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A Supercomputer Reveals the True Nature of the 'Disappearing Magic Ball'

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One of the most exciting aspects of baseball is the interaction between the pitcher and the batter. The main players in this interaction are the various breaking pitches that pitchers have developed, but the reasons why their trajectories change are not well understood. In particular, there is a theory as to why the forkball falls so sharply, but it has never been properly demonstrated. A joint research team of the Tokyo Institute of Technology, Kyushu University, and Keio University, led by Dr. Aoki, took on the challenge of elucidating the "fall mechanism" by using a supercomputer and thus discovered a previously unknown mechanism.

Does Forkball Fall Due to the Action of Gravity?

The first person to throw a forkball in Japan was Chunichi Dragons pitcher Shigeru Sugishita, some 70 years ago and it took the world by storm. It was called the “disappearing magic ball” because of its large drop and the fact that it seemed to disappear from the batter’s view. Since then, many famous pitchers have used the forkball as a trump card when facing batters. “For many years, it has been said that gravity is the reason that the forkball falls so rapidly. However, I have always believed that there must be other factors besides gravity,” Dr. Aoki recalls. In April 2020, the research team led by Dr. Aoki (Photo 1) began studying forkballs using hydrodynamic simulations.

Photo 1 :
The research team that has been working to elucidate the breaking balls

Back row, from left: Dr. Seiya Watanabe (Assistant Professor, Research Institute for Applied Mechanics, Kyushu University), Dr. Hiromichi Kobayashi (Professor, Faculty of Law, Keio University), Yuwei Yin (2nd-year master’s student, Tokyo Institute of Technology). In the front row is Dr. Aoki. In the lower right circle is Ryoga Ohashi, who completed his master’s degree at Tokyo Institute of Technology in 2021.

Normally, a thrown ball follows gravity and falls in a parabolic curve, but a fastball thrown by a pitcher flies in a straight line. This is due to the “Magnus effect” working on the ball. When a pitcher throws a fastball, he applies a strong backspin to the ball. Backspin means that the upper side of the ball rotates in the opposite direction of the direction the ball is going.

The air around a flying ball has a layer that flows along the ball, so-called boundary layer, but when it separates from the surface of the ball, in the process it creates turbulence behind the ball. As shown in Fig. 1, in the case of a ball with backspin, the airflow above the ball is dragged by the rotation of the ball, and the point where the layer flowing along the ball separates is shifted backward. Conversely, on the underside of the ball, the rotation of the ball and the surrounding flow oppose each other, causing the separation point to shift forward. As a result, the airflow behind the ball is biased downward. This adds an upward force to the ball, weakening the downward force generated by gravity. This phenomenon of a force (lift force) perpendicular to the direction of motion acting on a rotating object is called the “Magnus effect.” This effect increases with the number of rotations of the object. In other words, a ball with a strong backspin will be lifted by the Magnus effect, resulting in a fastball.

On the other hand, in the case of a forkball, the pitcher throws the ball with as little rotation as possible. This reduces the Magnus effect and makes the ball more susceptible to gravity, so it has been thought that the ball falls rapidly before reaching the bat.

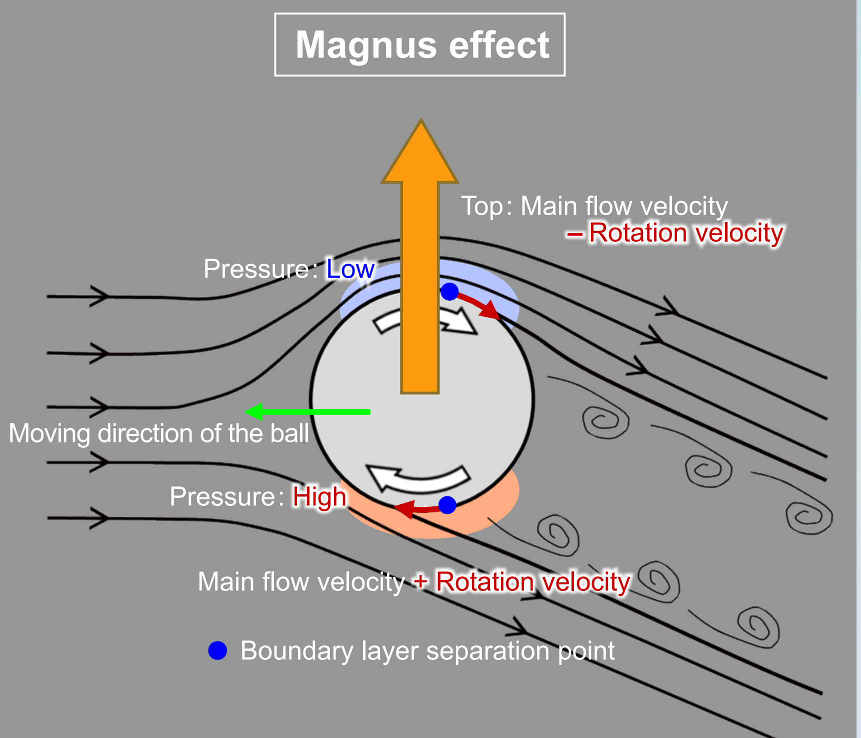


Fig. 1 :
Magnus effect working on a ball with backspin
A side view of a ball moving from right to left. The Magnus effect reduces the downward force generated by gravity.

Flow Simulation around a Ball with Seams

Dr. Aoki, who has been questioning the commonly accepted forkball theory, focused his attention on the seams of the ball. The surface of a baseball has a seam only 0.9 mm high. It has long been known that these seams affect the airflow. However, it was not well understood how it affected the ball. As the ball rotates at high speed, the position of the seam changes from moment to moment. It was impossible to evaluate the impact of the stitches on the ball without the help of advanced computational technology and high-performance supercomputers.

In recent years, however, the performance of supercomputers has improved dramatically. Furthermore, Dr. Aoki and his team have developed methods to perform state-of-the-art fluid calculations utilizing the capabilities of such supercomputers, which allowed them to achieve their results. At the same time, the development of accurate sport measurement devices has made it possible to measure detailed data about a pitcher's ball, such as its velocity, rotation speed, and trajectory drop. Recently, the Major League Baseball has begun publishing these measurements, which has made it possible to compare and verify the results of supercomputer simulations with actual data.

In fact, it was found that the direction of the ball's seam differs between a fastball and a forkball. When looking at a fastball from the batter's side, the seam appears four times per rotation of the ball, while on a forkball, the seam appears only twice (Fig. 2). For this reason, the rotation of the fastball is called "four-seam rotation," while the rotation of the forkball is called "two-seam rotation."

Dr. Aoki and his team used the TSUBAME3.0 GPU supercomputer at the Tokyo Institute of Technology to determine the difference in the way the ball falls between four-seam and two-seam rotations. For the numerical calculations, they used the cumulant lattice Boltzmann method, which is optimal for performing turbulence calculations. They set the same values for ball velocity and rotation number for four-seam

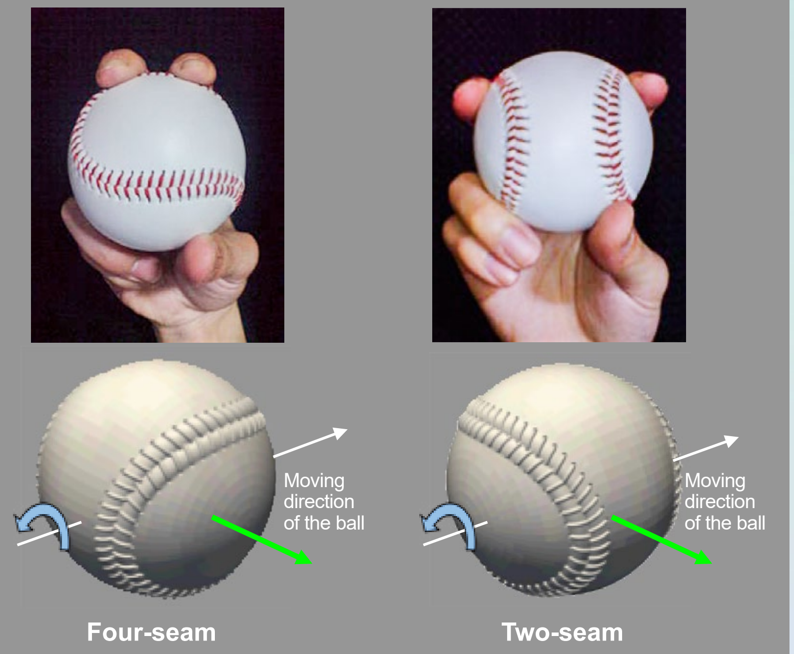


Fig. 2 : Four-seam rotation and two-seam rotation

and two-seam rotations. The space around the ball was then divided into approximately 370 million grids to simulate how the airflow was generated and how this flow affected the ball.

The simulation code was developed mainly by Dr. Seiya Watanabe, a graduate of Dr. Aoki's laboratory who is now an Assistant Professor at Kyushu University. "In the beginning, the calculation time needed to complete the process of a pitcher throwing a ball to a catcher was estimated at 200 days, even using TSUBAME3.0. We succeeded in reducing the time to about one week by improving the efficiency of parallel distributed processing and reducing the number of unnecessary grids," said Dr. Watanabe, looking back on the development efforts.

Discovery of the "Negative Magnus Effect"

The main results obtained from the simulation are as follows.

First, in the case of a four-seam rotation it was found that the point where the boundary layer separates from the surface of the ball shifted backward each time the seam came up, and conversely, on the underside of the ball, the point where the boundary layer separates was pulled forward by the appearance of the seam. Lift forces were also always positive. In other words, it was confirmed that the seam enhances the Magnus effect described above.

Second, in the case of a two-seam rotation (Fig. 3), when the seam was at the top, it was confirmed that on the upper side, as in the four-seam case, the boundary layer was less likely to detach and a downward flow behind the ball was generated. However, when the smooth part of the ball with no seam was on the pitcher side of the ball, the airflow behind the ball changed to an upward direction. Then, when the ball rotates and the seam was on top again, the flow changed downward again. When the airflow behind the ball turns upward, the ball is considered to be subjected to a force in the opposite direction of the lift force.

Mr. Ryoga Ohashi, then a second-year master's student in Dr. Aoki's laboratory, and Dr. Hiromichi Kobayashi, Professor at Keio University specializing in turbulence analysis, worked with colleagues in Dr. Aoki's laboratory to analyze in detail a large number of images obtained through simulations. As a result, they found that the lift force was always positive in the four-seam rotation, whereas in the two-seam rotation, the lift force

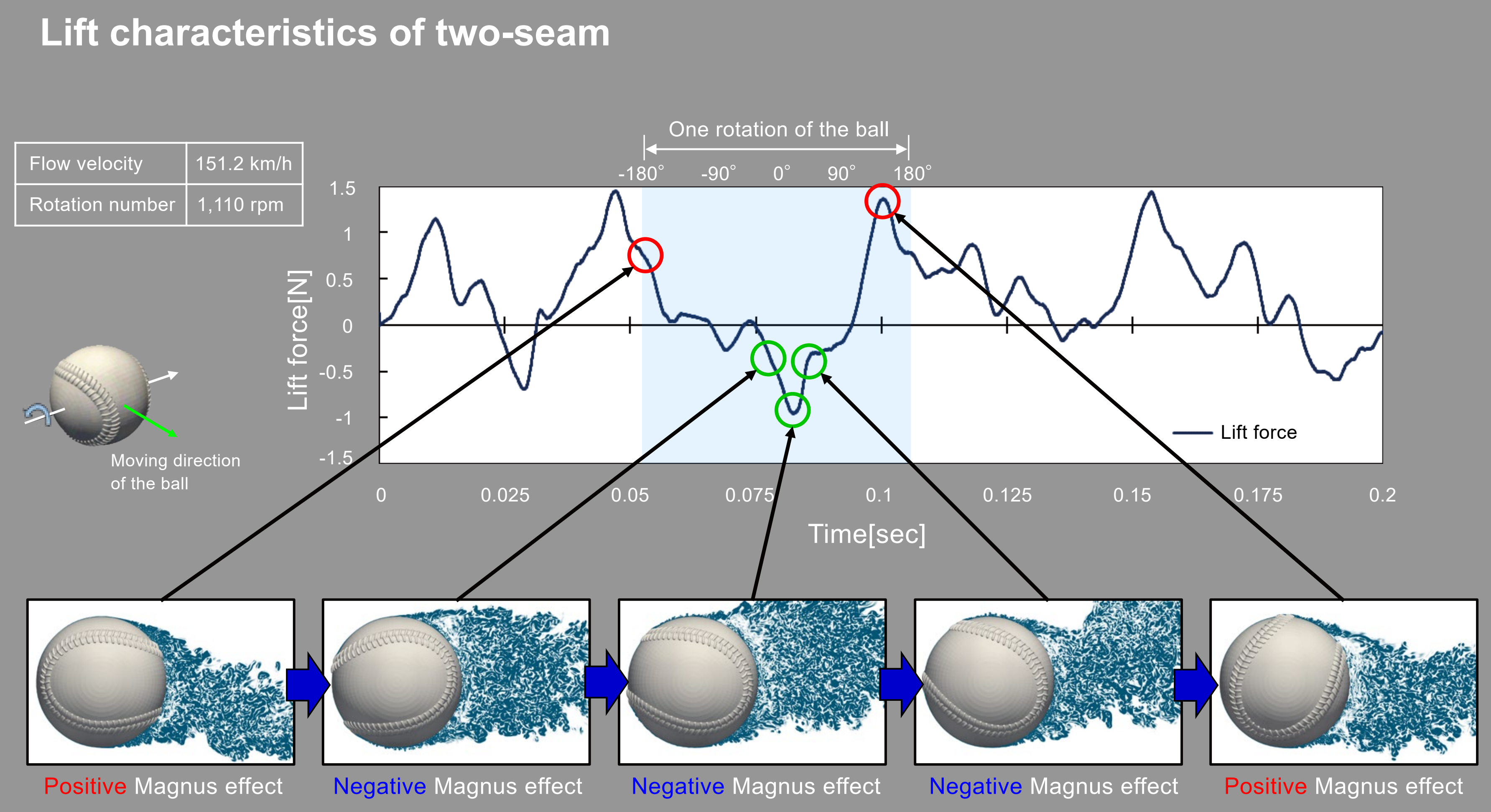


Fig. 3 : Analysis of two-seam turbulence
When the smooth part of the ball is on the pitcher side, a "negative Magnus effect" occurs, in which the lift force is negative, working to make the ball fall.

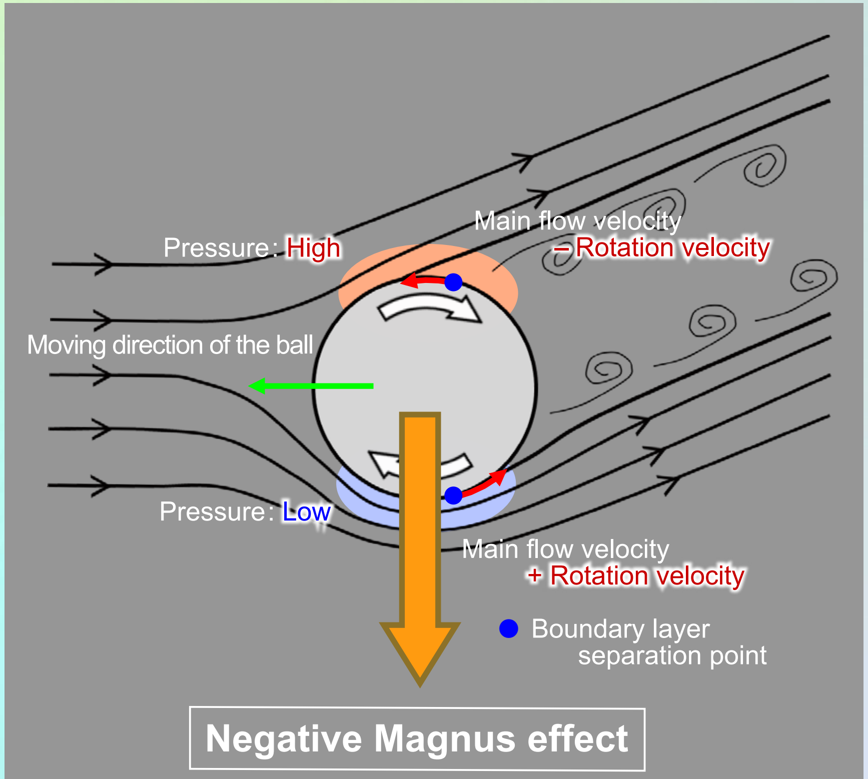


Fig. 4 : Negative Magnus effect

was negative at moments, as shown in Fig. 3. They found that when the stitch angle of a two-seam ball is in the range of -30 to 90 degrees, the force is in the opposite direction of the lift force.

It is known that on a slippery (no seam) ball, turbulence in the layers flowing along the surface causes a "negative Magnus effect" in the opposite direction of the "positive Magnus effect" that acts as a lift force (Fig. 4). Dr. Aoki recalled, "Mr. Ohashi pointed out that the negative Magnus effect might also occur on the slippery surface in two-seam rotation." As a result of the calculations and analysis, it was found that the forkball with two-seam rotation falls sharply not only due to gravity but also due to the negative Magnus effect. Furthermore, when the velocity and rotation number of the ball were set to the same value, the two-seam forkball fell about 19 cm lower on the home base than the four-seam forkball.

"This result shows how much the stitching affects the ball. This was the first time in the world that a negative Magnus effect was shown to occur on a baseball, and it was the moment when my long-held question was answered. This was also made possible by the fact that the supercomputer was able to capture the air changes around a ball with seams from moment to moment," Dr. Aoki explained.

The Mystery of Ohtani's Forkball Unraveled, Too

Next, Dr. Aoki and his team took on the mystery of the forkball thrown by Shohei Ohtani of the Los Angeles Angels and Roki Sasaki of the Chiba Lotte Marines, who achieved a perfect game in 2022. This was because the forkball they threw was said to have a sharper drop, even though it was spinning faster.

Dr. Aoki explained, "As the speed of the ball increases, the number of rotations of the ball increases. As the number of rotations increases, the frequency of the appearance of the seam increases, and the positive Magnus effect increases, so the ball's fall should decrease. However, it falls more sharply. I speculated that this was due to gyro-rotation rather than backspin." Gyro-rotation is a rotation in which the moving direction and the axis of rotation coincide (Fig. 5). Unlike backspin, when the ball makes one rotation, the forces received from the top, bottom, left, and right are canceled, so the Magnus effect does not occur.

“However, in the case of gyro-rotation, the airflow around the ball is more complex than in backspin, so the space around the ball must be divided into smaller grids and analyzed in several different patterns, including ball speed, number of rotations, and direction of the axis of rotation,” said Dr. Aoki. Therefore, Mr. Yuwei Yin, a graduate student in the Aoki Lab, conducted the simulation using Nagoya University’s “Flow” Type II subsystem (CX2570), a GPU supercomputer. In addition, Dr. Watanabe rewrote the code for CPUs and conducted detailed simulations on the supercomputer Fugaku. In this research, Mr. Yin played a major role by creating shape data from a 3D scan of an official MLB ball and analyzing turbulence together with Dr. Kobayashi.

The simulation results confirm that when the ball makes one rotation, the forces due to the airflow are canceled out in the vertical and horizontal directions, and only gravity remains. It is now clear that a forkball due to backspin receives lift forces, albeit with a negative Magnus effect, whereas a gyro-rotating forkball falls sharply because only gravity is at work.

Furthermore, Dr. Aoki and his team are gaining new knowledge by trying to elucidate Ohtani’s sweeper, a pitch that makes a big curve across the home base.

Thus, Dr. Aoki’s research team’s simulations have revealed that baseball breaking pitches are produced by the ball’s velocity, number of rotations, angle of the axis of rotation, and the effect of the ball’s seams. “In the future, I would be happy if we could combine the results of this research with virtual reality (VR) and augmented reality (AR) to create a device that would allow anyone to experience Ohtani’s magic ball. We may even see the emergence of a second or third Ohtani among the children who have practiced with such a device,” said Dr. Aoki with a smile.

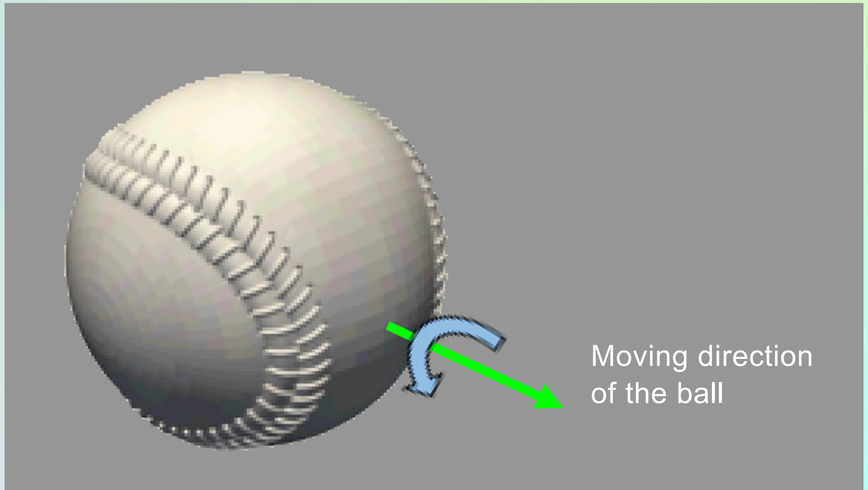
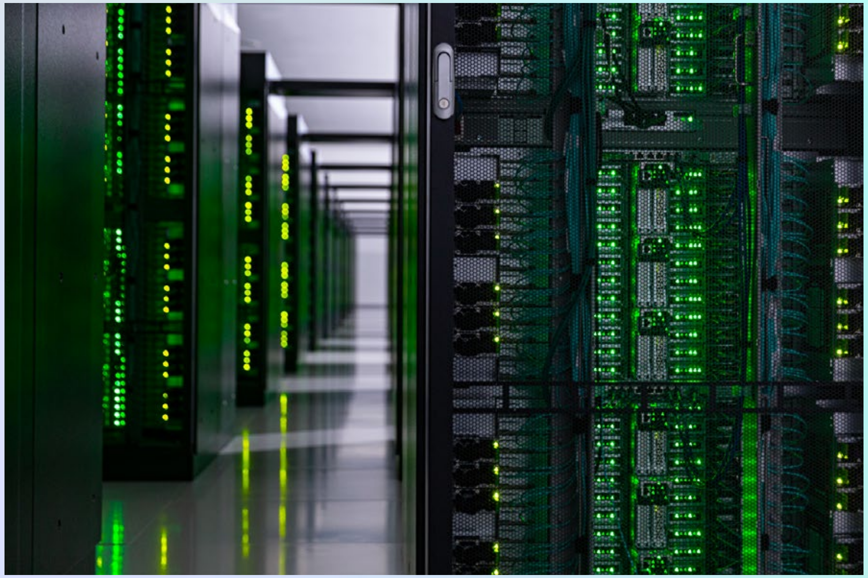


Fig. 5 : Gyroball rotation



About the
Researcher

Dr. Aoki specializes in fluid dynamics. As an undergraduate, he studied in the Department of Applied Physics, where he began researching the dream energy, nuclear fusion, in his graduation project. In graduate school, he went on to the Department of Energy Science, where he began conducting research using theory and simulation. It was during this time that the Tokyo Institute of Technology developed the world's first GPU supercomputer, TSUBAME. Dr. Aoki started hydrodynamic simulations using TSUBAME and received the Gordon Bell Prize Special Achievements for his numerical simulation of dendritic solidification of metallic crystals using TSUBAME2.0 in 2011. He is currently working on a wide range of topics from dolphin swimming to torrential rain disasters and tsunamis containing large amounts of debris and driftwood. Why did Dr. Aoki choose the theme of "breaking ball" for this project? "I thought that if I could do numerical calculations for complex torrential rain disasters, I would also be able to do so for breaking balls," he said. Working on this theme has changed the way he watches baseball games, which used to be a hobby of his. "I started to think, 'They should put in more slow motion so you can see the stitching on the ball'," he said. He hopes to continue to enjoy watching baseball games in between research projects.

Associated Research Projects:
Aerodynamics of Rotating High-speed Baseball (hp200070)
Aerodynamics of Gyro-rotating Baseball (hp220063)
Principal Investigator: Takayuki Aoki, International Research and Information Center, Tokyo Institute of Technology

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