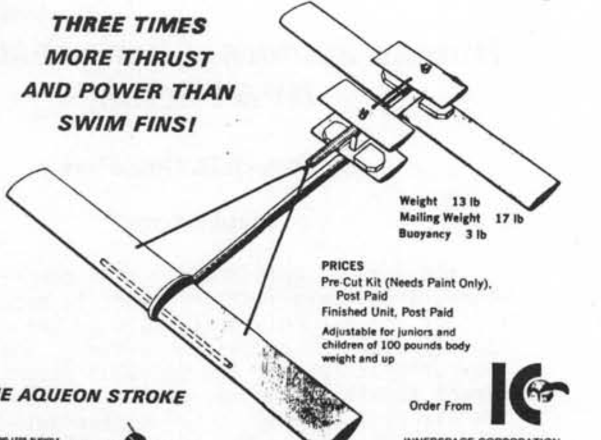
I still have some of our literature on the Aqueon. . . We made quantitative tests of several types - see the plot of diver's air consumption vs. speed. If the "hotel load" is subtracted (1 cfm) the consumption ratio is 5:1 in the Aqueon's favor. Also the timed distance tests of the Navy divers . . represents a six-fold increase in propulsive power over swim fins. From our tests and those by the National Institute of Health at the David Taylor Model Basin, the efficiency of fins with SCUBA is about 15%, making the Aqueon about 90%.

I have made various paddle boards and other craft propelled by oscillating foils over the years, the last of which was the kayak at EXPO'86. The long bulbous bow of my ship (photo) has a scaled-up foil that will be propulsive in a sea state.

Sorry I haven't time to write a paper.

Cal Gongwer, president, Innerspace Corp.
19017 E. Leadora Ave., Glendora, CA 91740

THREE TIMES MORE THRUST AND POWER THAN SWIM FINS!



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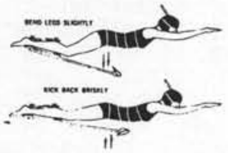
THE AQUEON STROKE



Forward motion results from simple leg movement only. DO NOT ATTEMPT TO SWIM WITH THE ARMS — this will only impede the forward motion.

Hold the body as straight as possible with the arms extended straight in front.

Bend the legs slightly — then straighten briskly by kicking back.

With this movement the front wings of the 'AQUEON' will dive and then return upwards. To make sure that this cycle is completed correctly, try to make the front wings almost hit the body.

During the early practice stages concentrate on smoothness and control. Try to resist the desire for speed.

A fast short stroke is recommended for maximum thrust, but the swimmer will soon learn the best style of stroke for himself.

Experimenting with the tension on the spring could result in improvements in both speed and control.

For diving and climbing, tilt the hands slightly down or up while under way and arch the body downward or upward. For turning, arch the hands and body to the right or left.

For minimum drag under water keep the head lowered between the arms; in effect, looking straight down.

Remember — to dismount, merely spread the legs.

PATENTS — UNITED STATES 3,122,759 — 3,204,699 — 3,204,262
AUSTRALIA — 274,701 • JAPAN — 6 158,166 appl'n • WEST GERMANY — 1,287,985 •
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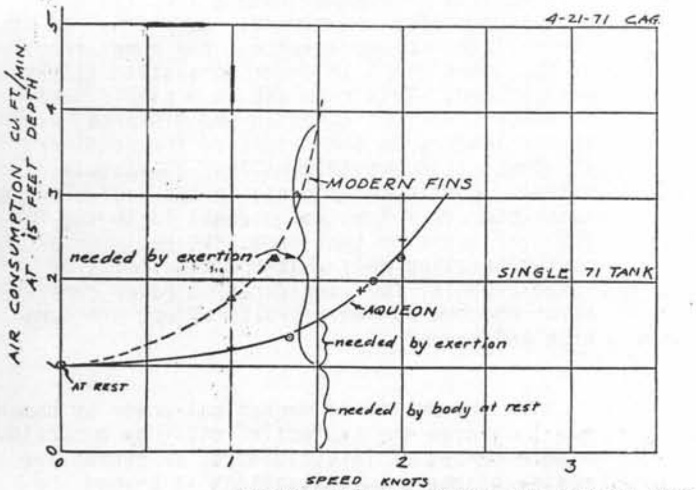
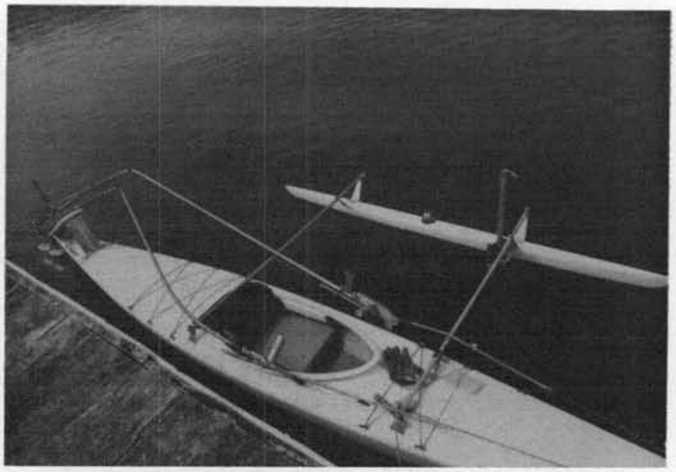
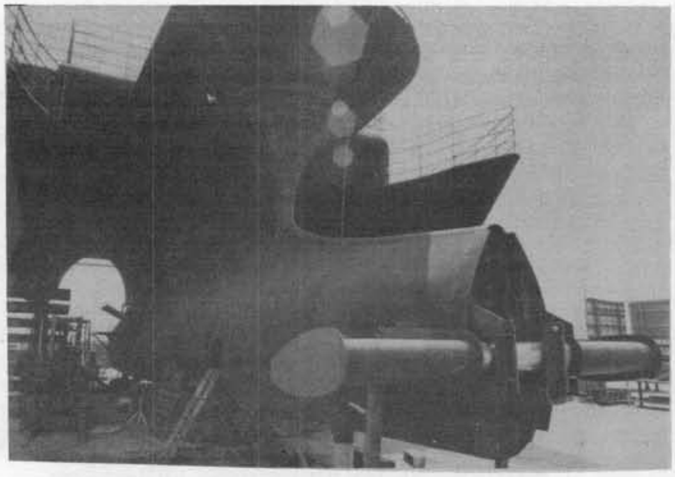
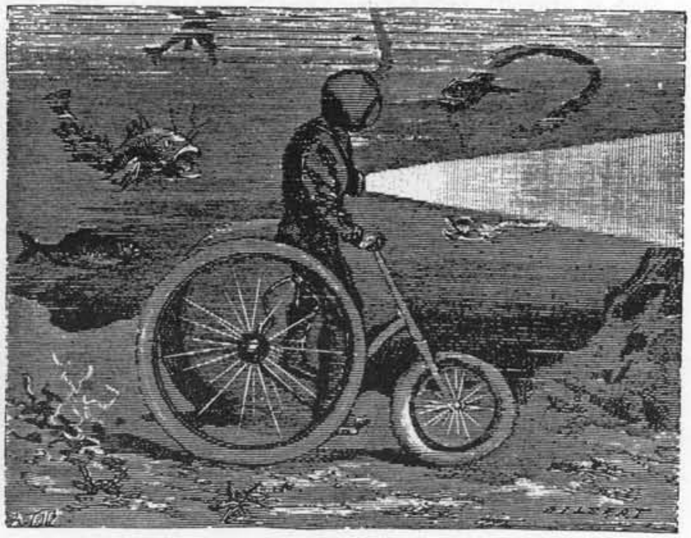


SCUBA TESTS OF AQUEON AND MODERN FINS



Human Powered Kayak (above). Bow (below) features a scaled-up foil. PHOTOS BY Calvin Gongwer





Human Factors of Long-Distance HPA Flights

By Steven R. Bussolari

INTRODUCTION

The design configuration of a powered aircraft, from heavy-lift transport to supersonic fighter, is strongly influenced by the characteristics of its propulsion system. The technological challenge of the Daedalus flight is a direct result of the use of the human pilot as the aircraft powerplant. The aeronautical engineer, who is unable to significantly alter the design of the human engine, is faced with the problem of optimizing the airframe to effectively match the capacity of the human pilot as the source of mechanical power as well as manual controller and decision-maker. In order to perform this optimization, it is necessary to formulate engineering models for human performance that may be combined with similar models for the aircraft. The resulting pilot/aircraft combination is then subject to analysis by formal engineering methods.

Early human-powered aircraft (HPA) required a relatively high power output from the pilot for flights of a few minutes' duration. As the aircraft technology advanced, the power required of the human pilot in order to sustain flight was reduced. This resulted in a significant increase in flight duration and distance, eventually leading to the flight of the Gossamer Albatross (2 hours 49 min/37km, 23 statute miles). Continued progress in the technology of human-powered fl%ght has brought forth the fundamental question that faces the designer of the next-generation HPA: what are the limits of human capacity for long-duration power generation and how do those limits affect HPA duration and range?

The production of mechanical power by humans has long been the subject of study by a considerable number of investigators. An exhaustive review of these investigations is beyond the scope of this report. In lieu of such a review, a general summary of human-power measurements as reported in the literature has been compiled and is presented in figure 1. The power produced by human subjects is plotted against the length of time during which that power was produced. The methods employed in the investigations summarized in figure 1 vary widely as do the results. It is important, however, to note that the measurements of human-power limitations are extremely difficult to perform, simply because each measurement must be carried out until the test subject is exhausted. The physiological preparation and psychological motivation of the test subject become important experimental variables that are difficult to control in a repeatable fashion. A further limitation of the reviewed literature was the fact that important parameters, including test-subject body weight, level of training, and details of the measurement techniques are not uniformly reported. The result is that limits of human endurance as expressed in figure 1, while useful for establishing rough bounds on the problem, are of little help in establishing the engineering feasibility of the Daedalus flight.

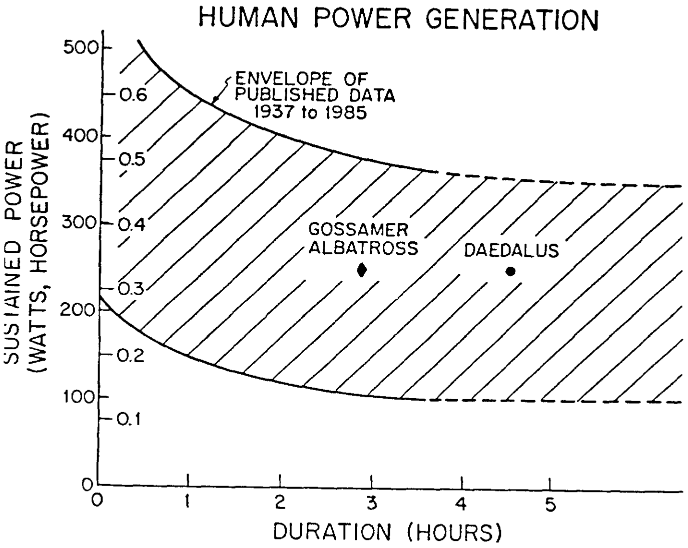


FIG. 1 Human Power Output as measured in Previous Studies. (adapted from Whitt & Wilson, ref. 4.)

The research described here was performed to formulate preliminary answers to the following questions.

1) What are the physiological mechanisms that limit the duration of human power production?

2) What power level (per unit of body weight) can be expected from a human pilot given a certain level of athletic ability and endurance training?

3) What countermeasures are available to ensure that physiological limits are not encountered during the Daedalus flight?

4) How large is the population pool from which appropriate pilots may be selected?

BACKGROUND

In order to move an object over a given distance, energy must be generated and converted to mechanical work. An automobile, for instance, requires the delivery of fuel and oxygen to the cylinders, in which energy is released by combustion. Similarly, a human requires the release of chemically bound energy to provide for both the contraction and relaxation processes in skeletal muscle. Energy is released to

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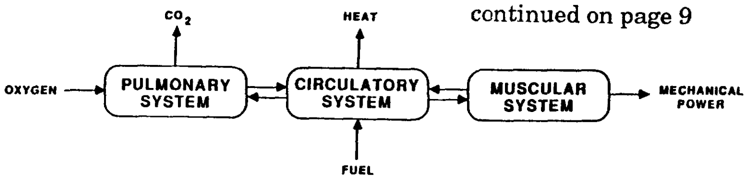

FIG. 2 Coupling between pulmonary, cardiovascular and muscular systems.

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the muscle cells by the hydrolysis of specific high-energy compounds, adenosine triphosphate and creatine phosphate. Since skeletal muscle stores these compounds in very small quantities, capable of supporting activity for a few seconds at best, continuous activity can be sustained only by providing sufficient delivery of oxygen and fuel to the muscle from elsewhere. The complete oxidation of the available fuel provides for the resynthesis of the high-energy compounds, making them available for hydrolysis and release of energy. An adequate delivery of oxygen and fuel ensures that adenosine diphosphate is re-energized to adenosine triphosphate at a rate equivalent to the hydrolysis rate.

Oxygen and fuel are delivered to muscle by an integrated organ-system response that is mediated by reflexes sensitive to the energy requirement. The body's fuels are stored in relatively large quantities in different sites. Most of the stored energy is in the form of triglycerides, or fats, located in adipocytes (specialized fat-storage cells). An average-sized person carries 100,000 kcal (420 ms) of potential energy in adipose tissue (it takes only 100 kcal (420 kJ) to run one mile). The rest of the stored energy is in the form of glycogen; around 1500 kcal (6 MJ) of potential energy in this form is stored in the liver and skeletal muscle. Despite the tremendous supply of fuel stored in these depots, they require mobilization and transfer by nervous and endocrine reflexes in order to be available for oxidation.

Although there is an abundant store of fuel in the body, the body's oxygen store is on the order of only one liter, a volume that can support moderate exercise for 30 seconds at best. Thus oxygen must be continuously transported from the ambient air to the muscle mitochondria in which the oxidative machinery exists in order to provide for the oxidation of fuels and the continuous release of energy. This is accomplished by increasing the rate of pulmonary ventilation to maintain a high oxygen tension in the lungs, ensuring optimal transfer of oxygen from air to blood, and by increasing cardiac output, ensuring a sufficiently high flow of oxygenated blood to the muscles. The integrated organ-system response to the elevated energy requirement in muscle during physical activity involves the close coupling of the pulmonary and cardiovascular oxygen-delivery systems to the oxygen-acceptor systems in muscle (figure 2).

Potential factors that can limit the regeneration of energy, and therefore the ability to maintain power output, can be deduced from the energy-production equation:

$$\text{CARBOHYDRATE} + \text{FAT} + O_2 \rightarrow \text{ENERGY} + CO_2 + \text{HEAT} + \text{WATER}$$

During activity up to 1.5 - 2.5 hours, fuel delivery is generally not a limiting factor. Oxygen delivery can be limiting if the energy demand from muscle exceeds the body's ability to deliver oxygen via, primarily, the cardiovascular system (the pulmonary system in healthy people exercising at sea level, for instance, is rarely limiting). Since anaerobic sources of energy production are inefficient in humans, and since they carry with them the penalty of decreasing the pH of muscle and thereby rendering it even less able to metabolize fuels aerobically, these need not be considered further. Finally, the build-up of the heat produced as a by-product of metabolic activity can be limiting if the body is unable to dissipate this heat at its rate of production (the rate of heat production during moderate exercise is 600-1000 watt, sufficient to raise the body-core temperature 1 degree Celsius every 5-8 minutes if no increase in the rate of heat dissipation occurs).

APPROACH

In order to predict the maximum power output we would expect from a pilot during a flight of at least four hours' duration, we needed to determine experimentally whether humans reached their limits in the oxygen, fuel or heat-transport systems at a sufficiently high power output on a cycle ergometer.

The maximum oxygen uptake (VO_2) of any individual is an objective index of that person's functional capacity to generate power. In elite endurance athletes the maximum oxygen uptake may be as high as 70 to 80 ml O_2 per min per kg of body weight. Assuming a 20-percent efficiency, we might expect a maximum output of mechanical work to be on the order of 4.5 W per kg of body weight from such an individual. Middle-aged, healthy adults average around 35 to 40 ml O_2 per min per kg and are able to increase this maximum by up to 20 percent within three months of beginning a moderately serious program of physical conditioning.

Increasing one's maximum aerobic power (VO_2 -max) provides obvious practical benefits. It allows a given work output, requireing a given rate of energy release in muscle (and therefore a given VO_2), to occur with relatively less reliance on anaerobic process. This minimizes the production of the anaerobic metabolites, particularly excess lactic acid and hydrogen ion (H+). When the VO_2 is less than 50 percent of VO_2-max, the net energy release in active muscle is essentially an aerobic. Above 60 percent VO_2 max in the average person, there is an increasingly greater reliance on anaerobic processes for the release of energy, with the consequent production of the anaerobic metabolites. Unless the body can adequately buffer the excess H+ in such conditions, exercise will eventually be limited by the developing acidosis in muscle. We expected that highly fit athletes, who have induced adaptations to physical activity in both the oxygen-delivery and oxygen-acceptance systems, would provide nearly all of the energy release in muscle aerobically at 70 percent of VO_2-max. In such conditions there should be no disturbances in the blood (or muscle) acid-base balance, and oxygen delivery to muscle should not be a limiting factor to prolonged exercise. Such athletes should be able to perform continuously until fuel availability or body temperature (or body-fluid balance, which will affect temperature) limit further activity.

Our experimental plan was formulated as follows. The object of the feasibility study was simply to determine whether athletes could produce a high power output continuously for four hours, and to follow certain physiological vari-

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ables that indicate oxygen and fuel availability to muscle throughout the test. By providing water ad libitum and controlling the environmental temperature, we expected to minimize the adverse effects of progressive dehydration and excessive hypothermia during the test. Prior to testing, however, we needed to recruit athletes who had a high VO_2 max and were motivated to participate in such a feasibility study.

We recruited volunteers by announcement through the news media. Recruitment was informal. We interviewed a number of potential volunteers by telephone and selected five for further study. These included a female national class field-hockey player, a male amateur triathelete, a female amateur tri-athelete, a male national-class wrestler, and a male national-class bicyclist. We planned to perform VO_2-max tests on each of these volunteers in order to determine their maximum power outputs and their power outputs at 70-percent VO_2 max. This latter determination would be an essential design criterion for the aircraft. We planned to then select one or more of these volunteers for the long-duration (four-hour) test.

INITIAL SCREENING (VO_2-max) TESTS

Determination of maximum aerobic power is a standard procedure for a human-physiology laboratory. We brought the five volunteers to the John B. Pierce Foundation Laboratory at Yale on a Saturday morning. After a brief orientation, we proceeded to test each of them in order to determine VO^2-max.

VO_2-max was estimated from an incremental test (Balke and Ware). Volunteers exercised using a cycle ergometer in the semi-recumbent position, with the legs nearly horizontal to the ground. VO_2 was determined continuously by the open-circuit method, according to the following technique. The subject breathed room air via a one-way valve. The mass flow rate of expired air was measured by a dry gas meter and the fractional concentrations of oxygen and carbon dioxide (fo_2 and fCO_2) in the expired air were determined continuously by electronic analyzers. VO_2 was calculated from fo_2 , fCO_2 and the volume rate of pulmonary ventilation and corrected to standard pressure, temperature and humidity.

The protocol used involved a brief, 5-min warm-up at an exercise intensity around 50-percent VO_2 max. Following a 5-min recovery period, the subject began the incremental test. The power requirement of pedaling the cycle ergometer at 60 rpm was adjusted to around 60 percent VO_2-max by adjusting the tension of the belt around the flywheel. At 2-min intervals the power requirement was increased by around 30 W. The subject maintained pedalling frequency until he or she could no longer do so, despite the encouragement offered by the investigators. The objective criteria for VO_2 lmax included: 1) a VCO_2/VO_2 ratio of greater than 1.1 (indicating excessive hyperventilation) and 2) no increase in VO_2 despite an increase in power requirement (levelling off). The VO_2-vs-power-output data are shown in figure 3.

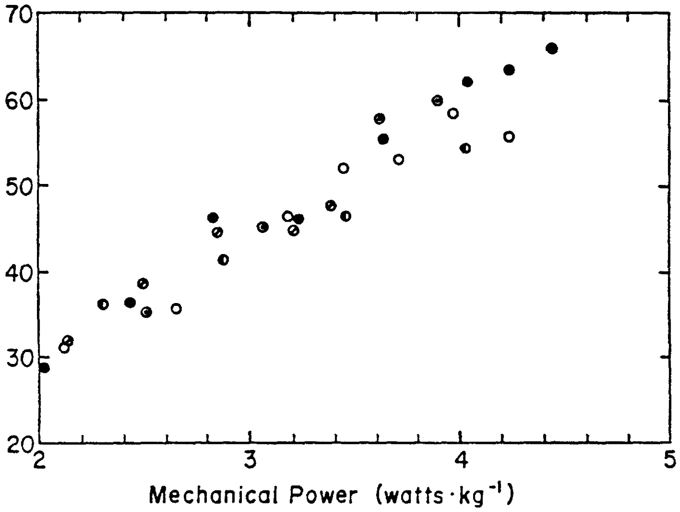

FIG. 3 Measured Oxygen uptake (VO^2) vs. power delivered during VO^2 -max tests.

Table 1 shows the salient features of the initial screening tests. Four of the five volunteers had VO_2-max values in the range of elite athletes. We selected the top two of these athletes, based upon their maximum power outputs, to return for the four-hour tests. Computed power output at 70 percent of maximum for these two people was around 3 W/kg. This value was transmitted to the aircraft design engineers who determined that this power level would result in a flight duration of 4 to 5 hours.

LONG-DURATION TESTS

The two selected individuals, RS and LM, were invited to volunteer for an experiment in which they would be expected to exercise on the cycle ergometer continuously at a power output of 70 percent of their maximum for four hours. This was to be a simulation of the Daedalus flight, with the proviso that we would optimize environmental conditions and allow them food and water ad libitum. We also wished to measure their metabolic status throughout the four hours by taking blood and expired-air samples at frequent intervals. Both accepted and agreed to come to New Haven in late January for tests. RS was scheduled to begin the test at 8:00 am and LM at 1:00 pm.

Upon arrival in the laboratory, each had the EKG electrodes attached and had a catheter inserted in an antecubital vein in the left arm. Each was instructed to maintain cadence in synchrony with a metronome in order to maintain power output. Each had VO_2 measured at intervals throughout. Blood samples were drawn at intervals for measurement of the following: glucose concentration, to assess the body's fuel status; lactate concentration, to assess the relative anaerobiosis and acid-base status; osmolality, to assess the body-fluid status; and the change in plasma volume from hemoglobin and hematocrit measurements, also to assess the body fluid status. Measurements of fluid intake were also recorded.

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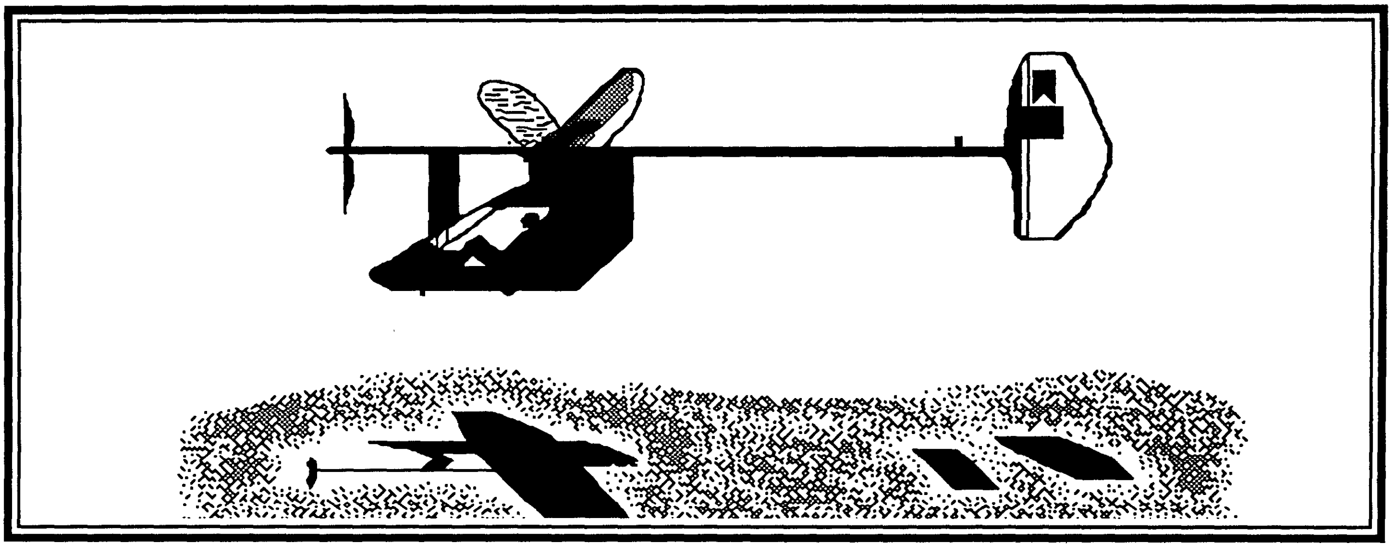

Eagle Makes Historic Flight in Mojave Desert

EDITOR'S NOTE: As the Winter 1986 - '87 issue of Human Power *went to press the human powered aircraft* **Eagle** *was making headlines with record-setting flights. Radio, television and print media in the U.S.A. gave excellent coverage, providing yet another boost to human powered activities. Due to the timing, we felt it important to prepare a story on the event. ("We," includes David Gordon Wilson, Lynn Tobias, Marti Daily and Tom Healy.) Following is a report on the* **Eagle** *flight compiled from articles in the* Los Angeles Times, *the* Boston Globe, USA Today *and a National Public Radio interview with John Langford.*

EDWARDS AIR FORCE BASE, Calif. - It has been nearly eight years since Bryan Allen pedaled 22 miles across the English Channel and into aviation history. On January 22 and 23, another chapter of aviation history was written as a financial analyst from Belmont, Massachusetts, and a medical student at the University of Connecticut set records for human-powered flight.

On a secured area of the Base, Lois McCallin, 29, an amateur triathlete, kept the Michelob Light Eagle aloft for 37 minutes and 38 seconds in a 10-mile triangular course, establishing three world records for human powered flight. "I was close to the limit," she told a *Boston Globe* reporter. "It was really tough at the end...It became more of a mental challenge to keep the plane level and keep pedaling." The records included the overall closed-course distance record and closed-course distance by a woman. There was no previous record in each of these categories which were established by the Paris-based Federation Aeronautique Internationale.

The following day, Glenn Tremml, 26, pedaled the 92-pound aircraft 37.2 miles in 2 hours, 13 minutes and 14 seconds - an average of 16 miles per hour.

While weather conditions were excellent, Tremml faced other problems. A malfunction in the drinking system left him dehydrated at the end of the flight. He also had difficulty keeping his specially-designed shoes on the craft's pedals. Three times during the flight he pedaled with one leg while attempting to fit his other foot onto the pedal. When his foot slipped off the pedal for the fourth and final time, the plane touched the ground.

The Eagle carried 4.4 pounds of water to replace fluid lost through perspiration. Due to malfunction he received only about 1.5 cups total. "I finally gave up because when I was playing around with the water system too much, I wasn't paying enough attention to my flying," he said. "It was very frustrating. By the third lap, I was beginning to get thirsty," Tremml told the *Los Angeles Times*. "I was very pleased I could go as far as I did without water, but that's not what you want to do." He lost three pounds during the flight.

Another problem occurred midway through the flight when perspiration began to condense on the inside of the cockpit. By the fourth lap, Trammel could barely see to make the turns.

The Daedalus team came here with the purpose of gathering further engineering data on the Eagle and they were successful. After the flight, the Eagle weighed four pounds heavier than expected and had a wingspan of 114 feet, two more than expected. John S. Langford, project director, said the extra weight was due to radio equipment and new wing tips which proved heavier than anticipated. The extra width came from foam tips on the wings that had not been included in calculations.

Both Langford and Steven Bussolari, flight director for the project, are optimistic that the planned flight from the island of Crete to mainland Greece will be successful. "My bet is that we can definitely make a flight from Crete to the mainland," Bussolari said. That flight is planned for this summer or the spring of 1988.

The Daedalus team planned to spend a week at the Base, located in the Mojave Desert, to perform additional tests, including aeronautic and physiological experiments and tests of a new autopilot system designed to use fiber optics, electric motors and computer chips to leave the pilot free to concentrate on pedaling.

HUMAN POWERED HELICOPTER UPDATE

Lynn Tobias, IHPVA vice-president of air, sent clippings on the subject of human powered aircraft.

VERTIFLITE, a publication of the American Helicopter society, featured a progress report on the efforts of Cal Poly students to design a human powered helicopter to win the Igor Sikorsky Human Powered Helicopter Competition prize.

The current prize for the six year-old contest is $20,000 (US) to be awarded to the team or individual who flies a human powered machine in a hover for one minute as well as flies a 10-meter square course at an altitude of at least three meters.

Cal Poly students are currently working on the third generation prototype of the "Da Vinci" machine, which features 50 foot radius rotors driven by three foot radius propellers at the tips. Optimum rotor speed for flight is thought to be six to seven RPM. Other highlights include:

- The total aircraft wight was estimated to be 300 pounds (including pilot.)
- The torqueless drive system is made of tip propellers rotated by a one-way drive consisting of thread wound around the prop shaft and winched in by the pilot.
- Power requirements for a 10-foot hover is .86125 hp and for a four foot hover .5267 hp.

Meanwhile, an engineer for a Santa Ana, California plastics firm is working on his own human powered helicopter design for the competition. Michael Brace says he's gotten his helicopter to "hop" but he's working on a new transmission to see if he can get his idea off the ground. "I want to show it can be done," Brace told the *Los Angeles Times*. "My goal is to have this machine wind up in the Smithsonian as one of the first of its kind."

Brace has received assistance from his firm which has donated most the material used on his design, including the 14 foot blades. So far the helicopter has cost the company $100,000. His machine currently weighs 65 pounds and carries a pilot weighing up to 150.

Rules and information regarding the competition are available from: AHS, 217 N. Washington St., Alexandria, VA USA 22314.

HUMAN POWERED MEDIA ASSAULT

Articles of interest to our members include the following:

"A Short History of Human Powered Vehicles," by David Gordon Wilson, *American Scientist*, July-August 1986. *Human Power* editor and past IHPVA president Dave Wilson gives an informative overview of where we've been and where we're heading in the realm of human power.

"Human powered Watercraft," by Alec Brooks, Allan Abbott and David Gordon Wilson, " *Scientific American*, December, 1986. Overview of this fascinating design field by the current vice-president, Water and two past presidents of the IHPVA.

"Games," *Omni Magazine*, January, 1987. Human-powered vehicle overview including *Gold-Rush's* record run and Flying *Fish II's* feats.

"88-pound pedal plane," *Popular Science*, Feb. 1987. Outlines design and reports on test flights of the Michelob Light Eagle.

IF YOU HAVEN'T DONE SO ALREADY, PLEASE RENEW YOUR MEMBERSHIP IN THE *IHPVA*. CHECK THE MAILING LABEL ON THIS ISSUE OF HUMAN POWER AND SEE WHEN THE EXPIRATION DATE IS. REMEMBER, YOU CAN ONLY KEEP UP WITH THE LATEST DEVELOPMENTS IN HUMAN POWER IF YOU ARE A MEMBER. SO RENEW TODAY!

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Throughout each experiment the room temperature was adjusted to maintain the subject's comfort. A fan was directed onto the subject's upper body to optimize evaporative cooling and prevent excessive heat storage. Subjects were encouraged to drink water and eat during the bout.

Although both subjects found the test demanding during the first two hours, neither had great difficulty in maintaining cadence. Heart rates during the first two hours averaged between 150 and 160 beats per min for both and VO$_2$ values were comparable and steady, between 40 and 43 ml 02 per min per kg body weight (figure 4). Power output was maintained at a steady 3 W/kg.

After two hours RS found the going increasingly difficult and was forced to stop at 3.5 hours, complaining of soreness and cramping in his legs. His blood osmolality had begun to climb at 2 hours, reaching 295 m)sm per kg plasma water by 3.5 hours (figure 5), indicating progressive dehydration. His heart rate also began to climb at 2 hours, reaching 180 beats per min at 3.5 hours. Both of these changes suggest an inability to maintain an appropriate distribution of blood flow to muscle and skin. The fact that blood lactate was not elevated implies adequate muscle blood flow. We were not able to measure body core temperature at the end of exercise.

LM, on the other hand, was able to complete the four hours easily, and could have, by her own assessment, continued for another 1/2 to 1 hour. Her physiological picture supports this claim (figures 4 and 5). She maintained a steady state in all variables throughout the bout. Of particular interest is that her blood osmolality was maintained, implying adequate replacement of fluid lost during the four hours. Her cumulative fluid intake was around 3000 ml, nearly three times that of RS. Her heart rate never climbed above 160 beats per min, implying a steady cardiac filling and no pooling of blood in the periphery.

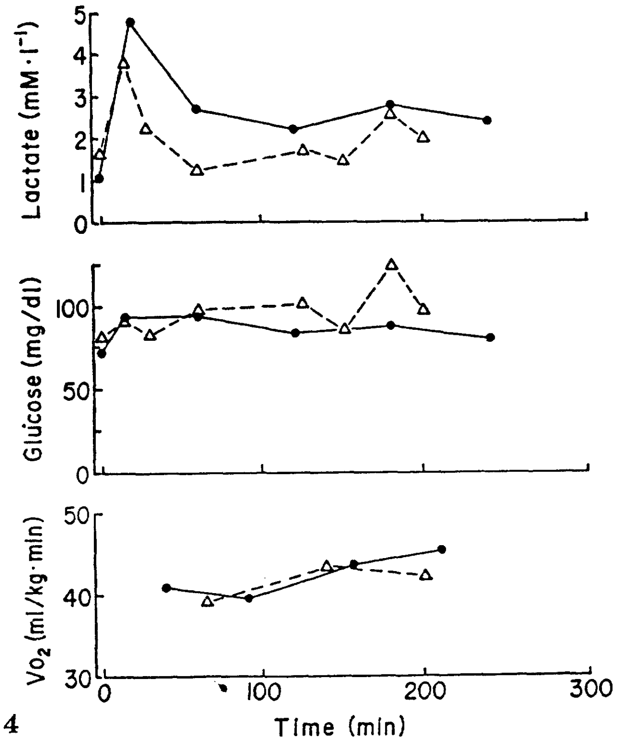

FIG. 4

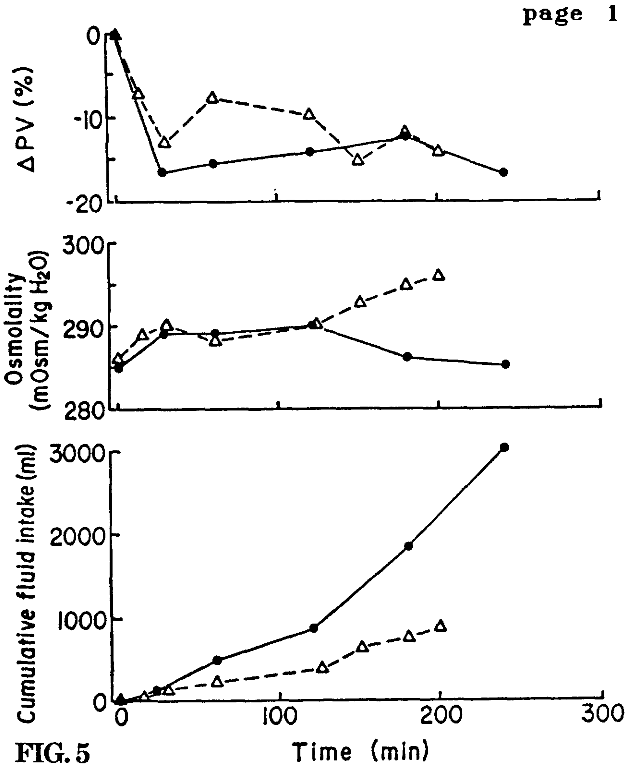

FIG. 5

From the physiological measurements we are able to draw several conclusions. Fuel delivery to muscle was apparently sufficient to sustain activity, based upon the steady concentration of blood glucose in both volunteers. Although we did not measure muscle glycogen, we might have expected blood glucose to decline somewhat if muscle stores were fully depleted. Nonetheless, glycogen loading prior to the long-duration test should be important to ensure adequate muscle stores. LM employed a glycogen loading regime prior to the test; RS did not. It will be important for the Daedalus pilot to do so.

The fact that blood-lactate concentration was not elevated in either subject throughout supports the notion that 70 percent VO$_2$-max can be sustained aerobically for extended periods by endurance athletes.

One likely reason for the difference in performance between our two volunteers was the difference in body-fluid status. LM drank freely throughout, maintaining her blood osmolality, while RS drank much less and shared a progressive rise in blood osmolality after 2 hours, indicating progressive dehydration. When water is lost from the body and not replaced, it must be drawn from all the body compartments. Dramatic changes in intracellular water content will have effects upon salute concentration and cellular function. Clearly, such an event must be avoided to ensure optimal performance.

We conclude that a well-trained endurance athlete can exercise at 70-percent VO$_2$-max for four hours in optimal conditions. It appears from this preliminary study that fluid replacement will be an extremely important factor to

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ensure the maintenance of the physiological steady state. Further, given optimal conditions, neither fuel transport nor oxygen transport to muscle should directly limit performance in this range.

CONCLUSIONS

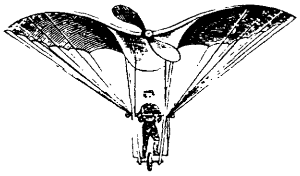
Based upon the work described above, several conclusions may be drawn concerning the feasibility of the Daedalus flight in terms of the capabilities of the human pilot. These conclusions are presented in the following paragraphs in answer to the fundamental questions posed in the introduction.

1) The physiological mechanisms that appear to limit the production of mechanical work by humans are related to the storage, transport, and metabolism of fuel and oxygen and the rejection of waste products and heat. Endurance-trained athletes have optimized these mechanisms to maintain key physiological variables in a stable state during exercise at relatively high power output (approximately 70% of maximum oxygen uptake) for long periods of time (several hours). The limits of endurance are characterized by departures from this steady state that result in the breakdown of transport and metabolic processes, with subsequent reduction of power output.

2) We have demonstrated that an endurance-trained athlete exercising on a recumbent cycle ergometer is capable of producing power at 70% of maximum oxygen uptake (corresponding, in this case, to a specific power of 3 watts/kg body weight) for a period of 4 hours. These values of power and duration correspond to the requirements for the Daedalus flight.

3) There are training and environmental countermeasures available to ensure that physiological limits are not encountered during the Daedalus flight. Endurance training conducted in conditions similar to those anticipated in flight will aid in the adaptation necessary to provide a robust equilibrium of the physiological mechanisms discussed above. In addition, control of the cockpit environment as well as the intake of water and food will decrease the load on these mechanisms.

4) The population pool from which qualified athletes may be selected appears to be sufficiently large to ensure success in locating appropriate pilots. The specificity of muscle-group training by endurance cyclists make this group a likely source of pilots given the proposed use of pedaling motion to produce power in the Daedalus aircraft. This was borne out in our feasibility study, in which the two subjects selected for the long-duration ergometer test were endurance cyclists. Regional-or National-class cyclists appear to have the level of fitness and training necessary to prepare for the Daedalus flight. Previous experience in piloting aircraft would be desirable but would not be required.



FUTURE WORK

The human-factors study described above was designed to provide information leading to an assessment of the feasibility of the Daedalus flight. This section outlines the follow-on research necessary during the building, testing, and flight-operation activities.

The selection of one or more pilots to participate in the construction and flight-test portion of the project should take place as early as practical in those activities. This will ensure adequate time for physiological and flight-skills training as well as establishing a comfortable working relationship with all members of the Daedalus team.

In parallel with the pilot-selection activities, the investigation of aircraft human factors should continue with ergometer testing under environmental conditions similar to those to be encountered in flight. In particular, the temperature, humidity, and airflow within the cockpit will have a significant effect on the production of power by the pilot and his/her requirements for food and water in flight. These ergometer tests will be used to fix physical aircraft parameters such as air-vent size and capacity of pilot water reservoir. Physiological measurements taken during the flight testing will validate predictions made during the ergometer tests.

The results of Phase II will be incorporated into a generalized pilot-training program for the Phase III activities leading to the flight operations in the Aegean. This program will include elements of physiological and flight training as well as pilot scheduling to account for the tapering of training and diet modification in the days preceding the long-duration flights.

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How to Get Traction on Ice

By James Donohue

The coefficient of friction between rubber and ice is very low. Steel studs or spikes can be installed on wide bicycle tires (e.g. - 20x2.125, 26x2.00) to improve a bicycle's traction on sheer ice and packed snow. For those who are so inclined as to want to ride a bicycle on frozen ponds and lakes, a technique for modifying off-road tires is herein described.

MATERIALS

First, select a set of knobby tires. They can be one half to three quarters worn out so long as they aren't worn all the way down. Knobby tires are preferable as the tread pattern can be followed when installing the studs. They also have thicker tread rubber into which the studs can be mounted so that they are less likely to bend over and pull out.

Second, get hundreds of 6-32 x 1/2" machine screws (round head) along with nuts and washers. Expect to use over 500 screws for a pair of BMX tires or well over 700 for a set of ATB tires. While you're in the hardware store, get some silicone-rubber caulk.*

TOOLS, PROCEDURE, etc

Tools which are useful for this procedure are: a drill with a #29 bit, a bench vise, a 5/16" wrench and an electric screwdriver or screwgun.*

Drill holes in the tires. This may seem contrary to the nature of pneumatic tires, but the holes will be filled by the studs so there won't be holes in the finished tires. Following the tread pattern, put a hole through the center of each block of rubber. Rubber is flexible, so the holes may be smaller than the drill bit.

Put washers on the screws and push the screws through the holes from the inside of the tire.

Put the nuts on the protruding ends of the screws by hand.

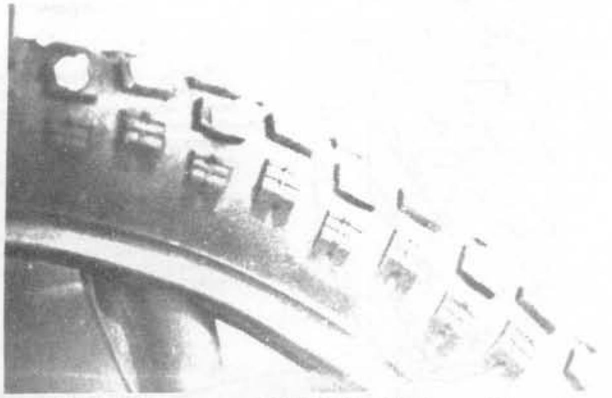
Secure the wrench in the vise. This frees at least one hand to work the screwdriver and hold the tire in place.

With the nuts held in the wrench tighten the screws with the screwdriver.

Cover the heads of the screws with silicone-rubber caulk and allow it to cure. This prevents the tube from being punctured by being forced to follow the contour of the screwdriver slot.

Mount the tire as any other tire. If the bicycle was designed for wide tires there should not be a clearance problem.

Take the bike for a test ride on the Ross Ice Shelf in Antarctica, or any solid frozen ice. These tires are also very good in snow. Unfortunately, the studs wear out rather quickly when used on pavement. They also don't grip well on pavement and should not be used on paved surfaces.



Studded bike tire. PHOTO BY James Donohue

James Donohue
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Glen Head, NY 11545

EDITOR'S NOTE: I use a rather similar technique for a slightly different purpose. However, I use self-tapping screws. These have points that help to get them through the rubber, and are thoroughly hardened, so that they don't wear out very fast. Rather than drill the holes, I force a pointed awl through the rubber to give the screws a start. The screws are then screwed through, the silicone glue acting as a lubricant first and as a sealant later. I haven't had to use nuts and washers, but my duty isn't as severe as James Donohue's. Experiment before substituting this technique for his! - Dave Wilson

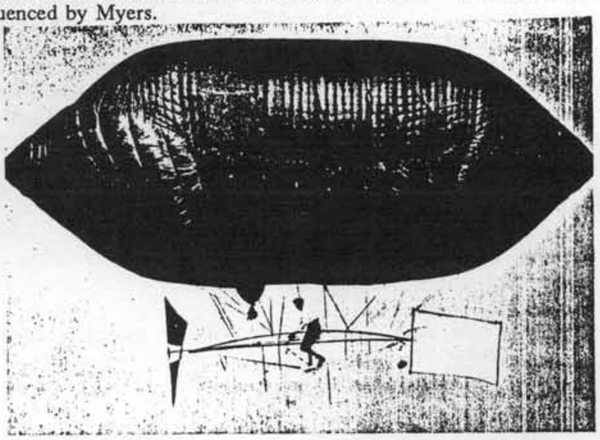
Early HP Blimps

Jim Papadopuolos sent in these delightful clippings. First, from the AMERICAN HERITAGE OF INVENTION AND TECHNOLOGY, no. 1, Summer, 1985:

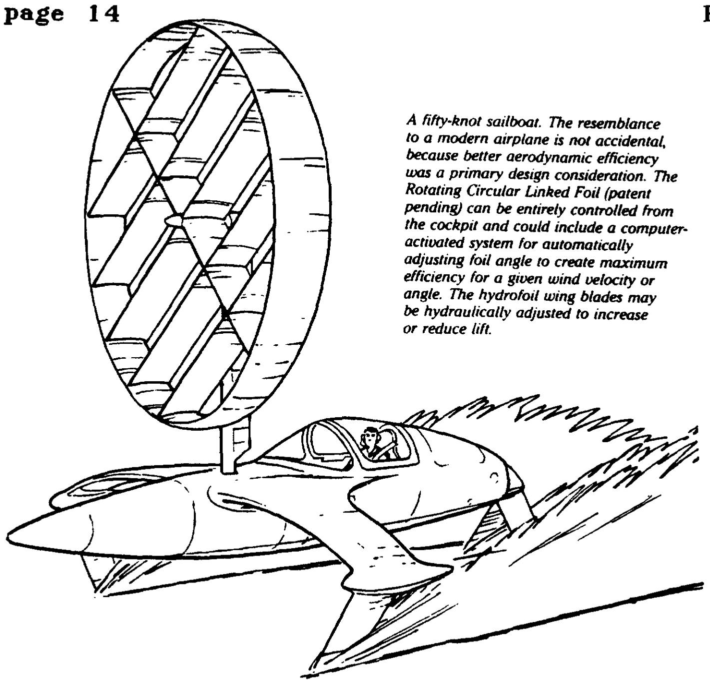
'POPULAR MECHANICS was uncertain about the future of flight for some time, not knowing whether light-or heavier-than-air craft would prevail. . One reason for this may have been that it wasn't fully known why the heavier-than-air variety flew. An article that appeared in 1904, the year after the Wrights' first powered flights, compared an airplane to a "stone which is flung into the air, and which, by means of its propellers, keeps propelling itself with a force equal to the initial throw.'

'...One of the leading American proponents of airships around the turn of the century was "Professor" Carl E. Myers, who traveled the country demonstrating his "skycycles," balloons shaped like elongated lemons that could be navigated after a fashion by a rudder plus a propeller turned by pedals, or a small gasoline engine...'

Second, from the Popular Mechanics ALBUM OF AVIATION, Throm and Crenshaw, 1953, showed the following pioneer, who perhaps was influenced by Myers.



Among the early aeronauts was 14-year-old Cromwell Dixon of Columbus, O. He made his own pedal-operated airship, the "Moon," with the help of his mother, who sewed together the 25-foot bag. At an air meet in St. Louis in 1907, young Dixon was blown across the Mississippi, landing in an Illinois cornfield unhurt.



A fifty-knot sailboat. The resemblance to a modern airplane is not accidental, because better aerodynamic efficiency was a primary design consideration. The Rotating Circular Linked Foil (patent pending) can be entirely controlled from the cockpit and could include a computer-activated system for automatically adjusting foil angle to create maximum efficiency for a given wind velocity or angle. The hydrofoil wing blades may be hydraulically adjusted to increase or reduce lift.

Ready About!

A new book by Garry Hoyt, published by International Marine, Camden, ME, $14.95 hardcover; reviewed by Dave Wilson

This is a book principally about sailing. Then why, you will be asking, is it being reviewed in HP? For three reasons. The first is that Garry Hoyt has designed and produced two human-powered boats, the Waterbug and the Mallard (see below), that appear occasionally in this book. The second is that there is a strong analogy between the revolution he is trying to foment in the sailing world and our efforts in the HPV world (a term meant to include rowing and bicycling). The third is that he is a free thinker, and his approach to every problem is to state the fundamentals and to start looking at all possible solutions, however radical. One could read this book, which is written in an engagingly direct style, just to soak up his design philosophy. But we in the HPV world could also learn from his four-point agenda.

His first has its counterpart in the practical-HPV contest: set a $100,000 prize for a sailboat that can be sailed over a triangular course after no more than one hour of instruction. (Sailing most boats is forbiddingly complicated).

The second is like the Du Pont prize: set up a one-million-dollar prize for the first sailboat to break the 40-knot barrier (and then offer another prize for 45 and then for 50 knots). (If this seems like a lot of money, he points out that at least $60-million has been spent by the US twelve-meter syndicates this year, to race boats that go at eight knots).

His third point has a message for us: "de-macho" the sport; make it appeal to women.

And the last could have direct application: develop sailing resorts, to popularize sailing in the way that ski resorts have taken skiing out of the realm of the exclusive rich.

An HPV resort with tracks and trails and a lake and a wide variety of streamliners, practical HPVs and off-road machines, and at least one HP blimp, could be an exciting development in itself and for our sport.

The major point he makes about "conventional" sailing, that it is in the hands of people bound by rules and traditions that stifle innovation, while all the action in sailing is in sailboards and multihulls, both outside the "establishment" - "T-shirts versus stuffed shirts", has a message for us. We must keep encouraging innovation and simplifying rules.

I'm an admirer of Garry Hoyt. He makes me simultaneously feel useless and hopeful. Useless because I teach design engineering, and he has more design capability than almost anyone I know, yet has no engineering degree. And hopeful, because although he has sailed all his life (very successfully) he worked in advertising until he was 50. Then he exploded into creativity, founding Freedom Yachts and setting the sailing world on its ear. Maybe I'll find something I'm really good at yet.

This is an exciting book of superb ideas.

Sea Test of the Mallard

On a bright, blustery Sunday in early October, Anne Wilson and I drove to Newport RI to test-ride the Mallard, Garry Hoyt's latest pedal-drive screw-propelled HPB. He took us down to the harbor, where his boat was tied to a jetty, heaving in the choppy sea. With the minimum of instruction and virtually no cautions he let us go. (The only real caution was with regard to the steering. Some joy-riders had stolen the boat one night previously and apparently had heaved at the steering levers on each gunwale in the belief that they helped drive the screw, bending the linkage and making the action a little less smooth than it had been).

There are several versions of the Mallard, varying in seating capacity and in degree of enclosure. This one had tandem seating, and a short windshield forward. The windshield sent the spray over the operator, in front, but in a cross sea Anne was not fully protected. Compared with trying the same trip in a dinghy, however, the degree of protection was high.

We headed a mile or so out into the harbor, circled a large Bulgarian cruise ship to give the people aboard a chuckle at the antics of these crazy capitalists, and returned. The sea and the wind were coming at our starboard quarter on the way out, and on the return we were almost keeping up with a sea that was coming diagonally from our left rear. Fishing and high-speed power boats saw no need to slow down or divert around us as they would (I hope) if we had been rowing. Anne is not British, and therefore was not brought up to believe that any relaxation of a stiff upper lip in the face of certain death would result in humiliation before Queen and country. She was, not to put too fine a point on it, scared at the seemingly mountainous seas, the towering ships and the high wind. But the Mallard took all in its stride, chugging up one side of a wave and down the other, refusing to be put off by wake or weather. It was great fun.

It is not, of course, a high-speed boat, except in relation to a dinghy being rowed in similar seas. When a displacement boat hits its high-resistance or "hull" speed, which is a function almost solely of length, only an enormous increase in power will get the vessel to exceed this speed, probably in a planing mode. Hull speed for the Mallard is between five and six mph, about 2.5 m/s, and it takes very little effort to keep it moving along at near that speed through wave and wind. The combination of a well

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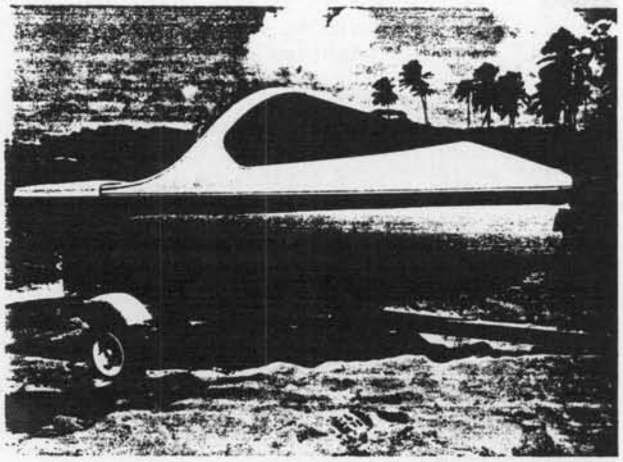

These photos of the Mallard-model pedal/prop boat show the benefits of streamlining. The aerodynamic nose cleanly sheds a wall of water, enabling the boat to handle waves that would swamp a conventional dinghy. Air, being a fluid, will flow around the nose in a similar fashion.

streamlined hull and windshield helps a great deal. The large mass of lead (I believe about 150 kg) prevents jack-rabbit starts, but, more importantly, keeps the boat going through a wave that would turn back a lighter boat. It also makes it absolutely stable.

My only recommendations for improvement would be to drop the pedal axis as far as possible, to give a pedalling position that recumbent bicyclists have found to be ideal, and to gear up the drive a little. But its present ratio would probably suit the high-revving majority very well. Otherwise, it's a delightful boat, suitable for solo or family outings, fishing, sight-seeing or just exercizing. Donna Hoyt told us that Garry takes the fully enclosed Waterbug out on the harbor in his shirt sleeves when the temperature is 14F, -10C. Unless he's developed a human-powered snowmobile by now, the ability to take healthy outdoor exercize in that environment is undoubtedly unique.

Dave Wilson

A New Automatic Bicycle Transmission

By James B. Reswick

ABSTRACT

A new torque-responsive automatic transmission for use on a bicycle or other HPV is presented. Design considerations are discussed and details of construction are shown. Performance characteristics for a set of assumed parameters are presented. Results from tests on a prototype are compared with theoretical calculations. Subjective comments on performance and the applicability of such drives are made.

INTRODUCTION

The quest for practical multispeed transmissions to use on a bicycle has intrigued inventors for the some 100 years that the chain-driven bicycle has been around. The present-day ubiquitous derailleur, when in good condition and properly used, is a truly elegant solution to the transmission problem from the point of view of efficiency and cost-effectiveness. The derailleur does, however, suffer some disadvantages. These include: it gets out of adjustment rather easily, it cannot be shifted when transmitting power and, probably most important, a great many riders do not understand what gears to use under varying conditions - nor do they really wish to learn. For these reasons and perhaps because inventors find it hard to resist a challenge, a number of innovative drives are mentioned in bicycle histories [1,2] and there now exist some that have been widely advertised but which have yet to make a major market impact.

The author (and inventor) was an avid bicyclist in his youth, but now at age 65 and 160 pounds weight considers himself to be an "experienced but average touring-type rider" who can maintain a speed of 12 mph (5 m/sec) with an energy expenditure of 0.1 hp (75 W) on a lightweight touring bicycle. (Ref. 1, p 38). These personal data are mentioned as they set the design parameters for the prototype drive and explain the basis on which subjective comments by the author are made. Actually, the motivation for developing an automatic variable-speed drive was the electric wheelchair.

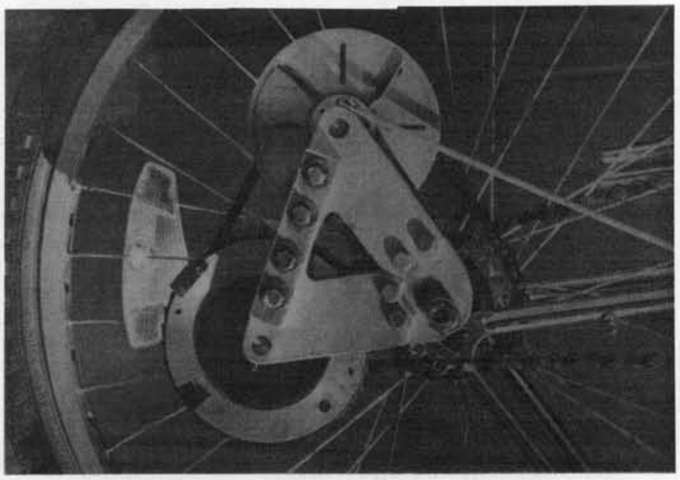

FIG. 1: RIDE-A-MATIC Automatic bicycle transmission. PHOTO BY James B. Reswick

Having developed and tested a novel automatic transmission called "RESATRAN" in an electric wheelchair [3], the author considered whether the same design concept might be useful on a bicycle. In the world of machines that employ speed-change transmissions, the bicycle is almost unique. Most machines transmit power from high speed and low torque to low speed and high torque. Of course, the bicycle is just the reverse and consequently requires a very robust system that can be subjected to maximum torques produced by forces on the pedals equal to or greater than a rider's weight - but which are usually more like one fourth his weight. A more robust unit was designed and built with the idea that it could be attached relatively easily to a standard bicycle. To distinguish it from the wheelchair drive, it was christened "RIDE-A-MATIC". This paper presents a description of the prototype with remarks comparing it to some other concepts, gives some theoretical performance characteristics and concludes with a discussion by the author of his subjective experience with the drive.

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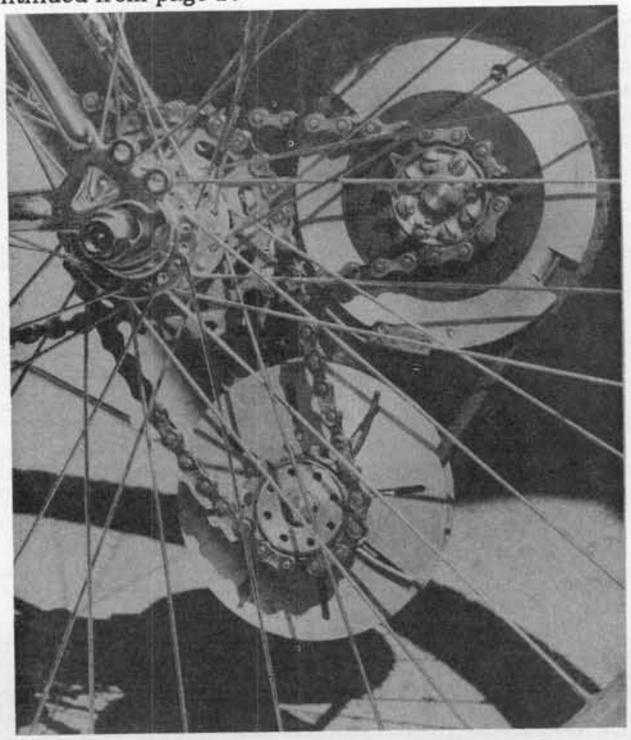

FIG. 2: Chain-side view of RIDE-A-MATIC transmission. PHOTO BY James B. Reswick

THE "RIDE-A-MATIC" AUTOMATIC BICYCLE TRANSMISSION

The RIDE-A-MATIC drive (U.S. Patent No. 4,608,034) is shown in figure 1 installed on a Mongoose trail bicycle. This bike was chosen for its 26-inch wheels, upright handle-bars, and "unisex" frame design. The unit is mounted on the rear of the bike with the pedal chain driving one pulley and the other pulley driving the rear wheel through a second small drive chain. Figure 2 shows the chain arrangement of the installation and figure 3 is a drawing giving sectional views that show details of the design. The prototype unit was machined and assembled by the author.

The RIDE-A-MATIC consists of two special pulleys that can change their diameters and are connected by a V-belt. The variable diameter is achieved by means of eight arms that pivot in or out. When all the way in, they nest to form what amounts to a solid V-type pulley. When out as far as they can go, they form a pulley that has about twice the diameter and with open spaces between the "heads" of the arms. These arms are unique in that the curved parts of the heads form a useful pulley without sharp edges in all of their positions from minimum to maximum diameter. The flexible V-belt rides smoothly over them easily bridging the gaps when rotating at bicycle speeds. The arms are kept uniformly spaced by side plates, or discs, that have radial slots (straight or curved) in which pins that pass through the arm-heads slide freely.

While the two pulleys have many similar parts, such as the pivoting arms, they are different in detail and function. The "drive" pulley "measures" the force exerted on the pedals by the rider and when this force exceeds a pre-set value, it automatically reduces its diameter in proportion to how hard the rider pushes on the pedals. It is equipped with strong spiral springs to do this. The initial value of spring tension is easily adjusted by means of the spring-tension pawl shown in figure 3. Spring size determines the slope of the relationship between speed ratio and applied torque. Because of the kinematics of the mechanism, this relationship is not linear. The "driven" pulley simply expands by itself to whatever diameter is required to keep the belt tight. It requires no springs to do this since the belt tension acts to pull the arms outward. In fact, because of the nature of the mechanism, the belt tension is actually increased when the arms are pulled out by the belt at high loads; this prevents the belt from slipping even when climbing a steep hill. It is this feature that makes a belt drive practical for a bicycle, perhaps for the first time in bicycle history.

The overall speed-ratio change possible with the drive is about 3.1, which is just about the range of most ten-speed derailleurs. Chain wheel and sprockets were chosen to give a high gear of 73 inches and therefore a low gear of 23 inches (see DISCUSSION for reasons for this choice). In order to keep the system as small and light as feasible and to reduce the torque handled by the drive, the "driven" pulley rotates at about twice the speed of the wheel, i.e., each of the pulley chain sprockets has 13 teeth while the wheel sprocket has 28. The larger pedal chain wheel having 48 teeth was used.

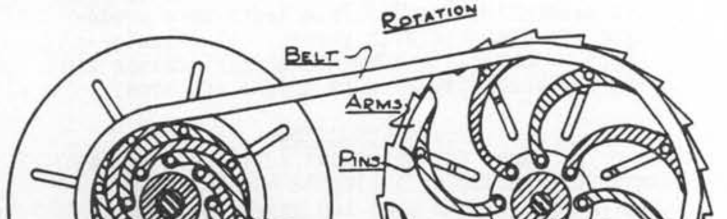

FIG. 3: Sectional Views of RIDE-A-MATIC.

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The design of the helical springs involved many variables and some arbitrary decisions. As may be seen on figure 3, the side plates rotate with respect to the hub of the driver as the arms are rotated inward in response to increasing belt torque over an angle of about 110° (or 1.9 radians) winding up the springs as they do so. As finally designed, the springs have a rate of 15.8 pounds (70.3N) force (measured on a pedal) per radian. The author assumed (and later found to be reasonable) that the spring preload should be 30 lbf. (about 135N) on the pedal and that twice this force or 60 lbf. (about 270N) should produce the lowest gear. A more athletic rider might set a higher preload while a much lighter youth might prefer a lower one. As mentioned previously, the initial preload is easily set by the rider to his/her preference, but the spring rate determines the pedal force to reach low gear.

One other feature shown on figure 3 should be mentioned. The "driven" pulley, while requiring no springs to extend its arms, does in fact have "springs" that come into play only when the arms are fully extended. These are the bent bars shown inserted in the hub and labeled "overload springs". Four of the eight guide pins in the heads of the arms extend beyond the side plates so that when the arms are fully extended, they come into contact with the overload springs. When this happens, the torque is transmitted directly through these springs from the arm heads to the hub and thence to the drive sprocket and rear wheel. This is done to protect the curved beams of the arms from breaking or from being broken by the belt. When the drive pulley arms are nested, the belt becomes inextensible and when the driven pulley arms are extended they have a large mechanical advantage between tangential belt force and the radial force on the arms.

The frame structure of the prototype is made from 3/8-inch (10 mm) aluminum in the form of a triangle (see Fig. 1). Two fixed shafts are cantilevered to support the pulleys which rotate on needle bearings. The triangular frame is split so that the center distance between the pulley can be adjusted. The frame is slotted so that it can mount easily around the rear axle and is held on by the axle nut. The slot permits adjustment of the drive-chain tension. A light stabilizer bar from the bike frame prevents rotation of the unit around the axle. The main chain from the chain wheel is increased in length so that it passes around the original 5-gear hub from which all but one gear have been removed and replaced with a spacer. This arrangement has the advantage that the very large force reaction to the chain force passes close to the rear axle. Installation is relatively easy and should be accomplished on most any bicycle within an hour or so.

THE RIDE-A-MATIC AND SOME OTHER DRIVES

Variable-speed-ratio drives require moment arms that can change their lengths. In a rotating device this means that the effective diameter for all or part of a cycle can be increased or decreased. In lever system drives such as the Alenax "Transbar Power System" the actual arms of the drive levers can be adjusted by the rider. Having no experience with lever drives, the author will confine his remarks to rotating drives that can change their effective diameter.

A variable-diameter mechanism has two important aspects. The first has to do with the structural elements that change the diameter and the second concerns how the desired diameter is selected or controlled. Almost all of the variable-speed-ratio drives known to the author including those shown in reference 1, pp. 290-293 (Whitt's Expanding Oval, Tokheim Speedisc, Hagen All-Speed Variable Diameter Chainwheel and the Octo Split-Sprocket Drive) are not automatic but rather seem to require some sort of controlling action by the rider. Even Excel's 16-speed Cambiogear requires the operator to select the gear.

A truly automatic drive should require no attention from the rider. An interesting question arises at this point, viz., to what variable or combination of variables should an automatic transmission respond? Should speed ratio be a function of say pedal cadence or pedal torque or both? The author gave up trying to find a simple mechanism to respond to speed and settled on pedal torque as the independent variable to which speed ratio would be related. Physically this seems reasonable as the ordinary rider usually pushes harder going up hills when lower gears are desirable than riding on the level. But this decision also imposes some constraints that may not be desirable - these will be discussed later.

The only bicycle drive that is automatic known to the author, other than his own, is the DEAL DRIVE. Only some advertisements and one magazine article were available to the author. It appears that the DEAL DRIVE is an automatic transmission that adjusts its diameter as a function of pedal torque. Being a chain drive, it could not be continuously variable, and apparently has eight detent positions that operate alternately to provide sixteen distinct speed ratios. Friction band brakes tend to hold the drive in a selected ratio. Apparently, upward shifts are relatively automatic while downward shifts require relaxation of pedal pressure to unlock the system and allow it to expand.

In comparison, the RIDE-A-MATIC is truly continuously variable. It operates smoothly and quickly but, interestingly, does incorporate sufficient internal friction to produce some hysteresis. The author believes this to be of considerable advantage since the drive does not respond to the cyclic changes in power for each pedal stroke, but rather tends to stay in the speed ratio represented by the he maximum force for each pedal stroke. This point will be mentioned again when performance characteristics are presented since average power depends on the average torque being transmitted, while the speed ratio is related to the maximum pedal force for each stroke.

As far as the author knows, the RIDE-A-MATIC is the only bicycle drive that uses a belt. On a bike, a belt has two distinct disadvantages over the chain -it may slip and it is less efficient. As mentioned earlier, slipping is counteracted by the inherent design that causes the belt tension to increase with increasing torque. The RIDE-A-MATIC with two chains and a V-belt has to be less efficient

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that a well-cared-for derailleur chain drive. How much less is not known at this time. A simple test of the bicycle showed that about one pound force (4.5N) on the pedal was needed to turn the wheel. If this is representative of actual riding, then the drive would be about 96% efficient when the pedal force is 30 lbf (133N). Since the drive would probably not be preferred by a racing cyclist, its value lies in a trade-off between slightly lower efficiency and improved riding convenience for the touring or commuting rider. This trade-off is analogous to the sports-car enthusiast's preference for a 5-speed shift while other drivers prefer the less-efficient automatic transmission in their commuting autos.

THEORETICAL PERFORMANCE CALCULATIONS

The graph showing the relationship between speed and pedaling cadence of a fixed-gear bicycle is simply a straight line of slope determined by the gear ratio. At any point on this line, pedal force and horsepower may have any value depending on the load conditions and the rider's strength and motivation. For a bicycle equipped, say, with a 10-speed derailleur, the graph now becomes 10 straight lines of different slopes, each defined by its particular gear ratio. But, just as with the fixed-gear bike, the rider can use any force she/he wishes in any one of the gears so that performance points cannot be represented. However, all of this changes when a torque-responsive automatic transmission is involved. Because pedal force and speed ratio are related by the kinematics of the mechanism and the spring preload and rate, a graph of all of these variables may be constructed, at least in the range that speed ratio is changeable. Another way of looking at this is to note that the rider, once his pedal force puts him in the range of speed-ratio change, has control only of pedal force and must accept whatever cadence, bike speed and horsepower that results.

With so many variables, viz., speed, cadence, pedal force, gear ratio, and horsepower all related, many possibilities exist for graphing performance characteristics. After trying each of cadence, pedal force and horsepower as abscissas, the author chose cadence as abscissa and speed as ordinate in the plot shown in figure 4. Straight lines are plotted for each pedal force between 30 lbf (133 N) and 60 lbf (267 N) at 5 lbf (22 N) intervals. All forces and related variables less than 30 lbf lie on the "30 lbf line" and all forces and related variables greater than 60 lbf lie on the "60 lbf line". Each line also corresponds to a certain gear as determined by the kinematics of the drive. That these lines are not uniformly spaced is due to the fact that the author has purposely made the radial slots in the discs of the drive to be arcs rather than straight (as shown in Fig. 3) so that the drive will be "stiffer" at higher gears than for lower. Even with straight guide slots the relationship between pulley radius and disk rotation is nonlinear due to the fact that the arms rotate about their pivot points. The present design is the result of a number of trials. Horsepower and speed equations are straightforward, the only difficulty being the following: as mentioned previously, the internal friction in the RIDE-A-MATIC keeps it from shifting down when the pedal force decreases cyclically during each rotation of the crank. This is important since the speed ratio then depends on the maximum force that is applied to the pedal. However, power calculations depend on the average pedal force for an entire revolution. The only reference found by the author as to the ratio of the average force to the maximum force was in reference 2, p. 268 where Sharp shows in fig. 231 an essentially rectified sine wave that he calls the "curve of sines" to represent the variation in pedal force. This agrees with the author's intuition and his desire for a simple mathematical relationship. Thus the ratio of average pedal force to maximum pedal force was taken as 0.63. This value was used in all of the calculations.

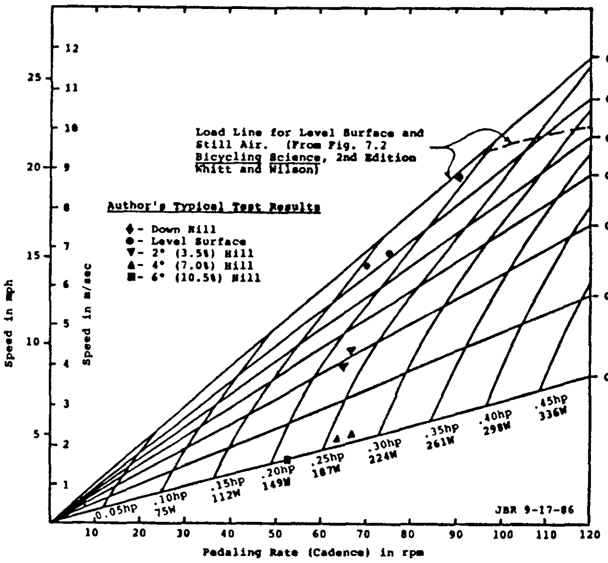

FIG. 4

Also plotted or indicated on fig. 4 are some of the load characteristics that might confront a rider. The load for riding on a level surface in still air from reference 1, p. 155, fig. 7.2 is plotted. Also indicated are the hill slopes that could be climbed by a rider plus bike weighing 200 lbf (about 900 N) at the various gear-pedal force combinations assuming no wind or friction losses. As before, these calculations are based on the average pedal force which is 0.63 of the forces shown.

RESULTS

The Mongoos Trail Bike on which the prototype unit was installed was equipped with a speed- and cadence-measuring unit. Speed in mph was calibrated to read two times the actual mph in order to increase its accuracy. The author, on several days, rode around his home on hills of various slopes. He endeavored to produce steady-state conditions for each reading, but this was difficult as it often is when dealing with physiological systems. Typical results are plotted on figure 4.

DISCUSSION

First, some comments on the choice of gears. The author was intrigued by an article written by Alan Hammaker in the May 1984 issue of Bicycling[4]. In this article entitled "Perspectives on Gearing", Hammaker refers to a Ron

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Shepherd who proposed for the " ±average' healthy cyclist with no aspirations to racing fame" what Hammaker calls "Ron's Rule: A Comfortable Gear is Twice the Gradient Denominator". Because of its elegant simplicity and the fact that it seems to fit well the comfortable range of the author, he selected the gears for the prototype RIDE-A-MATIC equipped bicycle to follow, more or less, "Ron's Rule". Thus, as seen on Fig. 4, for the 10% slope, where Ron's Rule would call for a 20 in. gear, the bike has 23 in.; the 5.0% slope would call for 40 in., the bike has 43 in.; and the 3.6% slope would ask for 55 in., the bike has 54 in. Having set the low gears, the high gear of 73 in. results from the 3.1 speed-ratio-change range of the RIDE-A-MATIC.

Some predictions of performance can be made from figure 4. The speed-vs.-hp. characteristics for riding on a level surface in still air (reference 1, p. 155, Fig. 7.2) are plotted on the figure. A little less than 0.15 hp (112 W) would be required to ride at 15 mph (6.7 m/sec) and the cadence would be 70 rpm. 0.20 hp (149 W) should achieve 20 mph (9 m/sec) at a cadence of 93 rpm. For each of these conditions, less than 30 lbf. (133 N) of pedal force would be required so the drive would stay in high gear at 73 in. To go 22+ mph (10 m/sec) would require 0.30 hp (224 W) at a cadence of 112 rpm and a pedal force of 38 lbf. (169 N). Such a high cadence could not be maintained for long, certainly by the author, so the top useful speed on the level of this prototype RIDE-A-MATIC-equipped bicycle is probably 20 mph (9 m/sec). Experience to date by the author confirms this. The performance on steep grades is well indicated by the figure. For example, 0.20 hp (149 W) would be required to climb a 10% grade at about 3.5 mph (1.5 m/sec) and cadence of 50 rpm and force of 60 lbf. (267 N). On such a 10% slope any pedal force greater than 60 lbf (267 N) will move the bike faster with corresponding increase in hp and cadence. Between 0.10 hp (75 W) and 0.2 hp (149 W) where corresponding speeds and consequently wind resistance are low, the characteristics vs. various slopes probably show pretty well what the rider may expect.

The actual test points shown on figure 4 agree generally with the theoretical predictions. The variation is well within the inaccuracy of the measuring instruments as well as the difficulty of the author to establish steady-state conditions. This result is not unexpected since the characteristics for figure 4 were based on the author's weight. It is interesting to note that for these few trials, the author kept his cadence between 60 and 70 rpm for all the conditions that the RIDE-A-MATIC was controlling speed ratio. The associated power required on the hills was probably higher than anticipated, but the level riding power was just about that desired.

Some subjective comments by the author on his reaction to riding the prototype may be appropriate. For convenience, he will shift to writing in the first person. When starting off on the level, I push rather hard, as do most riders, to accelerate. This causes the pedals to rotate about 1/2 turn without motion of the bike as the unit shifts quickly down to low gear. Acceleration is then rapid and smooth with a noticeable reduction in pedal pressure and only a moderate increase in cadence. I feel the unit reach high gear at about 10 mph (4.5 m/sec) and from then on my riding on the level is mostly all in high gear. It is interesting to try suddenly to accelerate. I push much harder with the result that my cadence increases suddenly, then gradually the bike accelerates as the pedal force decreases and the drive returns to high gear. This "decoupling" between the pedals and the wheel is at first somewhat disconcerting but I have become used to it and find it rather enjoyable. It helps that, intellectually, I know no energy is being lost by the process. On going down hills, I quickly reach the maximum cadence I can manage and so begin to coast. Starting up a hill means a rapid slow down until an operating point for the power I wish to expend is reached. To date, only I and a few of my friends have ridden the bicycle and none of us for very long. We have all found it a uniquely different experience and for me, I find it to be very satisfying. My young neighbors report that it was "fun" but they obviously found it much too limiting on their freedom of choice to race ahead or climb a hill while standing on the pedals.

CONCLUSION

A novel continuously variable automatic transmission has been built and initially tested on a bicycle. Its performance agrees with theoretical calculations and expectations. It would appear to be desirable for use by the casual rider who appreciates being freed from the necessity of manually shifting gears and who does not mind having his power output regulated more or less by the riding conditions and the characteristics (settings) of the drive.

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A Figure-Eight Drive

By Anthony L. Patroni

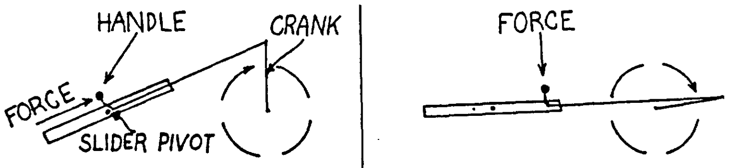
In response to an article in HPV news (Human Power Vol. 5 No. 3 Fall 1986 pg. 6) I would like to mention that I have two U.S. Patents on a slider-crank-type drive mechanism. (Pat. # 4,548,420 and # 4,584,889) The resultant motion of my drive mechanism is a horizontal Figure "8". The drive works very well and it also falls in line with the study mentioned in the article stating that the input force to a drive should be maximum at the same time the drive velocity is at its maximum.

In a study of the figure "8" motion two other important advantages are apparent. Although the drive is almost linear there is never a full stop during a change in direction, only a sharp turn. The other advantage is that the user never has to push directly upward. This is due to the location of the slider's pivot point which is dead center (or there about) in the path of linear travel. When the end of the stroke is reached by the pulling arm or leg the crank is moving upward but a downward force is required on the pedal because it is on the opposite side of the pivot from the crank. At the same time the pedal furthest from the rider has its crank moving downward. The pedal or handle being on the same side of the pivot would require a downward force to bring it around also. A slight pushing down at the full extension of the drive (turnaround point) by both arms or legs will overcome the 180° dead spots encountered on linear drives. This drive lends itself well to designs where the drive mechanism is pivotally mounted for steering the vehicle. This is because vertical forces of both arms are always downward and can be kept equal. A horizontal axis from front to back of the vehicle is the configuration I used on my first prototype arm-powered and-steered trike.

A short study of the figure 8 movement is as follows: Assuming that the rotary crank's velocity remains constant; the maximum velocity of the figure "8" motion will be when the crank is moving through the horizontal parts of its travel. When the drive forces are changing direction the linear velocity is at its minimum. Input forces will be highest nearest the pivot point and least at the change in direction. The input force and drive velocity are in synchronism.

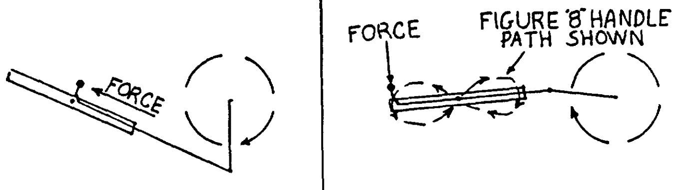
I arm-powered a bicycle to 20.4 mph in the 200-meter sprints at the 1984 IHPSC. I used a figure "8" drive which had both arms travelling together in a short rowing motion. The drive powered the front wheel and was mounted to the front fork also steering the vehicle. The bicycle had also a conventional crank and pedals. I rode in a 20 k road race using both arm and leg power to prove the handling of the machine.

FIGURE '8' DRIVE



CRANK AT 12 O'CLOCK: MAX HANDLE VELOCITY. PUSHING FORCE (RIDER TO LEFT) WILL MOVE THE CRANK AROUND THIS POINT OF THE CYCLE

CRANK AT 3 O'CLOCK: MINIMUM HANDLE VELOCITY. DOWNWARD INPUT FORCE WILL PREVENT A DEAD SPOT IN THE MOTION



PULLING FORCE NECESSARY AS CRANK PASSES 6 O'CLOCK AND STARTS TO TRAVEL UPWARD (MAX VELOCITY)

A DOWNWARD FORCE IS NECESSARY TO PUSH THE CRANK UPWARD PAST THE WOULD-BE DEAD SPOT (MIN VELOCITY)

Recently I've been busy finishing my prototype ergometer which uses a figure "8" drive for an upper-back-and-arm exercise. Then the sliders can disconnect to convert the machine. An added advantage is that one slider can be left on so that one arm and one leg can be exercised in the event of a disabled leg. I have future plans for an arm-powered lean-steered tricycle (w wheels front and one rear) and an arm-powered prop-driven lightweight boat. I prefer rotary drives for leg power although I leg-powered a recumbent with my drive. My personal opinion is that the changes in velocity at higher rpms on a linear drive might cause adverse effects to the knees. For information on figure "8" drives send questions or comments to A. Patroni, 9005 Amherst Ave., Margate, N.J. 08402, Phone # (609) 82308121

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