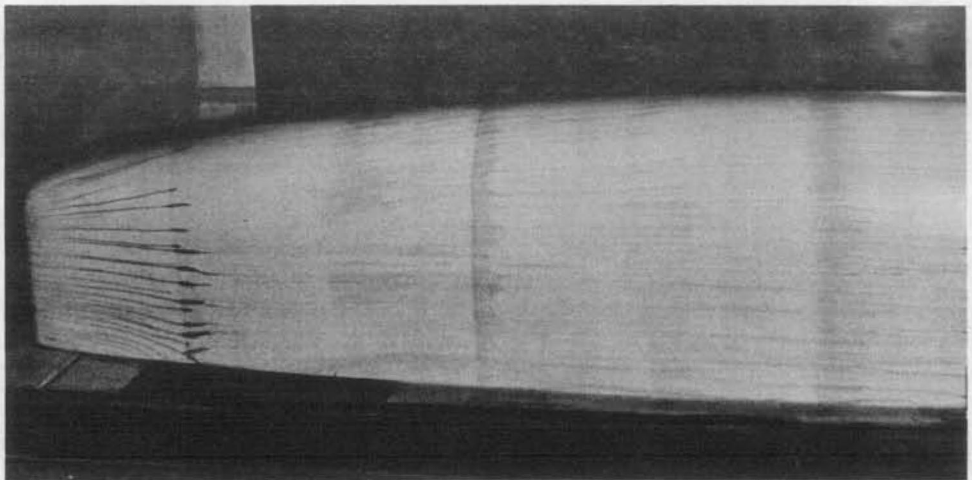


(Fig. 6) No. 2 in the wind tunnel test section. An oil-type paint is used to show the streamlines. The lines curve down in the front due to the suction slot used to draw off the boundary layer on the wind tunnel floor.

The Wind Tunnel Testing of White Lightning

(Text & Photos by Tim Brummer)

In October 1976, myself and two other students at Northrop University began discussing the feasibility of constructing a Human Powered Vehicle for the annual IHPVA race the following May. The design was finalized and frame construction was started in March. One week before the race the vehicle was ridden for the first time and we started to think about a body. A shell was hastily formed by taping clear plastic sheets over aluminum formers and was completed the morning of the race. The end result looked like a wet caterpillar and visibility was non-existent, but we still managed a credible 47.9 mph for 3rd place.

Realizing that a proper body shape would greatly increase the vehicle performance, I began investigating different shapes in June of 1977. It was decided to use the existing frame as it had proven both reliable and stable, and to shape a body around it. After some research I decided upon a 66-012 laminar flow airfoil, as it fit the frame nicely and had a very low drag coefficient. A 1/5 scale drawing was made for a wind tunnel model, with loft lines at various stations. Our original shape (Model No. 1) had a round bottom cross section and was mirrored somewhat in a horizontal plane so that the top matched the bottom, similar to Allan Abbott's machine. The entire body was a compound curve, with wheel pants and bulges for the front rider's heels. (See Figure 3). The forward wheel covering was designed to turn with the wheel for steering.

The model was built during the summer of 1977 in the school workshop. It was carved from a solid piece of pine, which was laminated from 4 pieces of 2 x 6 boards. Rough cuts were made using a band saw. The final shape was obtained by hours of planing and sanding. To ensure that the proper shape was obtained, the model was constantly checked against metal templates (Figure 2). Two metal fittings were glued flush with the bottom of the model to provide attachment to the force balance of the wind tunnel.

The model was finished with sanding sealer and four coats of white enamel. The final coat was fine-sanded with 400-grit sandpaper.

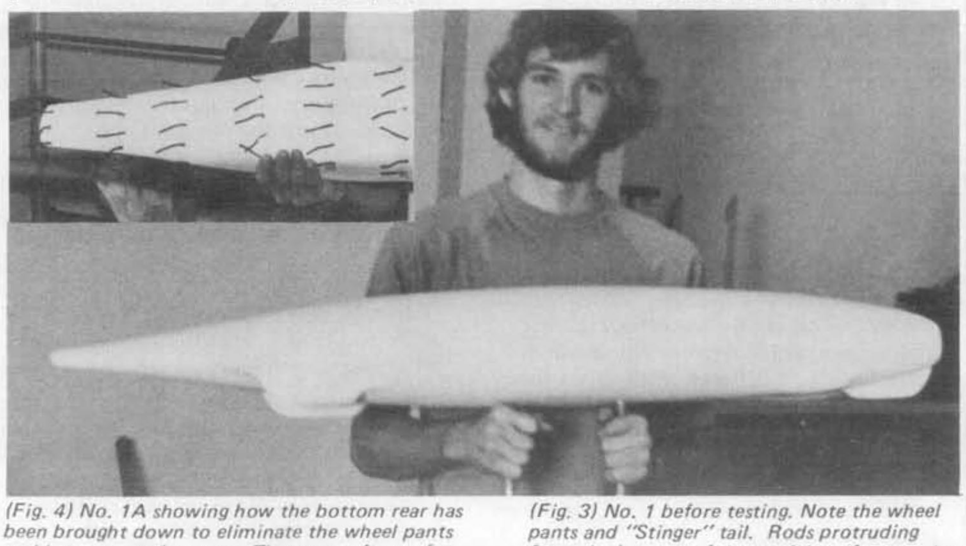
Wind tunnel testing of the model began in September of 1977. The Northrup University subsonic wind tunnel was used to conduct the experiments. The wind tunnel was built by students from an earlier class and is constructed mainly of wood. Power from a 100 HP electric fan produces velocities of up to 200 mph in the test section, which measures approximately 2 feet square and 4 feet long. Air loads acting against the model are transferred to the force-balance by metal rods.

The force balance assembly measures lift, drag, and moment forces using electronic load cells, and displays the results on a digital readout processor. To simulate ground effects as much as possible, the model was mounted close to the wind tunnel test section floor, and the boundary layer of air on the board was removed by a suction slot at the nose of the model.

The tests on Model No. 1 consisted of measuring the lift and drag forces at varying air speeds and ground clearance heights. It was found that the drag coefficient (C_D) decreased with increasing speed (Reynolds numbers, or R_n). The C_D also obtained for Model No. 1 was .061 with a ground clearance of .10 inches (½" for the full scale vehicle) at a R_n of 1,000,000.

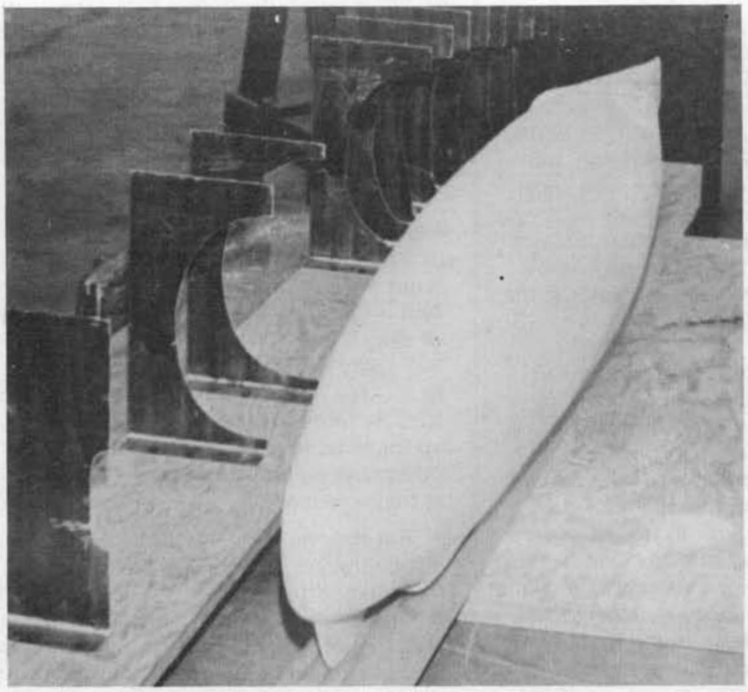
Flow visualization tests were also conducted using yarn tufts taped to the model. It was during these tests that large separation areas were noted on the lower rear part of the model, particularly between the wheel pants. After numerous modifications with clay, it was decided to eliminate the wheel pants and to add material to the lower part of the tail. The rear part of the model was modified and the resulting configuration designated Model No. 1A (Figure 4). Tests showed that the separated area was greatly reduced and that the C_D was considerably lowered. A minimum C_D of .030 was recorded at a R_n of 1,000,000 and a ground clearance of 10 inches.

At this time it was realized that we had developed a very low drag shape, but that it was going to prove to be very difficult to build a full scale vehicle with similar lines. With the added requirement of a simple as well as low drag shape in mind, a new body was designed. The new shape had flat sides, a square cross-section at the bottom, and a compound curve only on the top. Although patterned after the same NACA 66-012 airfoil as Model No. 1A, the new configuration had approximately 5% more frontal area than Model No. 1A due to the flat sides and bottom. A new model (designated No. 2) was built using the same methods as Model No. 1. The fabrication and testing of Model No. 2 was done as an Aero Lab project, with the assistance of another Aero student, Roy Dunn.



(Fig. 4) No. 1A showing how the bottom rear has been brought down to eliminate the wheel pants and large separation area. The yarn tufts are for flow visualization in the wind tunnel.

(Fig. 3) No. 1 before testing. Note the wheel pants and "Stinger" tail. Rods protruding from the bottom of the model are for securing the model to the wind tunnel force balance.



(Fig. 2) No. 1 in the shop after construction. Board with sheet metal templates was used to assure the model had the desired shape. Some templates were removed in this photograph.

The test procedure was the same as for Model No. 1, with the results being somewhat parallel. The C_D decreased as the ground clearance decreased and R_n increased. The lowest C_D obtained was .025 at a R_n of 1,000,000 and .10 inches ground clearance. This gives a slightly lower drag than model No. 1A, in spite of the increased frontal area. Being very pleased with these results, it was decided to use Shape No. 2 as the basis for the full scale vehicle.

As plans were being made to construct the full scale body, some thought was given to rider ventilation. Experience with our original plastic body the previous year showed that an enclosed body shell was very uncomfortable due to an excessive heat buildup. It was decided that Model No. 2 should be modified to test the effects that ventilation would have on the vehicle drag.

Two NACA type flush inlet scoops were cut into the upper part of the model. These scoops were connected to each other and to two outlets by large internal passages. One outlet was located on the top rear of the vehicle, while the other insulated the rear wheel cutouts on the bottom. NACA flush inlet scoops were chosen because of their low drag and high pressure recovery. They were placed on the top of the vehicle just forward of the riders' heads so as to give maximum cooling and eliminate the possibility of sucking up foreign matter. The scoops on the model each had an inlet area of .5 sq. in. (12.5 sq. in. for the full-scale vehicle). Wind tunnel tests, however, showed the drag increased 76% to a C_D of .044. An increase this large could not be tolerated on the actual vehicle. The scoops on the full-scale body were therefore hinged so they could be closed off during the acceleration and timing phases and opened during the deceleration period for cooling.

While I was conducting tests with the scoops on Model No. 2, Roy Dunn had constructed and was testing Model No. 3. This model was configured similar to Model No. 2 but was based on a NACA 0010-35 airfoil. As a result the model was thinner and longer, with the length being 4.4 ft. as compared to 4 ft. for Model No. 2. Testing showed this shape would yield no improvement over Model No. 2 as the minimum C_D was .032 at a R_n of 800,000.

It must be remembered that the drag coefficients noted were for the scale models tested in the wind tunnel, and are useful in comparing one model shape to the next. These results are not applicable, however, to a full scale vehicle due to the effects of a stationary ground plane, body joints, shape irregularities, and other factors. In coasting tests with the full scale White Lightning, a C_D of .110 at a R_n of 900,000 was obtained. This is an increase over the C_D of the wind tunnel model by a factor of four.

Much wind tunnel testing remains to be done to find the ideal body for a human powered vehicle. Investigation of the effects of a ground plane stationary to the air stream is one important area to study. I believe failure to do this in our wind tunnel studies effected the results considerably. Also, correlation studies between actual vehicles and wind tunnel models should be done. With further aerodynamic research and a proper engineering approach, I believe human powered vehicles can be built with speed capabilities in excess of 70 mph.

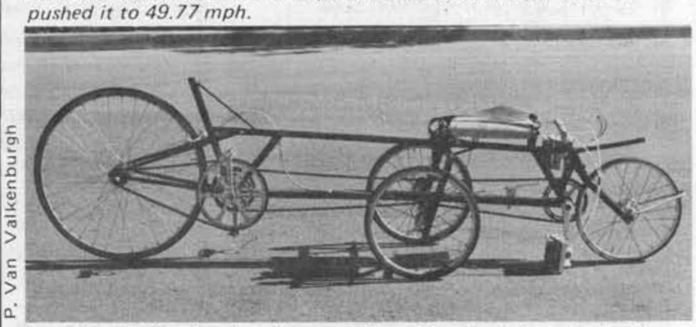
Aeroshell Answers

by Paul Van Valkenburgh

George J. Naoum

Aeroshell in its 1979 form with parachute brakes. Ralph Therrio pushed it to 49.77 mph.

P. Van Valkenburgh



Bare frame of the hand and foot cranker. Steering is by patented cable system.

The Aeroshell streamlined fairings have generated enough mail to justify a written explanation of their past, present and future. The standard upright version has been around for four years, running 46.5 mph to finish second in the singles in 1976. Since then it has been primarily run in road races (second at the Tustin Dog Days road race) because the new prone Aeroshell II has been so much faster. The prone, hand-and-foot powered quadracycle Aeroshell II has already been well described in word and photo, so we will concentrate here on the conventional upright version.

Seven "upper" Aeroshells have been built, including four rigid (two opaque and two transparent) and three inflatable ones. All of these have the same teardrop shape, and rest on the rider's body without touching the bicycle at all. Four rigid plastic "lower" Aeroshells have been built, including two opaque plastic, one transparent plastic, and one cardboard. These attach to the bicycle frame and enclose it to the top of the tires.

All of the plastic Aeroshells are constructed by vacuum-forming thermoplastics (ABS, Butyrate, or Vinyl) over plaster molds in a four by six foot oven. Although this technique lends itself to mass production, factors such as the cost of the material, the cost of the molds, and the availability of ovens make the end result rather expensive. Custom-built in limited quantities, they would have to be sold for 2-300 dollars. That might be acceptable, except that still more development work is necessary at this time.

The advantages of the rigid upright Aeroshell have been obvious in past races. In the first place, it's been the fastest standard bicycle in either straightaway or road races. In addition, it's been easy to get in and out of in a hurry, it provides

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