GEOFFREY DYSON MEMORIAL LECTURE

QUASARS AND QUINTESSENCE

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It is my pleasure and honor to present the Dyson Lecture. I think that this is a day of reflection, a time to think about the future, where we are going and what we want to produce. I was very impressed by the comments of the President of Montana State University encouraging us to go out of the traditional way of thinking and saying "Look there's a place for Sports Biomechanics; there's a place for everything." We need to try to synthesize information from many areas because we have many things in common, no matter which area of concentration, which background, which country, what our past experiences are; everybody has something to offer. I hope that during this conference we all will, in fact, talk to everybody and feel that we can learn from the young persons in the group as well as from those of us considered to be old-timers.

My primary question is "How far have we really come from the black hole of ignorance?" Our progress has been similar to the quasar, pulsating off and on through the dark ages to the technological present, searching for the quintessential answers. All of us were born before the computers, I-C chips, and robotics, although as I scan the room, there might be a few persons who basically saw the first computer when they were two or three years old. Yet, we use these products on a daily basis. We have the ability, then, having come through the pre-computer days to tie together the past while visiting the future. It's important to realize that not all generations are able to actually apply knowledge to the past because that knowledge is really the same as the present knowledge. Those who can apply are going to be able to create new futures that will be unbelievable. Take for example, the following scenario: Lean back in your water-filled, flexible glass, recliner chair designed to fit your particular anatomy. Flick the switch that slides back the solar panels to reveal your skylight. Watch Skylab wink its way across the night sky. Your house robot appears at the side of your chair, bringing you a drink which your computer has designed. It contains the precise amount of minerals and vitamins that you need to replenish what you've used during the day. Your friend comes to visit. Unfortunately, he's a quadraplegic, but he has a walking wheelchair that, on four legs, climbs up the stairs, descends the stairs, lowers so he will be at the same level as you when the two of you talk. When another person comes into the room, he flicks a switch and the wheelchair rises to eye level of the standing person.

In the past fifty years, television networks have been created and now every home in the USA has an average of two television sets. (I was going to say two and one-half, but it's a little hard to get half a television set to work.) Private or commercial jet airplanes speed us around the world, satellites monitor weather, defense and communications. Overall the omnipotent computer keeps track of the massive data collected every moment of the day. We live in an age of creativity and excitement that surpasses even that of the Renaissance. Never before has the human race faced the challenges it faces today. Knowledge is expanding at an exponential rate. Individual passenger video monitors which give you altitude and landing factors by video intercommunication between the passenger and the pilot are now available on commercial airlines. It may be that these monitors are only on a few airplanes, and you may not see those for the next three or four years, but they are there. A few years ago, who would have believed that this would have been possible?

But what about our illuminated pulses that come and go? Where are we in sports biomechanics? What have we done with this high technology? How far have we come from the days of Geoffrey Dyson? I believe that he would have had an exciting time sorting through some of the "toys of today." After all, didn't he, with little more than the eye and photography, enhance the performance of British athletes and share his knowledge internationally? Dyson relied on his photographic eye, empirical evidence and data gathering and the synthesis of these with the laws of mechanics. But we've come a long way, or have we really? Biomechanics has had a whirlwind evolution from the use of still-photography, mechanical force measuring devices, the crude measurements of time and space, fragmented analysis of a few subjects, a few trials, and many, many weeks of analysis by hand advancing to three-dimensional, multi-transducer, highly-sophisticated instruments well known to most of you in this room.

Unfortunately, the leading thrust of this evolution exists only at elite laboratories. To what extent are the devices, the instruments of today and the high-technology actually being utilized by coaches? Have these devices emerged from within the sports, or have they emerged outside the sports? What conceptual questions have been raised that stimulate the development of new instrumentation, rather than having the instrumentation of our times determine the questions to be studied? It is as if the age of high-technology did not exist. Go to the coaches, they are still doing things by eyesight. How many of our devices can we actually take to the coach and use right then and there in competition, in practice, and in training? Compare this to the number of devices that must be utilized in the laboratory?

In other words, sports biomechanics at the practical level is truly still in a black hole: in the dark ages. Why? Will this continue to be? The basic hindrance is that coaches have always believed that the athlete is a unique person, each athlete needs to be individually coached. A coach knows that two athletes are too different and too unique for her/him to be able to apply the same information to each athlete in all situations.

It's true, though, at the less-skilled level that coaches believe there are general principles that are appropriate. We can teach those principles that are obvious and easily assimilated by coaches. Sports biomechanists are probably not needed. Historically, coaches have observed and then modified athletes' performances. The researchers have recorded and diagnosed, but not always been able to make the application. Success of the athlete was the sole goal of the coach. As biomechanists, we should think in terms of being able to see the difference biomechanical analysis makes. Let me direct your attention to three other sub-goals to success: S. E.E. The S is to investigate the movement pattern from a **S**afe point of view. Are there going to be injuries? What is the safety element? Many coaches do not have a grasp of the injury problem. Only the sports biomechanist can truly search and supply such answers. **E**ffective is the first E in that SEE acronym. Success is being effective and able to have an enhanced performance. The last E is for **E**fficiency, mechanical efficiency. Mechanical efficiency may be thought of as being synonymous with the word "optimization" which was brought to us from the computer age.

Thus, it becomes imperative that we know what the quintessential questions are. What's the important element or what I call the "pure, the perfect essence" of the element, that needs to be understood in sports biomechanics? Several examples of how we derived some of the answers and developed concepts in the past will be cited, but these only represent a portion of the history in this area. Each valuable portion could be transferred to all topics at this 6th International Biomechanics of Sports Symposium.

The first historical summary to be presented is in aquatics. We've made great gains due to the fact that John Councilman, a past Olympic coach in the United States scientifically sought to answer the quintessential questions. He was one of the first to investigate light traces of swimmers and identify why swimmers had such peculiar hand propulsion patterns. He evolved a basic concept that has been the foundation for biomechanical theory: "lift forces are as important, if not more important, than drag forces in swimming." None of this could have been substantiated without actually gathering quantitative data. Merely using the eye as coaches were doing would have been inadequate. Filming is tedious, however, and thus forces were measured during swimming by attaching small force transducers to the hand. Unfortunately, such highly sophisticated techniques are tools, that at the present time are used only in research laboratories. Why doesn't every swimmer have a transducer glove? The swimmer would put the glove on the hand, go into the swimming pool and swim, while force data would automatically be transferred to the computer. You could then see if there was any slippage, that is, any loss of force production during a given part of the phase and based on fact, be able to demonstrate what has happened. The underwater phase of swimming is very difficult to observe by the coach! We can rely on electrogoniometry and electromyography. Combined with photography, we can look, for example, at what happens kinematically in the kick — the angle at the knee, the ankle and the hip, and combine this with EMG output of the gastronemius muscle during sprint kicking, then compare the sense output to pace swimming.

Another new concept that has been verified in many areas is that the effects of speed and load are not predictable. If a person performs the same action but swims a little faster, or a little slower, the same muscles won't necessarily contract in the same way because of the movement pattern changes, and the muscle function changes. Some of the early work by Nemessuri from Hungary in the 50's was indicative of the fact that we needed to look at the "muscle person." It has been said that EMG is too difficult; how will we ever get that into the field situation or the training situation? There's a need for us to solve the problem. How can we get telemetry EMG transducers on the body in order to watch the muscles perform? Why isn't there a common package in the coaches' kit, so to speak, for analyzing movement patterns? The cost isn't really prohibitive, it's just that biomechanists really don't have the influence to get today's high-technology onto the playing fields or into the gymnasium.

Hay, Shetty and Adrian, Brown, and others have investigated forces during weightlifting. The premise was that if you lift a weight, the moment of force acting at the knee or at the hip joint can be predicted, and if you lift a greater weight, the moment of force will be greater. The moment arms, however, change with respect to adjustments made in response to the weight. The horizontal distance between the vertical line of weight and the vertical line of weight from the knee can be much shorter while the resistance is much higher. We cannot show that as you increase the load you necessarily are going to increase the stress at the joints. The individual may increase the stress at one joint and decrease it at another.

The next area is efficiency - mechanical efficiency. All of you who live in a cold climate and must shovel snow must consider how often you shovel efficiently? Do you want to get it over? You probably shovel much more stressfully than necessary. It's not optimum movement efficiency. In our youth, we quite often do things non-optimally and we get by and no harm is done. However, as we work with athletes who are repeatedly performing a movement over and over, week in and week out, it is very important to identify what it is that's happening to an individual. It's very important to look at individual performance and construct a model to determine what body parts are being stressed more frequently in a given individual. We must not look only at group data. This is probably one area in which sports biomechanists can produce the greatest contributions: that of technique and injury. How can you be sure that a technique that is being taught is not potentially harmful? What contribution can the biomechanist have with respect to conditioning and technique?

In talking to some persons, it was said, "Let's look at strength and conditioning with respect to the person from a biomechanics point of view." We must not think merely of the physiology of strength and conditioning and/or from a general fitness approach. Let's evaluate the technique, know what the stresses are, know which muscles are producing what kind of forces. Let's scientifically diagnose and then develop a strength conditioning program that will actually reduce the risk of injury. We can then increase the potential for achieving the technique as quickly as possible, and thus enhance the performance.

I'd like to now analyze the status and trends of a few sports. Each of you could take your own sport and ask "What is happening in that sport today that is different, and how will that affect the game?" If you've been watching some of the Wimbledon games in tennis, you have noticed that they now have electric line judges. How can this same technology be used to assess your athletes, or how can you change your sport? One new development in fencing is the electric saber. In the world of fencing, there are three weapons: the epee, the foil, and the saber. The epee and foil have been electric weapons for several decades. For the first time in the United States, the women's Saber Competition at the USFA National Championships were introduced to electric saber (the top four fencers fenced electrically). A full metallic jacket was worn, with a guantlet on the hand, and a clip of wire from the jacket was connected to the mask. There was an accelerometer in the saber. When you hit the opponent, the accelerometer is activated and the light flashes to signal that a touch has been scored. Only if you hit the metallic jacket would the light be activated. If you hit the leg of the opponent, nothing would happen. This changes the sport dramatically. What does that mean then for those people who are working in the biomechanics area? What new techniques, what new types of movement, what kinds of decision-making strategies and timing skills would be important?

Changes that are taking place in equipment become important for the biomechanist. What changes have been made, and what is being proposed? Biomechanists can identify changes and try to perform research on this new equipment as changes are taking place or before the changes take place.

An example is the 11" softball. The reduction in size from 12" has made a drastic difference in the girls' and women's softball games with reference to being able to hold the ball in one hand: throw it, pitch it, and do various kinds of things that were not possible by some of those girls and women previously.

Similarly, there have been many changes taking place in bats. Noble has done some research on the design of bats and House has conducted a review of the biomechanics of bats. I'd like to use some of House's information to enhance your awareness of some of the bats that are on the market. The Broadsider is a three-sided bat. Have you seen anything other than a cylindrical bat in your lifetime? The Broadsider is a bat that has three sides and is built like a triangle. The Bomb bat is a bat with pressurized air inside the bat, supposedly enhancing the hitter's power in order to propel a softball farther. The Tidal Wave II contains water so that when you swing the water moves toward the end of the bat. In the ready position, the water is concentrated at the handle, easy to hold due to a small radius of gyration. The swing would then cause the water to move to the end of the bat due to centrifugal force and will give a concentration of mass at the spot at which you want the bat to hit the ball. The Wizz bat has many numerous holes in the barrel to try to reduce the aerodynamic drag on it.

What do you know about the new bats, or in your particular sport, the new equipment that is out there? Is it being sold as a gimmick? Are people purporting that certain things are happening and they really aren't true? Should research be done on these devices? And should we also try to develop data bases of research?

Another first is the programmable running track. The computer automatically will tilt the floor and change the banking of the track. This track exists at Indianapolis at the TAC Center. On any particular day, you can have a different track and different set of conditions. Thus, biomechanists will have a controlled laboratory. If you want to test what happens to runners at a 5-, 10-, 20-, or 30-degree angle, you just keep changing the position of the track, collecting data and seeing what happens.

In what other ways can we utilize our computer technology: programmable swimming pools, surf, white water, bob sled runs? We could evaluate what has taken place with the athletes in real life and compare mathematical models and simulations of real life with performances in a computerized reprogrammed environment. It's amazing how often when you model on a computer you find that the human being doesn't really adapt, modify and change the same way the computer predicts. This is because we have an inanimate object put into the computer as a series of rigid body links with different lengths and different degrees of freedom. It is vital that we integrate the biology and the humanness of the performer with the mechanical, electronic technology of instrumentation. We must put artificial intelligence into our computer modeling.

We must use our own creativity as we study what exists in our world — outside sports biomechanics. In the USA, we have many magazines that are new that present ingenious ideas that are being used in industry and used in various areas outside sports. SOMA is one such magazine. We can capitalize on the opportunity of what's happening elsewhere, for example, imaging to improve sports performance. Images on the computers look like multi-colored photographs. You can't see a pixle in the picture. There are inexpensive systems costing less than $20,000 in which you can get 1,000 colors. You can get a million colors with the very expensive, sophisticated equipment. Any color can be duplicated in the art world and in architecture. You can design and make anything you would like to design. Speaking of looking at internal mechanisms of the body, imaging is a fantastic way to show function. We must look outside sports biomechanics to solve our problems. In particular, I'd say if you have not seen the July 1988 issue of Omni magazine, read it. I think it's well worth reading about the exciting things that you might be able to utilize in the sports biomechanics world.

Above all, we must share international knowledge. Think of all the magazines in sports biomechanics written in all the languages of the world. We need to bring all these ideas together in order to be more productive and share and collaborate as we work in this area.

I would like to use four particular examples, then, of things that are taking place in the United States that I feel are directions for sports biomechanics. The first involves a wheelchair research project, a fairly localized sort of collaboration, but one which is typically biomechanical. We have researchers from Northern Iowa, the University of Texas at Arlington, and the University of Illinois at Urbana-Champaign who are working on a group of approximately seven different analysis projects with sports performances. The group will work with anyone else who is interested. Some persons here from Georgia, persons from Arizona and Texas have indicated that they would like to do so. We want to avoid fragmentation and duplication. We came together and said, "what are you doing, what are we doing, how can we complement, how can we better understand wheelchair athletes?"

In this research, the high-speed shutter camera becomes very important. You can look at views simultaneously and you can stop the action and get no blurs from the picture. For example, the high-speed videocamera can capture a picture of javelin throwing with no blur whatsoever. Sequence videoprints from the use of such a camera were used to measure the angle of attack of the javelin, release characteristics, and range of motion of the body parts.

Wheelchair racing is a popular area of investigation in sports biomechanics. Among the parameters analyzed, we point-plot patterns and line segment graphics of the arm as it goes through one stroke cycle. We can compare the symmetry of right and left arms of individual racers during distance racing, the first stroke of acceleration, the second stroke, etc. Each athlete appears to have a unique arm "signature." which is the best pattern? Which is the ideal pattern? Does it depend on the individual; do they have an inappropriate wheelchair? Are they positioned improperly to the handrim with respect to the wheelchair, or is the handrim too large or too small? We look at three items: 1) the performer's anatomy; 2) the performer's equipment; and 3) the task.

Combining physiological and biomechanical sports research provides a more comprehensive approach to improving sports performance. Following a 30-second anaerobic wheelchair test to develop anaerobic power, point plots of the shoulder, elbow and hand (with respect to the handrim) were obtained to show what happened during the first ten seconds of the test compared to the last ten seconds. The following adjustments were made by the subjects as fatigue occurred: the shoulders traveled in a more vertical path, the hand had a greater loop in its pattern, and thus slightly more wasted energy. We can also look at the tempo conditions.

It's important, however, to investigate wheelchair sports beyond track and field. Many researchers are investigating athletics. It seems to be one of the easiest to do and the sport that is most visible. There is a dearth of information on weightlifting for the wheelchair athletes and physically handicapped athletes, e.g. wheelchair basketball, wheelchair archery, wheelchair table tennis, etc. Sports biomechanists need to capitalize on the research with able-bodied athletes, and forge ahead in seeking new knowledge relevant to wheelchair sports.

A second area is gymnastics. The Sports Biomechanics Committee of the United States Gymnastics Federation welcomes any interested persons. The focus of this committee is to build a biomechanics network in which we actually do have the ability of having nationwide research centers performing concurrent analyses. We've had approximately six or seven studies on landing forces, and I think that after the next two we should be able to write a very definitive paper on "everything you want to know about the stress and strains the human body experiences when gymnasts land." For example, Danny Too has worked on a project in which he found that the ground reaction forces were greater with persons who showed excess lumbar curvature in the lower back than those who landed without as much curvature in the back. The coach can use the video camera, or using only the eyes, can look at lumbar curvature. If the gymnast, young or old, has an excess curvature, then changes in some of the training devices, landing mats, the number of times the person is performing, the technique and strength of the body are warranted.

Biomechanists are working, too, with new stunts. The important thing in gymnastics is not to study the old stunts, but to look at what is being proposed. Just recently, as a result of the death of an athlete in recent competition overseas, one of the new stunts will be outlawed in USA competition. More research is needed immediately on new stunts. We have a male gymnast at the University of Illinois who can do a triple somersault from the landing mat and we're looking at what makes it possible to perform a triple somersault. When do you allow a person to actually attempt the triple somersault? Comparisons are being made among his triple, double, and single somersault performances. The plan is to develop a data base in order to identify some of the components of the gymnasts and their performances that are successful or unsuccessful.

The area of fencing in conjunction with the United States Fencing Association is being studied in a similar way to that of gymnastics. A national test battery and performance profile are being developed. The first tests were conducted in the spring and we will do some more testing this month at the National Junior Training Camps to try to identify some of the components necessary in order to become an elite champion in fencing. We will investigate when to perform a particular move, how to perform it, what is required for endurance, anaerobic capacity, etc.

We know, however, that as we develop the database, we will probably not be able to predict successfully who the expert is by just comparing what the characteristics are of the expert and the non-experts. Because any number of performers in many different combinations may create the same end result, the person who is elite may score high in factors one, two, and five; another person could score high in factors eight, nine and three, and produce the same end result. If we can, however, identify the near-elite fencers that are less successful, we at least can identify those factors that are missing, for which the near-elite athlete must compensate. In other words, you can be a champion while still having a weakness, if nobody discovers what that weakness is. That's how, I think, in the past, researchers erred. They said, "we're going to predict everything" and they found that it wasn't possible. I think we're coming back again (with the use of the computer and high technology instrumentation) to the point that we can possibly perform valid predictions. We, however, need to have a more realistic viewpoint and measure more variables. Then we may be able to list the factors and scores that probably are most important. If we can identify certain minimums, we will have been successful. It's important to attain this in fencing in the United States because the United States has never been a powerful figure in fencing.

Research has been an integral part of the USFA sports medicine committee. This is not unique to fencing. Sports biomechanics committee members team up with sports medicine committee members of national sports governing bodies to try to research not only the performance itself, but the prevention of injuries, the shoes, the playing surfaces, etc.

There are some instances in which, as with dancers, fencers perform on a carpet or a metal strip placed on a concrete floor. Performing on concrete floors shouldn't happen in this day and age of high-technology; that defies everything that sports biomechanists understand and know. Biomechanists need more ability to cause change in sport environments.

The next example is probably unique to our country. The National Association for Girls and Women in Sports has a Research Network Committee. One of their first projects was to publish a series of Applied Research Papers to be distributed at four national coaching institutes so that coaches themselves would benefit. This was not just sports biomechanics, it was all of sports sciences, including sports psychologists, sociologists, physiologists, and biomechanists.

In the United States it is now time to emphasize sports for girls and women. We haven't investigated, to any extent, the human female participant in the sports world, and therefore more and more information needs to be collected. For example, in the sport of lacrosse, there is youth lacrosse, women's lacrosse, and men's lacrosse. There is a vast difference in the protective equipment used by these three groups. Are the games of lacrosse so different? Are the requirements and the rules so different? We haven't even begun to study what needs to be known about female performers, about youth and about male performers. We must develop a large body of information on women athletes.

Profiling is important to consider. It is important to say whom are we comparing. Do we want to compare the ten-year old athlete with the elite athlete at the Olympic Games, or should we compare one ten year old person with another ten-year old or with 16-year olds? For example, when we looked at girl basketball players, the ten-, eleven-, and twelve-year olds had a drastic difference between dribbling the ball with the right hand and dribbling the ball with the left hand on a 30-second test. However, by the time these girls were 14- and 15-years old, dribbling was equal with the right and the left hand. Thus, if by the age of 15 or 16 you don't have any right and left hand dominance in dribbling a basketball, you don't need to consider it as a predictor of later success. Maybe we can identify two trends within ages and within skill levels. We may be able to say that at some level these are things of importance and this is what we need to attain and realistically what might be possible at given ages.

So how do we do this? I feel we need to break with tradition and look at some non-traditional or new trends that are occurring in biomechanics today. We need to be aware that biomechanics can lead to a different way of looking at things. What I call control biomechanics is a synthesis of what is the traditional biomechanics: time, space, force of human movement and the effects of force on the human body and neuromuscular physiology. The end product is a more complete understanding of how optimal movement and force produce and control movement. However, at this time, the control biomechanists really have not done anything with trauma and safety aspects in biomechanics. They have looked only at trying to say how we can optimize the movement. Experimental data are collected most often with respect to movement adaptation using imposed conditions and constraints that sometimes resemble the real world and sometimes do not. I see this as an area in which the neurophysiological area and biomechanical area may combine and make a contribution to sports biomechanics.

Ecological biomechanics comes from Turvey and Kugler. It is an energy approach to the analysis of goal-directed human movement. If you remember, we looked first at time, space and force. We measured speed, acceleration, velocity, and then we began to look at force production, impulse and momentum. Biomechanists still have not looked at energy to any extent. Even some of the energy work in gait analysis has been limited. We're using systems in which we have to transfer three-dimensional film to obtain energy data. Thus, error is higher than with other types of data. Examining energy is important, but the concept in ecological biomechanics is the combining of psychology, physics and biology with the geometry of the movement pattern itself.

The movement approach of Kugler and Turvey lies midway between the highest boundary underlying the theory of relativity and that of quasars. We know that some of the energy is not conserved; it's non-linear, non-analytically continuous, non-polynomic. Therefore, human beings choose to direct and re-direct their movements according to their goals, and thus, we need to look at movement from a non-conservation frame of reference. The person may change the goal in producing a pattern, and thus cause a pattern difference.

The last area, synergistic biomechanics, was introduced by Garrett several years ago. I believe this really grew from the work that was originally produced at Purdue University by Carol Widule and her colleagues. We need to progress from what we learned originally with modeling and say "let's look at it from a more creative approach"; synergistic biomechanics is a synthesis of art and science. It implies that the rational and metaphoric, the qualitative and quantitative, the humanist and reductionist are brought together, and only then can we get a complete understanding of movement. It is an emergent entity that's greater than the sum of the parts. It is combining the knowing, the feeling and the imaging of the right half of the cortex with the analytical and verbal knowing of the left half of the cortex.

As we look at movement, it is something other than a static, analytical mechanistic situation. It becomes something that we can sense and feel. We can reach through and into the sport, the performer, the equipment and environment. So I say again that we must reach out for the quasars and achieve the quintessence of sports biomechanics.

Excerpts have been used from the book, Biomechanics of Human Movement by Adrian and Cooper, Benchmark Press, Indianapolis, 1988.