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An Analysis of Computational Fluid Dynamics in Sports Performance of Professional Sport

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ABSTRACT

The application of Computational Fluid Dynamics in professional sports performance is groundbreaking. This not only optimizes the design of sports equipment but also provides valuable insights into biomechanics, aerodynamics and environmental conditions to athletes, coaches and teams contributing to improved performance which ultimately increases their competitive advantage and performance levels. This research was carried out to conduct research analysis regarding CFD in sports performance of professional sports from research that has been carried out. In addition, this research provides comprehensive insight into the field of sports science that uses dynamic computing approaches to improve performance. Bibliometric analysis and theoretical analysis are used as research methods. This research also consists of five steps, namely (i) determining the research theme; (ii) collection of publication data; (iii) bibliometric data processing, (iv) bibliometric mapping analysis and (v) preparation of research results reports. The keywords used in this research are ("Computational Fluid Dynamics", "CFD" and "Sports Performance"). Based on the search results, 12 documents were obtained from 2003 to 2023. The trend of research publications on this theme which were first published in International Journals was carried out in 2013. The highest number of publications occurred in 2018, 2021 and 2022 with a total of 2 journal publications. Based on the results of the study, it is known that the CFD method is used to train, improve performance and find out sports patterns or techniques in the field of swimming. This research was conducted with the hope that it can become a reference for future researchers in developing sports performance using the CFD method approach.

1. Introduction

Sports performance is an interdisciplinary field of science that includes many subdisciplines of sports science [1]. A person who focuses on a particular practice or focus related to the subdiscipline is known as a professional in terms of sports performance. Progress in professional sports is the result of the synergy of various parties, in this case, science and scientific methodology are used by all elements such as sports practitioners, academics in universities and the corporate sector to improve the performance and achievements of athletes. Most competitive teams and programs employ

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several professionals to improve sports performance. These sports performance professionals work closely with coaches and teams to prepare athletes to perform their best and succeed in competition. Strength and conditioning coaches, sports dietitians and nutritionists, athletic trainers, physical therapists, sports medicine and specialist physicians, biomechanists, sports scientists and sports psychologists are all specialists who fall into this category. Sports performance is very important in professional sports. Performance is not only about individual skills, other aspects shape sports performance so that it can be optimal. Sports performance is the ability to perform under pressure, contribute to team success and meet the high demands of fans, sponsors and sport's governing bodies. Sports performance can directly impact an athlete's career, team success and the sports industry as a whole.

Currently, there has been a lot of research on sports performance in professional sports, including research on sustaining cultural change in professional sports performance teams [2], motor image and sports performance [3], the influence of oral health on elite sports performance [4], the application of information technology to sports performance [5] and others. Based on several studies regarding sports performance, it can be concluded that supporting or improving sports performance in professional sports can be done using various methods. The methods used are not only limited to conventional tools, the use of technology plays a very important role in sports performance [5]. One technology that can be used to support sports performance is Computational Fluid Dynamics (CFD) technology.

CFD is a popular technology today, CFD is a technology used to test product designs through computer simulations of fluid flow around the product [6]. CFD is used in the automotive, aerospace, construction and other product industries to test product designs before production [7]. CFD analysis of professional sports performance reveals the significant impact of technology on various aspects of athlete performance. CFD is a branch of fluid mechanics that uses numerical analysis and algorithms to solve and analyse fluid flow problems. In sports, CFD has revolutionized how athletes and teams approach training, equipment design and performance optimization. The application of Computational Fluid Dynamics in professional sports performance is groundbreaking. This not only optimizes sports equipment design but also provides athletes and teams with valuable insights into biomechanics, aerodynamics and environmental conditions, ultimately increasing their competitive advantage and performance levels. As technology advances, the integration of CFD in sports is expected to become more common and significantly improve athlete performance.

Currently, several studies examine CFDs in sports performance. Based on the results of the search we conducted, research that discusses CFD in sports performance is the use of CFD methods to present sports performance in rowing [8], computational fluid dynamics for Nordic combined ski jumping [9], research on 3D CFD on glide swimmers in passive hydrodynamic drag [10], CFD analysis of the influence of differences in male and female body types on swimming [11] and estimation of cycling aerodynamic performance using anthropometric measurements via CFD approach [12]. Search results regarding CFD research on sports performance in professional sports are still relatively small, where from 2003 to 2023 only 12 journal publication articles were found regarding this research theme. Even though CFD can be used to improve sports performance. Therefore, this research was carried out to conduct research analysis regarding CFD in sports performance of professional sports from research that has been carried out. This research was conducted with the hope that it can become a reference for future researchers in developing sports performance using the CFD method approach. It is also hoped that this research can become a reference and increase researchers' interest in using CFD in sports.

2. Methodology

This research uses a bibliometric analysis method supported by theoretical analysis and bibliometric analysis. Data visualization is carried out based on the working principles of bibliometric analysis through a quantitative approach. Data collection was carried out on October 29 2023 from the Google Scholar database. The research procedure was adapted from research steps carried out by Al Husaeni *et al.,* [13]. The research steps consist of determining the research theme, collecting publication data, processing bibliometric data, bibliometric mapping analysis and preparing research results reports. The keywords used in this research are ("Computational Fluid Dynamics", "CFD" and "Sports Performance"). The search was carried out using the Publish or Perish application version 7. Keyword searches were carried out with the prerequisites for finding the keywords, title and abstract of the article. The articles used in this research are articles that have been published indexed by Google Scholar. Apart from that, there are several conditions set during the search process, namely the publication of journal-type articles, articles must be in English and the search year is 2003 to 2023. The article data that has been collected is stored in three formats, namely *.csv and *.ris. Data processing is carried out via Microsoft Excel and VOSviewer applications. Each format that has been prepared has its use. *.csv format is used for data processing using Ms. Excel and *.ris are used for data processing using VOSviewer. The VOSviewer application is used for the data mapping process resulting from research bibliometric analysis.

3. Results and Discussion

3.1 Trend in Number of Publications and Citations Per Year Articles

Figure 1 shows the publication history of the number of articles regarding Computational Fluid Dynamics Design (CFD) in Sport Performance in Professional Sport. Based on the results of research data searches, it is known that the trend of research publications on this theme which was first published in International Journals was carried out in 2013. These results were concluded based on search results via Publish or Perish version 7, the search year was in the range 2003 to 2023, but the publication data The first time there was in 2013.

Based on the results of the annual research report shown in Figure 1, research on CFD in Sports performance of professional sports published in international journals can still be said to be very small, in the period 2013 to 2023 only 12 publications were found, namely 1 publication in 2013, 2014, 2015, 2016, 2019 and 2020. Then, there were no publications in 2017 and 2023 and there were 2 journal publications regarding CFD in sport performance of professional sport in 2018, 2021 and 2022. Table 1 shows details of publication trends and several citation articles about CFD in sports performance of professional sports published in an international journal indexed by Google Scholar. The number of citations in academic writing articles can provide recognition to the author, support research arguments and help build a strong foundation in writing a scientific work [14]. Citation is an approach to determining influence, publication quality and relationships between authors, research groups, research topics or countries [15]. The number of articles per year and the average total citations per year can show publication and citation trends [16]. The development of citation ranking lists is an effort to highlight published works that have the potential to influence future research patterns.

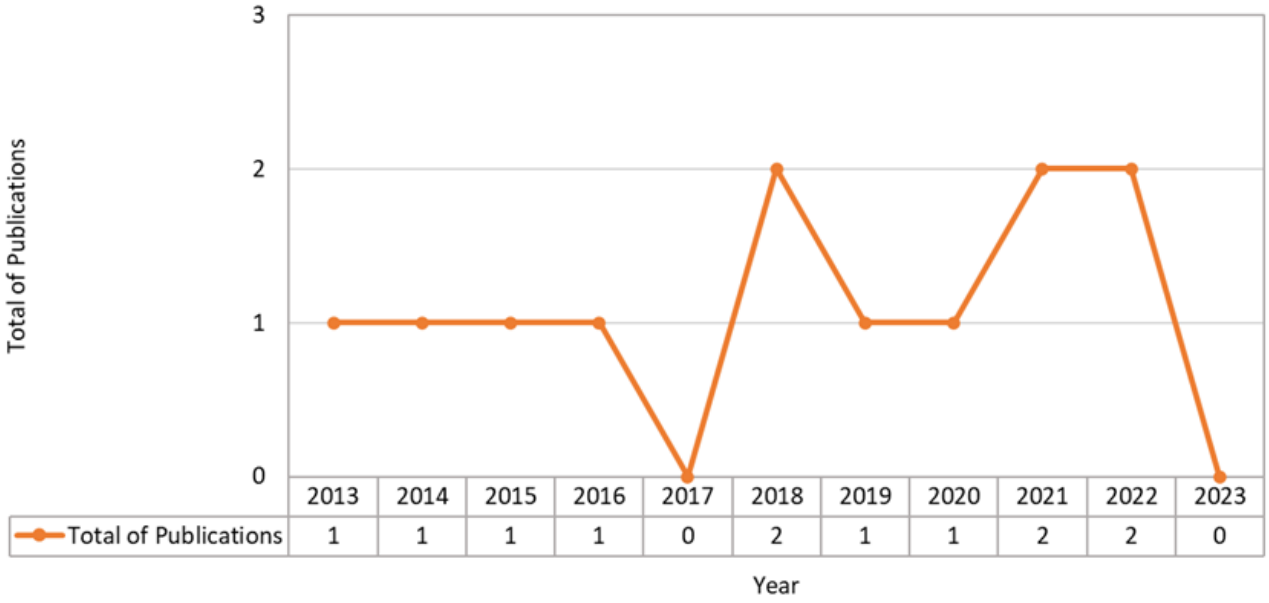


Fig. 1. Annual report publication in sport performance of professional sport

Based on the data in Table 1, it is known that the number of citations to published articles regarding CFD in sports performance of professional sports is still relatively low. Of the 12 articles, there is 1 article that does not yet have citations, namely the research article by Liu *et al.,* [17] which discusses the aerodynamic changes of the upper airway after MSE in adult patients was explored based on three-dimensional reconstruction technology from cone computed tomography data and computational fluid dynamics numerical simulation technology. Meanwhile, of the 11 articles that have been cited, one of them is the articles title "Body Segment Inertial Parameters of Elite Swimmers Using DXA and Indirect Methods" by Rossi *et al.,* [18] is the article with the highest number of citations, namely 36 times with an average annual citation of 3.60. Rossi *et al.,* [18] discussed identifying significant differences in BSIP as measured by DXA between male elite swimmers, female elite swimmers and/or Caucasian young adult swimmers. Additionally, Rossi *et al.,* [18] analysed errors associated with BSIP computations for these three populations quantified using five indirect estimation methods commonly used in assessing human movement. Another article that has the highest number of citations is the article titled "Steady Hydrodynamic Interaction Between Human Swimmers" written by Yuan *et al.,* [19] with several citations of 28 and the average number of citations per year is 7.00. Yuan *et al.,* [19] conducted research that focused on hydrodynamic interactions between two or three human swimmers in competitive swimming. Experiments conducted by Yuan *et al.,* [19] show evidence that a swimmer's drag force can be modified by the presence of other competitors nearby.

The results of the analysis of the number of citations show that 4 articles have been cited more than 20 times, 4 articles have been cited more than 10 times and 4 articles have been cited less than 9 times. Based on the results of the number of citations between articles, it can be seen that the number of citations does not depend on how long the article has been published. The number of citations depends on the contribution and quality of the article and the journal in which the article is published.

Table 1
Most cited articles

No	Title	Year	CPU	TC	Ref
1	Body segment inertial parameters of elite swimmers using DXA and indirect methods	2013	3.60	36	[18]
2	Steady hydrodynamic interaction between human swimmers	2019	7.00	28	[19]
3	A systematic review of propulsion from the flutter kick–What can we learn from the dolphin kick?	2018	4.40	22	[20]
4	The influence of the hand's acceleration and the relative contribution of drag and lift forces in front crawl swimming	2015	2.75	22	[21]
5	Analysis and influence of the underwater phase of breaststroke on short-course 50 and 100m performance	2021	9.50	19	[22]
6	Validation of an outdoor coast-down test to measure bicycle resistance parameters	2018	2.40	12	[23]
7	Pacing profiles, variability and progression in 400, 800 and 1500-m freestyle swimming events at the 2021 European Championship	2022	11.00	11	[24]
8	Validity of an inertial device for measuring linear and angular velocity in a leg extension exercise	2020	3.67	11	[25]
9	Analysis of free-surface effects on swimming by the application of the computational fluid dynamics method	2016	0.71	5	[26]
10	Spatial uncertainty in modelling inhalation exposure to volatile organic compounds in response to the application of consumer spray products	2021	1.00	2	[27]
11	Impact of the Smart Textile on the High-Level Sports Performance and Patient Behaviour in Medicine	2014	0.22	2	[28]
12	Effect of Maxillary Skeletal Expansion on Airflow Dynamics of the Upper Airway	2022	0.00	0	[17]

Note. TC=Total Citations; CPY=Cited Per Years

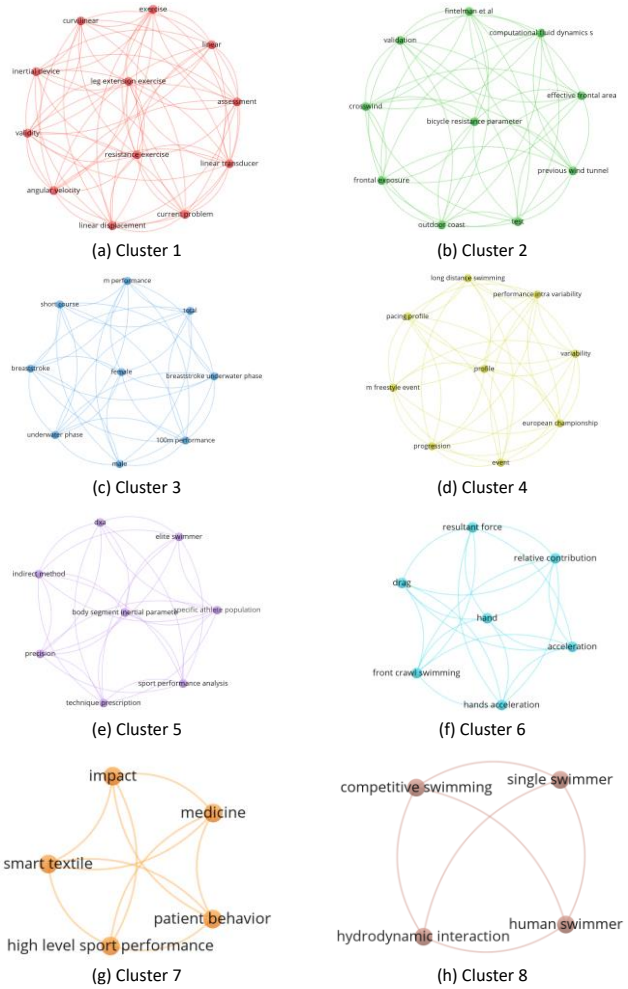
3.2 Trends in Subjects and Research Topics

The results of the analysis of subject and topic trends in CFD in sports performance research using the bibliometric data mapping method from the 12 articles that have been obtained are presented through VOSviewer analysis. VOSviewer is used as an application for converting bibliometric data into mapping data. Determining trend subjects or topics is done by looking at keywords or terms that are often used by researchers. In this research, 107 terms were obtained in CFD research in sports performance. Of these 107 terms we have 60% of the most relevant. Thus, we found 64 relevant terms found in the bibliometric data of 12 articles regarding CFD sports performance. Next, 64-word terms were separated into 8 clusters. Each cluster is not connected, meaning that the division of clusters is carried out based on terms that are connected. The division of word term clusters in CFD research in sports performance is shown in Table 2.

Figures 2(a) to 2(h) illustrate the relationship between terms depicted in a term mapping. Interconnected terms give us knowledge that these terms are often associated with terms that have a link to them. For example, in Figure 2(h) 4 terms appear. The four terms in Figure 2(h) show that hydrodynamic interaction is often associated with competitive swimming, human swimmers and single swimmers. So, readers can find out what topics might be discussed in CFD research in sports performance and what topics can be connected through the information network visualization presented in Figure 2.

Table 2
Cluster division in bibliometric data mapping with VOSviewer

No Cluster	Colour	Total Items	Items	Shown in
1	Red	12	Angular velocity, assessment, current problem, curvilinear, exercise, inertial device, leg extension exercise, linear, linear displacement, linear transducer, resistance exercise and validity.	Figure 2(a)
2	Green	10	Bicycle resistance parameter, computational fluid dynamics simulation, crosswind, effective frontal area, fintelman, frontal exposure, outdoor coast, previous wind tunnel, test and validation.	Figure 2(b)
3	Blue	9	100m performance, breaststroke, breaststroke underwater, female, m performance, male, short course, total and underwater phase.	Figure 2(c)
4	Yellow	9	European championship, event, long-distance swimming, m freestyle event, pacing profile, performance intra variable, profile, progression and variability.	Figure 2(d)
5	Purple	8	Body segment inertial parameter, DXA, elite swimmer, indirect method, precision, specific athlete population, sports performance analysis and technique prescription.	Figure 2(e)
6	Cyan	7	Acceleration, drag, front crawl swimming, hand, hands acceleration, relative contribution and resultant force.	Figure 2(f)
7	Orange	5	High-level sports performance, impact, medicine, patient behaviour and smart textile.	Figure 2(g)
8	Brown	4	Competitive swimming, human swimming, hydrodynamic interaction and single swimmer.	Figure 2(h)



(a) Cluster 1 (b) Cluster 2
(c) Cluster 3 (d) Cluster 4
(e) Cluster 5 (f) Cluster 6
(g) Cluster 7 (h) Cluster 8

Fig. 2. Network visualization

3.3 Trends in the Sports Field that Apply CFD Methods to Sports Performance

Trends in the sports sector using the CFD method were carried out by analysing the problems underlying research on CFD in sports performance from the 12 journal articles found. This is because problem analysis involves identifying the main problem and determining the causes and effects associated with the problem [29]. The first research was conducted by Yuan *et al.,* [19] regarding the use of CFD on steady hydrodynamic interactions between human swimmers. What underlies the research of Yuan *et al.,* [19] are questions regarding what mechanisms determine swimmer interactions, which positions experience reduced drag or increased drag and how much drag can be reduced or increased in a formation. Yuan *et al.,* [19] said that this research question had not been asked much in several previous studies. Yuan *et al.,* [19] researched to discover the mechanisms of hydrodynamic interactions between human swimmers and measured these interactive effects using a soft potential flow solver.

The second research is research by Rossi *et al.,* [18] regarding the inertial parameters of elite swimmers' body segments using DXA and indirect methods. This research is based on technological improvements in storage, processing and computer simulation, camera resolution and acquisition frequency allowing a better understanding of swimming biomechanics. Rossi *et al.,* [18] said that CFD can explore how external forces (propulsive and drag) are generated by water media as a result of body kinematics underwater. In the next research conducted by Andersen *et al.,* [20], the problem underlying CFD research in the field of sports, especially sports performance, is the problem in swimming. According to Andersen *et al.,* [20] one of the most important factors in front crawl swimming performance is produced by both the upper and lower limbs, however little is known about the driving mechanism of the alternating movement of the lower limbs in the flutter kick (FK). In improving this performance Andersen *et al.,* [20] said that visualization and simulation techniques, such as particle image velocimetry (PIV) and computational fluid dynamics (CFD), are non-invasive tools that can effectively model water flow without affecting the swimming technique.

Another research that is based on the use of CFD due to problems in swimming is research conducted by Gourgoulis *et al.,* [21]. Gourgoulis *et al.,* [21] researched to see the effect of hand acceleration and the relative contribution of drag and lift forces in front crawl swimming using a CFD approach. Likewise, research conducted by Tengattini *et al.,* [23], López-Belmont *et al.,* [24] and Hayati *et al.,* [26], the problem that underlies using the CFD method in sports performance is the problem that exists in the sport of swimming. Based on the basic problems taken by previous researchers, it is known that many researchers use the CFD method to train, improve performance and find out sports patterns or techniques in the field of swimming. This is because CFD technology makes it possible to estimate the acceleration of the water so that the driving reaction force acts on the swimmer [20]. CFD allows researchers to test complex scenarios that are impossible to recreate in the real world and ensure the highest level of accuracy for precision products, so that many previous studies have used the CFD method [30-38].

4. Conclusions

Sports performance is very important in professional sports. The application of Computational Fluid Dynamics (CFD) in professional sports performance can not only optimize sports equipment design but also provide athletes and teams with valuable insights into biomechanics, aerodynamics and environmental conditions, ultimately increasing athletes' competitive advantages and performance levels. The research publication trend regarding CFD in Sport performance of professional sport which was published in International Journals was first carried out in 2013.

Research regarding CFD in Sport performance of professional sports published in international journals can still be said to be very small, in the period 2013 to 2023 only 12 publications were found, namely 1 publication in 2013, 2014, 2015, 2016, 2019 and 2020. Then, there were no publications in 2017 and 2023 and there were 2 journal publications regarding CFD in sport performance of professional sport in 2018, 2021 and 2022. The results of the bibliometric mapping analysis show that 64 terms are relevant to CFD research in sports performance of professional sports. Each term is divided into 8 Clusters based on their connectivity. This research found that many researchers use the CFD method to train, improve performance and find out sports patterns or techniques in the field of swimming. This is because CFD technology makes it possible to estimate the acceleration of the water so that the driving reaction force acts on the swimmer. This study has research limitations where the analysis is based on 12 publications over a period of 20 years. We recommend further research to be able to analyse publications on the use of CFD in the field of sports with a larger number of publications in order to produce comprehensive conclusions. Further research is expected to add case studies regarding the successful use of CFD in sports training or equipment design, so that the practical relevance of research findings can be more applied.

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References

[1] Glazier, Paul S. "Towards a grand unified theory of sports performance." *Human movement science* 56 (2017): 139-156. https://doi.org/10.1016/j.humov.2015.08.001

[2] Cruickshank andrew, Dave Collins and Sue Minten. "Driving and sustaining culture change in professional sport performance teams: A grounded theory." *Psychology of Sport and Exercise* 20 (2015): 40-50. https://doi.org/10.1016/j.psychsport.2015.04.007

[3] Mizuguchi, Nobuaki, Hiroki Nakata, Yusuke Uchida and Kazuyuki Kanosue. "Motor imagery and sport performance." *The Journal of Physical Fitness and Sports Medicine* 1, no. 1 (2012): 103-111. https://doi.org/10.7600/jpfsm.1.103

[4] Needleman, Ian, Paul Ashley, Peter Fine, Fares Haddad, Mike Loosemore, Akbar de Medici, Nikos Donos *et al.,* "Oral health and elite sport performance." *British journal of sports medicine* 49, no. 1 (2015): 3-6. https://doi.org/10.1136/bjsports-2014-093804

[5] Liebermann, Dario G., Larry Katz, Mike D. Hughes, Roger M. Bartlett, Jim McClements and Ian M. Franks. "Advances in the application of information technology to sport performance." *Journal of sports sciences* 20, no. 10 (2002): 755-769. https://doi.org/10.1080/026404102320675611

[6] Oyinloye, Timilehin Martins and Won Byong Yoon. "Application of computational fluid dynamics (CFD) simulation for the effective design of food 3D printing (A review)." *Processes* 9, no. 11 (2021): 1867. https://doi.org/10.3390/pr9111867

[7] Cheng, Jiangfeng, He Zhang, Fei Tao and Chia-Feng Juang. "DT-II: Digital twin enhanced Industrial Internet reference framework towards smart manufacturing." *Robotics and Computer-Integrated Manufacturing* 62 (2020): 101881. https://doi.org/10.1016/j.rcim.2019.101881

[8] Leroyer, Alban, S. Barre, Ganbo Deng, J. Wackers, Emmanuel Guilmineau, Michel Visonneau and P. Queutey. "Fluid-Structure Interaction and High-Performance Computing to serve sport performance in rowing." In *24ième Congrès Français de Mécanique, CFM 2019*. 2019.

[9] Gardan, Nicolas, J. Laheurte, E. Gouy, Nilanjan Dey, Ellie Abdi, Umer Asgher, Mohamed-Amine Choukou, Alexandre Schneider and Redha Taiar. "Computational fluid dynamics for the nordic combined skiing jump." *Series on Biomechanics* 29 (2015): 31-38.

[10] Mantha, Vishveshwar Rajendra, Daniel Almeida Marinho, Antonio Jose Silva and Abel Ilah Rouboa. "The 3D CFD study of gliding swimmer on passive hydrodynamics drag." *Brazilian archives of biology and technology* 57 (2014): 302-308. https://doi.org/10.1590/S1516-89132014000200020

[11] Wang andrew XG and Zbigniew J. Kabala. "Body morphology and drag in swimming: CFD analysis of the effects of differences in male and female body types." *Fluids* 7, no. 10 (2022): 332. https://doi.org/10.3390/fluids7100332

[12] Garimella, Raman, Thomas Peeters, Eduardo Parrilla, Jordi Uriel, Seppe Sels, Toon Huysmans and Stijn Verwulgen. "Estimating cycling aerodynamic performance using anthropometric measures." *Applied Sciences* 10, no. 23 (2020): 8635. https://doi.org/10.3390/app10238635

[13] Al Husaeni, Dwi Fitria and Asep Bayu Dani Nandiyanto. "Bibliometric using Vosviewer with Publish or Perish (using google scholar data): From step-by-step processing for users to the practical examples in the analysis of digital learning articles in pre and post Covid-19 pandemic." *ASEAN Journal of Science and Engineering* 2, no. 1 (2022): 19-46. https://doi.org/10.17509/ajse.v2i1.37368

[14] Jomaa, Nayef Jomaa and Siti Jamilah Bidin. "Perspectives of EFL doctoral students on challenges of citations in academic writing." *Malaysian Journal of Learning and Instruction* 14, no. 2 (2017): 177-209. https://doi.org/10.32890/mjli2017.14.2.7

[15] Cao, Xuanyu, Yan Chen and KJ Ray Liu. "A data analytic approach to quantifying scientific impact." *Journal of Informetrics* 10, no. 2 (2016): 471-484. https://doi.org/10.1016/j.joi.2016.02.006

[16] Yazdani, Wasi, Mohd Shamim Ansari and Lamaan Sami. "A bibliometric analysis of mandatory corporate social responsibility using rstudio: Based on scopus database." *International Journal of Professional Business Review* 7, no. 6 (2022): e0744-e0744. https://doi.org/10.26668/businessreview/2022.v7i6.744

[17] Liu, Zhenggang, Nan Zhang, Shuai Chen and Li Lei. "Effect of Maxillary Skeletal Expansion on Airflow Dynamics of the Upper Airway." *Journal of Craniofacial Surgery* 33, no. 6 (2022): 1684-1689. https://doi.org/10.1097/SCS.0000000000008442

[18] Rossi, Marcel andrew Lyttle, EL-SALLAM Amar, Nat Benjanuvatra and Brian Blanksby. "Body segment inertial parameters of elite swimmers using DXA and indirect methods." *Journal of sports science & medicine* 12, no. 4 (2013): 761.

[19] Yuan, Zhi-Ming, Mingxin Li, Chun-Yan Ji, Liang Li, Laibing Jia and Atilla Incecik. "Steady hydrodynamic interaction between human swimmers." *Journal of the Royal Society Interface* 16, no. 150 (2019): 20180768. https://doi.org/10.1098/rsif.2018.0768

[20] Andersen, Jordan T. and Ross H. Sanders. "A systematic review of propulsion from the flutter kick–What can we learn from the dolphin kick?." *Journal of sports sciences* 36, no. 18 (2018): 2068-2075. https://doi.org/10.1080/02640414.2018.1436189

[21] Gourgoulis, Vassilios, Alexia Boli, Nikolaos Aggeloussis, Panagiotis Antoniou, Argyris Toubekis and Georgios Mavromatis. "The influence of the hand's acceleration and the relative contribution of drag and lift forces in front crawl swimming." *Journal of sports sciences* 33, no. 7 (2015): 696-712. https://doi.org/10.1080/02640414.2014.962571

[22] Sánchez, Lourdes, Raúl Arellano and Francisco Cuenca-Fernández. "Analysis and influence of the underwater phase of breaststroke on short-course 50 and 100m performance." *International Journal of Performance Analysis in Sport* 21, no. 3 (2021): 307-323. https://doi.org/10.1080/24748668.2021.1885838

[23] Tengattini, Simone and Alexander Bigazzi. "Validation of an outdoor coast-down test to measure bicycle resistance parameters." *Journal of Transportation Engineering, Part A: Systems* 144, no. 7 (2018): 04018031. https://doi.org/10.1061/JTEPBS.0000152

[24] López-Belmonte, Óscar, Ana Gay, Jesús J. Ruiz-Navarro, Francisco Cuenca-Fernández, Ángela González-Ponce and Raúl Arellano. "Pacing profiles, variability and progression in 400, 800 and 1500-m freestyle swimming events at the 2021 European Championship." *International Journal of Performance Analysis in Sport* 22, no. 1 (2022): 90-101. https://doi.org/10.1080/24748668.2021.2010318

[25] Pino-Ortega, Jose, Alejandro Bastida-Castillo, Alejandro Hernandez-Belmonte and Carlos D. Gomez-Carmona. "Validity of an inertial device for measuring linear and angular velocity in a leg extension exercise." *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology* 234, no. 1 (2020): 30-36. https://doi.org/10.1177/1754337119878296

[26] Hayati, Arash Nemati, Hamed Ghaffari and Mehrzad Shams. "Analysis of free-surface effects on swimming by the application of the computational fluid dynamics method." *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology* 230, no. 3 (2016): 135-148. https://doi.org/10.1177/1754337115598488

[27] Jung, Yerin, Yoonsub Kim, Hwi-Soo Seol, Jong-Hyeon Lee and Jung-Hwan Kwon. "Spatial uncertainty in modeling inhalation exposure to volatile organic compounds in response to the application of consumer spray products." *International journal of environmental research and public health* 18, no. 10 (2021): 5334. https://doi.org/10.3390/ijerph18105334

[28] Taiar, R. "Impact of the Smart Textile on the High Level Sport Performance and Patient Behavior in Medicine." *Global Journal of Researches in Engineering: A Mechanical and Mechanics Engineering* 14, no. 8 (2014): 22-28.

[29] Mahto, Dalgobind and Anjani Kumar. "Application of root cause analysis in improvement of product quality and productivity." *Journal of Industrial Engineering and management* 1, no. 2 (2008): 16-53. https://doi.org/10.3926/jiem.2008.v1n2.p16-53
[30] Putranto, Vicky Adrian and Allessandro Utomo. "Interaction Analysis of Micro Bubbles in the Flat Plate to Reduce Drag using Computational Fluid Dynamic." *Semarak Engineering Journal* 4, no. 1 (2024): 18-28.
[31] Ahmadi, Muhammad Aiman, Nurshafinaz Mohd Maruai, Mohd Fadzli Haniff, Ahmad Faiz Mohammad, Farah Mohd Redzuan and Shahir Mohd Yusuf. "Numerical Investigation on Tandem Body Configurations in Prospect to Enhance Low Wind Energy Harvesting." *Semarak Engineering Journal* 3, no. 1 (2023): 9-13.
[32] Kamarudin, Saddam, Iskhrizat Taib, Muhammad Shaiful izzat Shaharudin, Muhammad Aiman Nasri, Muhammad Zulfaqar Mohd Madzni, Muhammad Nur Aiman Rahmat and Muhammadu Masin Muhammadu. "CFD Analysis of Different Baffles in Shell and Tube Exchanger." *Semarak Journal of Thermal-Fluid Engineering* 1, no. 1 (2024): 1-10.
[33] Oo, Ye Min, Makatar Wae-hayee and Chayut Nuntadusit. "Experimental and numerical study on the effect of teardrop dimple/protrusion spacing on flow structure and heat transfer characteristics." *Journal of Advanced Research in Experimental Fluid Mechanics and Heat Transfer* 2, no. 1 (2020): 17-32.
[34] Arafat, Mohammad, Izuan Amin Ishak, Muhammad Aidil Safwan Abdul Aziz andrew Wee Shong Soh, Woei Ting Tiong, Nur Rasyidah Roziman, Nur Amiza Mohd Hairul *et al.,* "A Hybrid RANS/LES Model for Predicting the Aerodynamics of Small City Vehicles." *Journal of Advanced Research in Experimental Fluid Mechanics and Heat Transfer* 17, no. 1 (2024): 1-13. https://doi.org/10.37934/arefmht.17.1.113
[35] Sudarja, Sudarja and Sukamta Sukamta. "Experimental Study on Flow Pattern and Void Fraction of Air-Water and 3% Butanol Two-Phase Flow in 30o Inclined Mini Channel." *Journal of Advanced Research in Experimental Fluid Mechanics and Heat Transfer* 1, no. 1 (2020): 11-20.
[36] Zakaria, Mohamad Shukri, Farzad Ismai, Masaaki Tamagawa, Ahmad Fazli Abdul Azi, Surjatin Wiriadidjaya, Adi Azrif Basri and Kamarul Arifin Ahmad. "Computational fluid dynamics study of blood flow in aorta using OpenFOAM." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 43, no. 1 (2018): 81-89.
[37] Isa, N. M., RA Mohamad Rushdi, A. Sadikin, S. M. Basharie, M. Universiti and T. Hussein. "Investigation of the fluid motion with various clearances in biodiesel reactor by using CFD." *Journal of Advanced Research Design* 10, no. 1 (2015): 1-8.
[38] Razali, Azlizul Aizat and Azmahani Sadikin. "CFD simulation study on pressure drop and velocity across single flow microchannel heat sink." *Journal of Advanced Research Design* 8, no. 1 (2015): 12-21.