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Response to Questions

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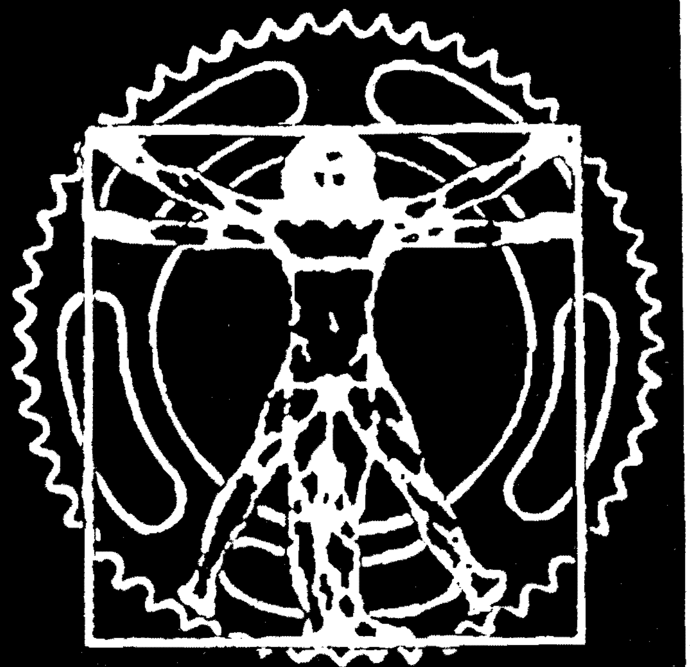

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Human Power (ISSN 0898-6908) is published irregularly, ideally quarterly, for the International Human Powered Vehicle Association, an organization dedicated to promoting improvement, innovation and creativity in the use of human power generally, and especially in the design and development of human-powered vehicles.

IN THIS ISSUE

The phantom trailer

Andreas Könekamp tackles the problem of the occasional heavy demands that are made on family bicyclists and that could result in them giving up bicycling altogether. He applies the creative concept of designing a "smart" trailer containing a battery, motor and transmission, and controls that add motor torque only when needed.

Measuring drive-train efficiency

Angus Cameron wanted to find out what the efficiency of his bicycle transmission was, but realized that a full dynamic test involves very accurate instrumentation and expensive rig components. On the other hand, he saw that a static test would be within reach of most enterprising bicyclists, and virtually all high-school science labs. He shows data from his own experiments that are both believable and mind-opening.

Predicting wheel dish from hubs

One would think that wheel "dish" or lateral eccentricity would increase with increase in the number of chain cogs in the cluster. Vernon Forbes shows that while this is generally true, there are many exceptions. He produces graphs showing how a number he calls the "dish ratio" is related to other hub variables, and provides guidelines helpful in the design of new wheels.

A bicycle with auxiliary hand power

Many inventors in the past have produced bicycles that could be powered by hands and feet simultaneously. Duhane Lam and his co-authors believed that these predecessors all had fatal flaws. They have produced a bicycle with interesting and valuable characteristics. We'll be interested to learn the views of our readers.

TECHNICAL NOTES

Follow-ups to "Lower-extremity output in recumbent cycling"

Authors R. F. Reiser and M. L. Peterson report an error made in their paper in the last issue of HP in their interpretation of data of Danny Too. Their paper stimulated much interest in Too's work, and Danny Too responded by reviewing many of his papers and answering questions of correspondents. He has kindly given us permission to publish all of these reviews and responses.

Drag of two bodies in tandem and side-by-side

Jim Papadopoulos and Mark Drela discuss, interpret and analyze drag data on the interference drag produced by two bodies (e.g., two vehicles or riders or frame tubes) close to one another and spaced laterally or in the line of travel, given in Hoerner's famous text on fluid-dynamic drag—a very erudite and informative note.

IHPVA record wind rules: a participant's perspective

Paul Buttemer, in the midst of setting some remarkable new long-distance HPV records, sent in these recommendations for changes in the rules for permissible wind speeds for records to be recognized.

LETTERS

Wayne Estes comments on wind resistance as it relates to pedaling *vs.* coasting.

EDITORIALS

An appreciation of the life of Gunter Rochelt

A note of appreciation is made for Gunter Rochelt, who accomplished amazing feats with the aid of his family and other team members, with the human-powered aircraft he designed and built. Sadly, he died in 1998.

Human-Power numbering and indexing

Volunteers are indexing Human Power, and we have taken the opportunity to change the often-irrational volume-plus-issue system by which past contributions were identified. We have gone to a simpler issue-number system. A conversion table is given.

CONTRIBUTIONS TO *HUMAN POWER*

The editor and associate editors (you may choose with whom to correspond) welcome contributions to *Human Power*. They should be of long-term technical interest (notices and reports of meetings, results of races and record attempts, and articles in the style of "Building my HPV" should be sent to *HPV News*). Contributions should also be understandable by any English-speaker in any part of the world: units should be in S.I. (with local units optional), and the use of local expressions such as "two-by-fours" should be either avoided or explained. Ask the editor for the contributor's guide. Many contributions are sent out for review by specialists. Alas! We are poor and cannot pay for contributions. They are, however, extremely valuable for the growth of the human-power movement. Contributions include papers, articles, reviews and letters. We welcome all types of contributions, from IHPVA-affiliate members and nonmembers.

Danny Too: Table showing differences depending on crankarm length (CL)

CL (mm)	110 hip/knee/ank	145 hip/knee/ank	180 hip/knee/ank	230 hip/knee/ank	265 hip/knee/ank
UP (deg)	142/124/111	137/119/107	134/113/108	130/109/106	123/105/112
REC (deg)	80/115/100	80/109/96	77/105/94	75/95/93	73/94/91
POWER	PP / MP	PP / MP	PP / MP	PP / MP	PP / MP
UP (W)	880 / 546	913 / 690	949 / 741	859 / 697	843 / 683
REC (W)	1123 / 757	1103 / 786	1093 / 806	979 / 772	896 / 748

more complex, since changes in crank-arm length affect not only hip angles, but also knee angles. There are also other variables and factors to consider, including the interaction between muscle force-length, and force-velocity-power relationships; since there apparently is an interaction between crank-arm length, load, and cadence.

Currently I have two papers related to crank-arm length in review for publication:

1. Too, D., & Landwer, G. The effect of pedal crankarm length on joint angle and power production in upright-cycle ergometry. Submitted to *Journal of Sport Sciences.*

2. Too, D. The effect of pedal crankarm length on joint angle and power production in recumbent-cycle ergometry. Submitted to *Ergonomics.*

I am currently analyzing data for a paper, comparing the power production between an upright and recumbent position with changes in crank-arm length. The same subjects were used for all test conditions in the upright and recumbent.

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DANNY TOO RESPONDS TO QUESTIONS

(Danny Too responded to some questions on aspects of his papers, and was gracious enough to allow us to publish them. Questions are shortened in several cases. —Dave Wilson)

Question: John Riley (j.riley16@genie.com) wrote: "Out in the real world things get very complex and with unfaired bikes, people manipulate the position to get better aerodynamics. That said, the Tour Easy and Rans Stratus come close to matching your optimum position and they do have a reputation for good performance. The BikeE is also close, but does not have a good reputation for performance. The BikeE does apparently perform better when the rider hunches forward, and I think the rider also hunches forward in the fully faired Tour Easys that have won so many races. Your optimal position seems to have a riding angle (angle formed by a line from the BB to the seat base and a line up the seat back) of 115 degrees. Perhaps a slightly tighter riding angle, with the BB still below the seat, might be even better, especially for anaerobic work. The tighter riding angle can constrict the lungs and so might not be best for aerobic work."

Danny Too: There are many factors that affect cycling performance.

A cycling position that maximizes power production and cycling effectiveness, but also happens to maximize aerodynamic drag, may not necessarily maximize cycling performance (as defined by maximal velocity or minimal time to cover a pre-set distance). The optimal cycling position may very well result in a trade-off between the two. Rider conditioning and training in any given position will also be a factor.

But I would speculate that recumbents with similar cycling positions will not necessarily result in similar cycling joint angles and kinematics during a pedaling cycle. This would explain why different recumbents with similar cycling positions may not result in identical cycling performance. This would also explain why "hunching forward" in certain vehicles may improve performance. This "hunching forward", probably results in more effective hip and knee angles in the production of force. Recumbent cycling positions are as exclusive and diverse in trunk angles, joint angles, seat-tube angles, and crank-arm lengths as the vehicles themselves (and the people who design them). This, I believe, is what makes comparisons among recumbents very difficult. Each recumbent vehicle available on the market is unique in some fashion, and it is the interaction of a multiple of variables (trunk angle, joint angles, etc.) that ultimately results in performance. Therefore, to compare different recumbent vehicles is like comparing apples with oranges.

What I have attempted to do in my research is to eliminate all these interactions and confounding variables by systematically manipulating one variable while controlling for all the others. This, then, provides objective information regarding trends and patterns with extreme manipulations in crank-arm lengths, seat-tube angles, joint angles, trunk angles, etc.

Question: Cyril Rokui (croku@juno.com) wrote: "Thanks very much for the summary of your papers. I found it to be very interesting reading and may incorporate some of the findings in future bikes I intend to build. Have you done longer-duration (30 minutes or one hour) crank-arm-length studies that would simulate a bike ride rather than a very short test just for peak power? Also, I notice that mean power output is highest in the recumbent position for the 180-mm cranks and this was for 30 seconds vs. the 110-mm cranks at 5 seconds for the peak-power measurement. Does this mean that the 180-mm cranks are more efficient for long-term production of power?"

Danny Too: No, I have not examined longer-duration (30 minutes or 1 hour) studies with changes in crank-arm length. It may simulate a bike ride, but subject motivation would probably be a confounding variable affecting the results, and it would also be difficult to obtain subjects who would be willing to participate in such a study. However, I have collected data examining the effect of incrementing workload on cycling duration with changes in crank-arm length. I have not yet had the time to analyze the data.

First, a correction for flywheel acceleration and deceleration was not accounted for in that abstract. In the full manuscript (submitted to *Ergonomics*), this correction has been made and results in the 145-mm crank-arm length producing the highest 5-second power. Second, mean power, being highest for the 30-second test, would suggest that they are more efficient for long-term power. However, it is more complex than that. There appears to be an interaction between crank-arm length, pedaling rate and workload/resistance. When fatigue sets in (15 seconds into the 30-second test), pedaling rate starts to decrease. When pedaling rate is least during the last 5 seconds, the crank-arm length that results in the largest minimal power is the 230-mm crank-arm length. The 180-mm crank-arm length results in the largest mean power for the 30-second test, and the 145-mm crank-arm length will result in the largest peak power during the first 5 seconds of the test.

Question: Rolf Mantel wrote "Will you do more studies using cranks that represent a sampling of what's readily available in the marketplace e.g., 165, 170, 175-mm cranks? Even a small difference may be significant in racing or trying to set a speed record."

Danny Too: No, I will not be doing studies using cranks that represent a sampling of what's readily available in the marketplace (e.g. 165, 170, 175-mm cranks). I am using extreme (short and long) crank-arm lengths to observe the trend in performance that occurs, and to understand the mechanisms involved. It appears that it is not so much the length of the cranks that is important, as it is the joint angles of the lower extremities in producing power.

The difficulty with using the same individuals for repeated tests over a period of time is the training effect that would occur. The data with different crank-arm lengths would be confounded by the improvement in performance due to training. It would then be unknown whether performance differences with different crank-arm lengths are attributed to crank-arm lengths, a training effect, or both. To control for the training effect, the crank-arm-length test sequence needs to be randomized across subjects (i.e., a different crank-arm-length test sequence for each subject).

Question: Gary King wrote: "Though D. Too's experiments were probably very accurate, I don't believe they prove high-BB bikes (SWBs) are slower climbers than low-BB recumbents (many LWBs). Were his subjects using cleats? Did they know how to pedal high-BB bikes? The pull-back stroke is a very powerful stroke on these kinds of bikes. Also he showed that the upright position was not the most powerful position in the high-load situation (equivalent to climbing I assume). I read only the summary, but I guess the rig he used was fixed, rigid. In the real world the upright rider can sway the bike, use his arms to climb, centre his weight over each pedal etc. I suspect the results would have been very different if subjects were able to rock the test rig from side to side—only a slight amount would do it."

Danny Too: First, my experiments do not show or prove that "high-BB bikes (SWBs) are slower climbers than low-BB recumbents (many LWBs) or vice-versa. The experiments were never designed for that purpose.

They were designed to: (1) provide objective information regarding how cycling performance changes with systematic manipulations of different variables while controlling for all others; (2) provide objective and unbiased information that can be replicated and quantified by others; (3) provide information to designers in the development and construction of faster and more effective HPVs. How the data and results from my research are interpreted and used by others is not in my control.

My subjects did not use cleats, but used toe-clips. They were untrained recreational cyclists who did not know how to pedal high-BB bikes or who had any significant experience with recumbent bicycles—although some were engineering students involved in the development of HPVs. If trained cyclists (of uprights or recumbents) were used, the data would be biased and the results may very well have been different. This is due to specificity of training.

Subjects were not allowed to stand upright, sway the bike, shift weight, use the arms, etc., during testing in the upright positions (because the ergometer and seating apparatus are fixed structures, eliminating balance as a factor). If they were allowed, the results could very well be different, and then it would not be known whether differences in performances would have been attributed to the variable being manipulated, and/or to other uncontrolled variables that confounded the data.

Question: Akash Chopra writes: "Thanks for posting the summary of your papers. I do have one question regarding your claim in the paper 'The effect of body orientation on power production in cycling' where you state that: 'A neutral position (90-degree trunk angle to the ground) or one where the leg weight assists in pushing the pedals (60-degree trunk angle) would be more effective than a position where one has to overcome gravity. This clearly explains why recumbents (especially those where the pedals are above the hips) are not effective in climbing hills.'

"I would have thought that the majority of hill climbing would require aerobic effort (it certainly does where I live!) and that the performance would not be determined by peak power output. You mention that another study which was 'conducted aerobically...revealed no significant difference between all three angles.' This would suggest that the recumbent position is not responsible for any lack of hill-climbing performance (from the results of these papers, at least)."

Danny Too: Thank you for interest in my research and for the question you posed. The aerobic study to which you referred is

Too, D. (1989). The effect of body orientation on cycling performance. In W.E. Morrison (ed.). *Proceedings of the VIIth International Symposium of the Society of Biomechanics in Sports*, (pp. 53–60). Footscray Institute of Technology, Victoria, Australia.

In that study, there were no significant differences (statistically significant ones) between the 60-, 90-, and 120-degree body orientation. However the longest cycling duration was found with the 120-degree orientation, followed by the 90- and 60-degree orientation, respectively. Therefore, the trend in aerobic performance is similar to that found anaerobically. It is possible, with a larger sample size, statistical significance may be found. I am hoping someone will replicate my study to either support my results, or provide additional information.

Question: Sean Williams wrote: "Your abstracts did not state your position on the issue. I suspect that there is a decrease in power-output performance. I suspect the ergonomics of the recumbent position allows for greater endurance. Depending on leg mass, center of mass, how much of a change there is in vertical displacement and where in the cycle (in terms of the power stroke) it occurs there appears to be a loss of about 8% of available power.

"Assuming: almost all power is given to the pedals by the pushing leg; a 50-mm vertical rise in the centre of mass; all vertical rise in CoM is during power stroke; a 10 kilo leg; 100 rpm over one minute, then the total energy = 0.05 * 10 * 9.8 * 100 = 490 joules per minute = 8 watts. Given that both legs are doing this, 16 watts is removed from the power stroke just to lift the leg.

"The upright position gives this loss on the return stroke so different muscles are used than to provide push on the pedals.

On a recumbent going uphill the same muscles are used to lift the leg as to push the pedals. The ergonomic factors rather than power factors come into play on long bike rides. I would like to hear your opinion as you have done research on the subject and my opinion is merely supposition."

Danny Too: There are many factors that will affect cycling performance and there is a very complex interaction among these variables. Engineers often approach cycling performance from an aerodynamic and mechanical perspective whereas I am examining performance from a kinesiological perspective (and attempting to bridge the gap between man and machine by using an interdisciplinary approach in my research).

The change in cycling performance from manipulations in cycling position, orientation, crank-arm length, seat-to-pedal distance, etc., is not attributed just to mechanics and aerodynamics, but also to a complex interaction between muscle length (of single- and multiple-joint muscles), muscle moment-arm length, and the muscle tension-length, and muscle force-velocity-power relationships to produce force/torque/power. To truly maximize performance, all factors have to be considered and tradeoffs may have to be made.

My research is an attempt to understand how a systematic manipulation of each of these variables (while controlling for all others) will affect performance and the mechanisms involved in force, torque, and power production.

Based on what you have presented, your assumptions may very well be true. However, I suspect the change in joint angles may be a more important factor affecting performance.

Question: Raoul F. Reiser wrote: "I am hoping you could shed a little additional light on your subject populations from a couple of your previous studies? Specifically, in 'The effect of hip position/configuration on anaerobic power and capacity in cycling' (1991) and 'The effect of trunk angle on power production in cycling' (1994) you refer to the subjects as recreational cyclists. Do you recall what form of recreational cycling they used most often? Were they recreational road cyclists, off-road cyclists, track cyclists, or other?

"I ask because it seems that the position that a person uses for cycling might influence the optimal cycling position and the above three styles of cycling require slightly different body configurations from the rider."

Danny Too: The subjects, in general, were recreational road cyclists. There were a couple who also rode mountain bikes (but not competitively). In the 1991 study ("The effect of hip position/configuration on anaerobic power and capacity in cycling"), the type of cyclist tested would probably not have significantly affected the results. In that study, I had also tested one competitive road cyclist and one competitive triathlete. I did not include their data in the study, but their data (with changes in hip position/angle) revealed the same trend.

Question: Cyril Rokui wrote: "With so many variables to consider, no wonder there are so many opinions about optimal seat/crank position. Even if the seat-post angle was constant for the tests, because of variation in human anatomy (big *vs.* small buttocks, tilt of pelvis, curvature of spine, length of leg bones, etc.) the hip/leg angle would be different for many riders sitting in the same seat. I wonder if a variation of 50 mm in hip-joint height would make a measurable difference—different enough for people riding the same bike to experience different levels of exertion for the same speed?

"Figuring optimal seat/crank position for upright bikes must have been trivial in comparison because of the relatively direct contact of the seat with the sit bones (ischial tuberosities) producing a much smaller amount of variability.

"I have come upon another puzzling observation. I tested my heart-rate monitor using a high-bottom-bracket (BB 215 mm above seat bottom) recumbent 'mag' trainer and an upright bike on a mag trainer. On the 'bent trainer at 150 bpm I was starting to feel uncomfortable and was at my aerobic threshold at 160. I then rode the upright and at 173 bpm was not winded. I don't understand the performance difference. Could it be that the 'bent position constricted my diaphragm and reduced my lung capacity and upright position opened up the rib cage and diaphragm? I know that this is not your area of study but I find it to be an interesting observation. Maybe others with a similar setup and a heart-rate monitor would like to try their own tests and see if they get similar results."

Danny Too: Yes, it is very possible that a 50 mm variation in hip-joint height (or less) would make a measurable difference for people riding the same bike to experience different levels of exertion for the same speed. A 50-mm variation in crank-arm length will definitely have an effect on cycling performance. However, it may not have the same effect for everyone (or affect everyone to the same extent). This is the reason why research studies are conducted with groups (instead of individuals) to find a general trend (if there is one), and statistical analysis undertaken to determine what is the probability that differences in performance are attributed to chance (or random variability), or attributed to the manipulated variable.

First, you have not indicated whether you were using the same workload in both the recumbent and upright position and obtaining different heart rates (or whether these heart rates were obtained with different workloads in the different positions). Second, are the heart rates you are recording, maximal heart rates or submaximal ones? Third, I suspect your recumbent position is not only different in trunk orientation with respect to the ground, but also in joint angles and joint range of motion during the pedal cycle. If this is the case, then you have a confounding variable, and will not be able to determine whether differences in heart rate between the upright and recumbent positions are attributed to the change in trunk orientation, or joint-angle differences (affecting power production and efficiency), or both.

On the assumption that your joint kinematics are similar during the pedaling cycle in both the recumbent and upright position, then differences in heart rate (and cycling performance) would be attributed to trunk orientation and blood-flow hemodynamics. Regardless of whether this is the case, the research literature shows that heart rate will be lower when cycling in the supine position than when cycling in the upright when the same submaximal workloads were used (although no information was provided whether the joint kinematics in the supine and upright were the same). The reason? It would appear that a certain cardiac output is required to supply blood to the working muscles for a given workload. Cardiac output is a function of stroke volume (the amount of blood pumped from the heart with each beat) and heart rate (i.e., cardiac output = stroke volume × heart rate). For any given cardiac output, the greater the stroke volume, the lower the heart rate. This is the reason why endurance athletes have a lower resting heart rate. For the same cardiac output at rest, an endurance athlete will have a greater stroke volume with each heart beat (when compared to a sedentary individual) and hence a lower resting heart rate (which translates into less heart beats, and work for the heart over the course of a lifetime). In a supine position, venous blood flow is facilitated and returns to the heart much more easily, fills the heart more, resulting in a greater stroke volume, and hence a lower heart rate for any given cardiac output (when compared to an upright position). The maximal heart rate also appears to be less in a supine position than in an upright position. Therefore, your heart rate at 160 bpm in a supine position may be at the same percentage (e.g., 90% of your supine maximal heart rate) as your 173 bpm heart rate in an upright position (e.g., 90% of your upright maximal heart rate).

As for whether "the 'bent position constricted my diaphragm and reduced my lung capacity and upright position opened up the ribcage and diaphragm?"

It is possible. A study by Faria *et al* (1978) comparing a top-bar and drop-bar cycling position (on an upright), reported the maximal oxygen uptake for the drop-bar position to be greater than that attained for the top-bar position. A top-bar position was described as sitting semi-upright on the saddle with the hands resting on the uppermost portion of the handlebars, while a drop-bar position was described as sitting in the saddle while assuming a deep forward lean, with the hands resting on the drop portion of the turned-down handlebars. The differences in maximum oxygen consumption was attributed to: (1) the activity of a larger muscle mass (greater use of the arm, shoulder girdle, and lower back muscles) in the drop-bar position; and (2) the greater forward body lean angle in the drop-bar position which appears to relieve the weight of the arms and shoulder girdle from the thorax. This reduced weight plus the suspended chest is believed to ease chest expansion, thereby enhancing pulmonary ventilation potential and possibly decreasing the energy requirement for respiration. So reduction of lung capacity and constriction of your diaphragm in a recumbent position is a possible explanation for a decreased work capacity. However, I have not seen any literature that has examined the accuracy and validity of this statement and explanation. It is also unknown as to whether the greater lean in the drop-bar position altered joint angles and allowed a more mechanically advantageous position to produce force when compared to the top-bar position.

If you are interested in references related to heart rate, stroke volume, cardiac output, oxygen consumption, pulmonary ventilation, and work output during rest and exercise between supine and upright position, e-mail me and I will send you an attached text file reference list.

SOME COMMENTS ON THE EFFECTS OF "INTERFERENCE DRAG" ON TWO BODIES IN TANDEM AND SIDE-BY-SIDE

Mark Drela and Jim Papadopoulos

(Editor's note: This was contributed to a mailing list "Hardcore bicycling science" organized by Jim Papadopoulos, and has been edited and reproduced here with Jim's and Mark Drela's permission. Jim opened the discussion by commenting on the relevance of data in a book to pairs of HPVs, including bicycles and riders, and Mark gave his explanation of the theoretical background. —Dave Wilson)

Jim Papadopoulos: One of the most outstandingly useful books on fluid dynamics measurements and theory is *Fluid-Dynamic Drag*, written and published by Sighard F. Hoerner. (For the uninitiated, 'fluid' includes not only water but air, so this book bears strongly on the aerodynamic resistance of a bicycle and rider.)

Recently, I chanced on chapter 8, "Interference Drag", and wanted to share a little of what I found there. Note that the measurements relate to idealized, smooth-surfaced shapes, and not actual riders. But I think they are valuable for suggesting what might possibly happen, perhaps to a different degree, in the real world.

For example, figure 1 concerns two disks, broadside to the direction of travel, with one sheltered behind the other (drafting). Although the drag force on the forward disk is not affected by its follower, the follower is actually 'dragged along' if it is fairly close (1.5 diameters). If the two disks were connected together, for example like riders on

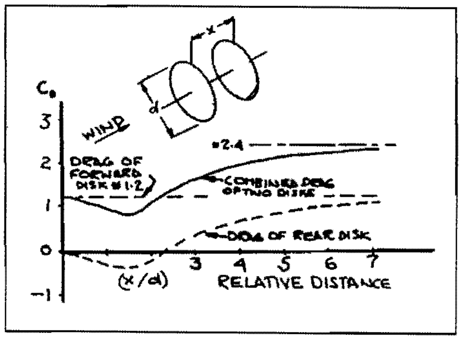

Figure 1. Interaction between two disks placed one behind the other.

the same tandem, the second would effectively perform a streamlining function for the first. If the analogy (of a 'disk' to a 'rider') held good, a tandem would need less power to propel than a single bike.

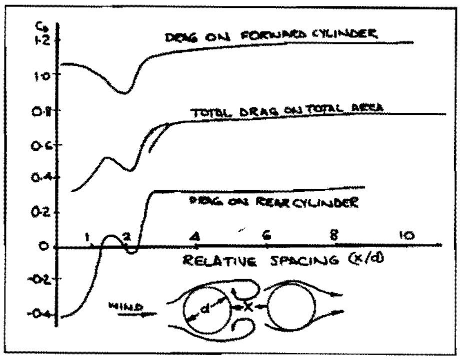

Figure 2. Drag coefficients of two circular cylinders, one placed behind the other.

Figure 2 relates to two round cylinders, roughly like one very tall runner following another. When the gap is about two diameters, the lead runner actually experiences about a 15% reduction in drag. The rear runner, in that position, experiences approximately zero drag. When the separation increases to four diameters, the lead runner loses any benefit, while the rear runner's drag is about 25% of the solo-runner value.

In figure 3, streamlined cylinders (like airplane tails or upright HPVs) are treated. When they are close, the drag on the rear

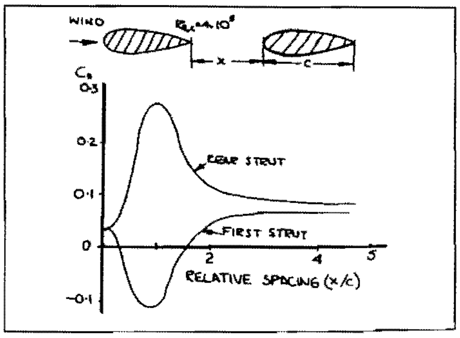

Figure 3. Drag of a pair of strut sections, one behind the other, in tandem.