Physics in sports - swimming

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Agenda

1. Introduction
2. Physics of Swimming - general overview
3. Fluid properties
4. Fluid dynamics
5. Forces in swimming
6. Energy Dynamics
7. Kinematics in swimming

08. Physics of Different Swimming Strokes
09. Deep Dive into Each Stroke
10. Starts and Turns
11. Human Factors
12. External Factors
13. Conclusion
14. Literature and References

Importance of Physics in Sports

- Sports performance is not just about athleticism; it's a science.
- Physics offers a lens to understand, analyze, and optimize performance.

- In every jump, dive, stroke, and turn, there are principles of physics at work.
- In competitive swimming, even fractions of a second count

By understanding physics behind, swimmers can refine their techniques, improve their times, and optimize their training.

Source: Examplary images from google.com

Key Physics Concepts in Swimming

Swimmers aren't just moving in water; they're interacting with a medium that has its own properties and behavior.

Key Concepts:

- Fluid Mechanics: fluid properties, fluid dynamics and fluid static
- Forces in Swimming: buoyancy, drag, propulsion, and gravity's influence
- Energy and Efficiency
- Kinematics: distance, movement, time, speed and velocity

A deep grasp of these principles allows swimmers to work with them, rather than against them, optimizing performance in the pool.

FLUID MECHANICS | FLUID PROPERTIES | FLUID DYNAMICS

Fluid Properties

Density [1] (ρ) :

- The mass of fluid per unit volume.
- Influences buoyancy and propulsion in water, determining swimmers' floatation and resistance.

Viscosity [2] (μ or η):

- A measure of a fluid's resistance to shear or flow.
- Is the primary source of frictional drag

- Incompressibility

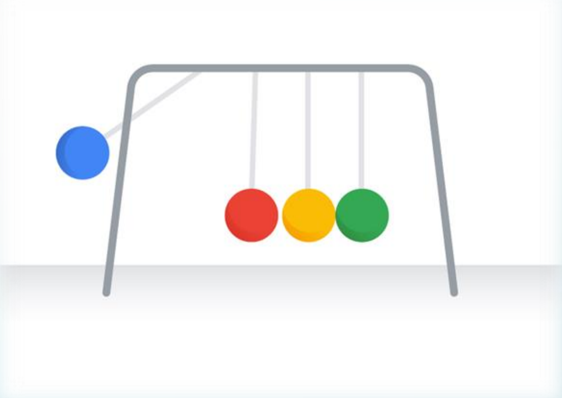
Surface Tension [2]:

- Cohesive force at the liquid's surface.
- Impacts entry, exits, and stroke efficiency.

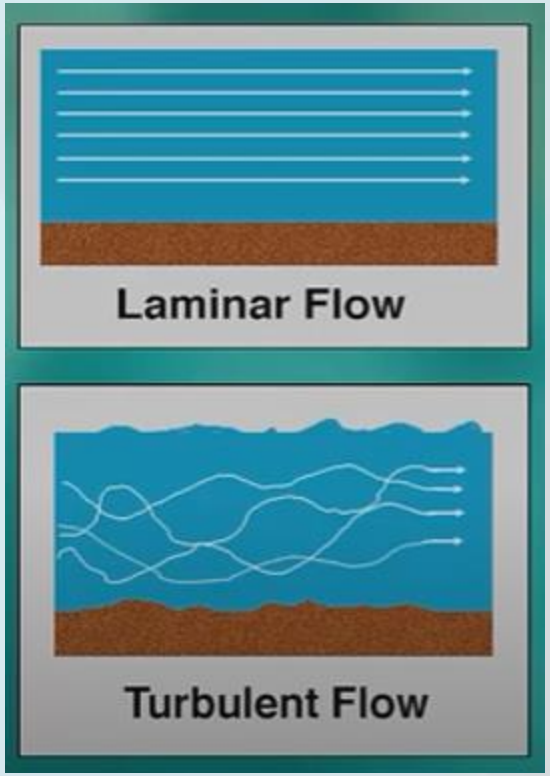
[3] Source: Photo by Ian MacNicol/Getty Images

[1] https://en.wikipedia.org/wiki/Density
[2] https://chemed.chem.purdue.edu/genchem/topicreview/bp/ch14/property.php

Fluid Dynamics (hydrodynamics)



- Newton's Third Law [4]:
  - Principle: For every action, there is an equal and opposite reaction.
  - When swimmers push against the water, the water pushes them forward, resulting in propulsion.
- Flow patterns [5]:
  - Laminar Flow: Smooth and orderly flow. Desirable around a swimmer's body to reduce drag.
  - Turbulent Flow: Chaotic and disorderly flow. Increases drag, making it harder for swimmers to maintain speed.
- Boundary Layer [6]:
  - Thin layer of fluid closest to the swimmer's body where flow velocity changes.
  - Transition from laminar to turbulent flow occurs here, affecting drag.

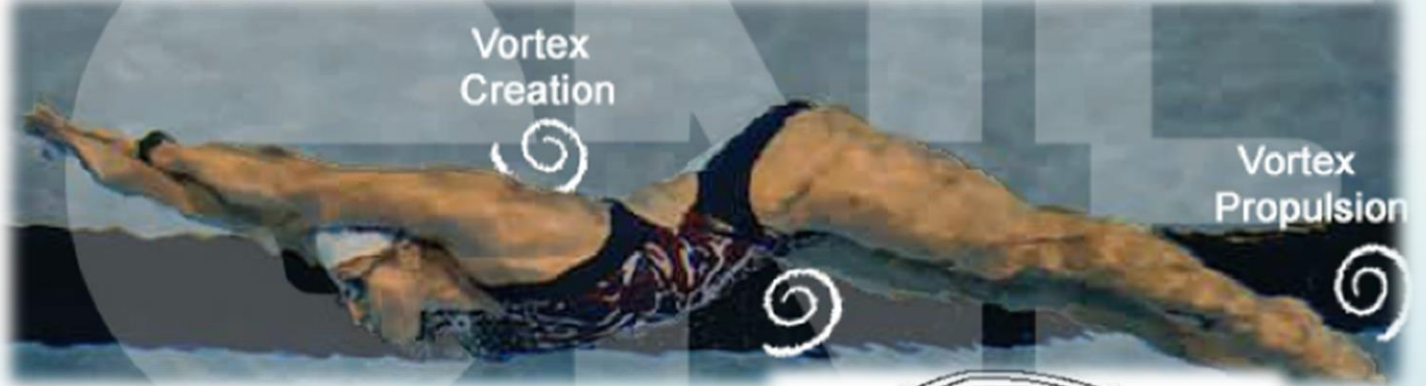


[7] Source: https://2021.help.altair.com/

[4] Source: https://express.adobe.com/page/7XbglND0tG2Yk/
[5] Source: https://engineeringlibrary.org/reference/laminar-and-turbulent-fluid-flow-doe-handbook
[6] Source: https://en.wikipedia.org/wiki/Boundary_layer

Fluid Dynamics II

[8]



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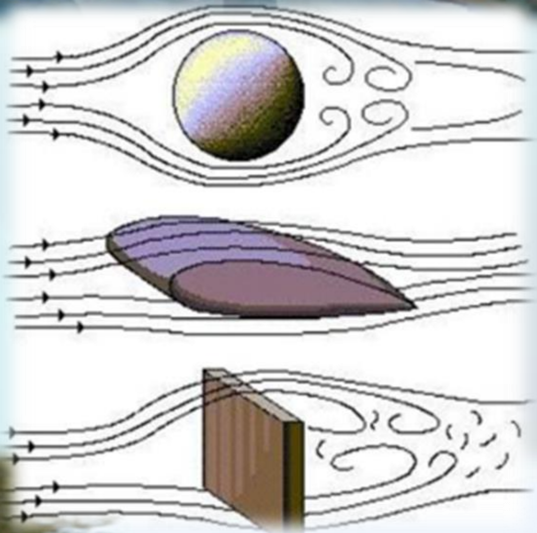


- Vortices:
  - Generated during specific stroke phases.
  - Proper technique harnesses beneficial vortices for propulsion.
- Wakes:
  - Large, turbulent wakes increase drag.
  - Drafting technique: outside turbulent zones.

[9]

- Streamlining: Minimize frontal area to reduce drag. Creates Laminar flow

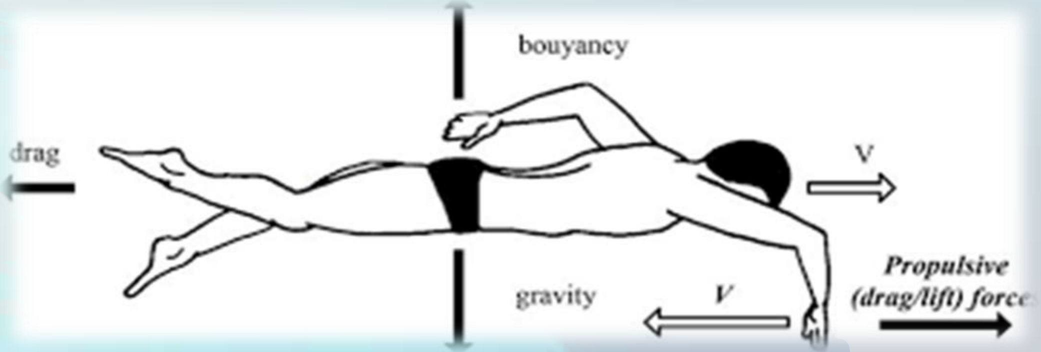
[8] –Source: https://swimswam.com/how-to-build-underwater-power-your-5th-stroke
[9] – Source: https://phikwadraat.nl/duck_wakes/
[10] – Source: https://www.ozmo.io/the-aerodynamic-properties-of-water-drops/

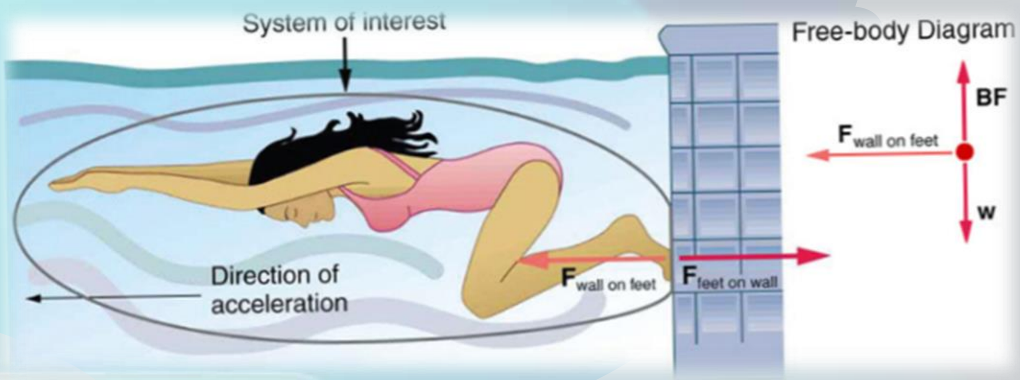
Forces in Swimming

Propulsion in Swimming

[4] Momentum Formulua:
P = Mv - P Is Momentum, M Is Mass In Kg And V Is Velocity In M/S

- Swimmers push water backwards, and due to Newton's 3 Law, water pushes them forward. [4]
- The acceleration depends on the mass and the amount of force applied – Newton's 2 Law. [4]
- Sources of propulsion!
- Key Factors!
- To maximize forward movement and to reduce drag!



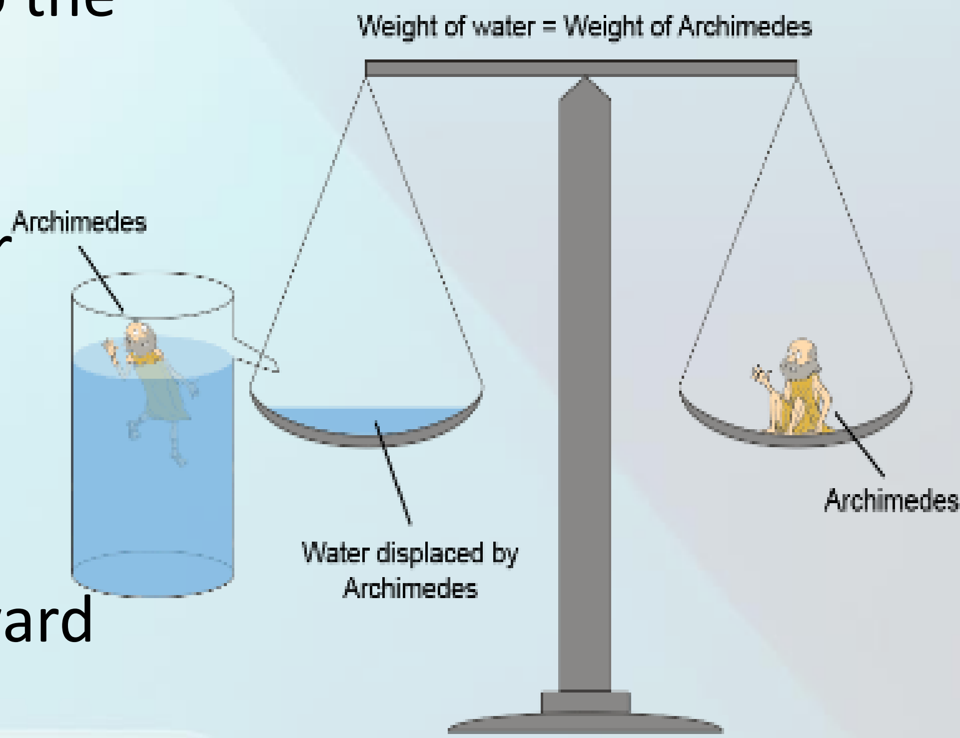


[4]

Buoyancy and Archimedes' Principle [11]

- Buoyancy: The upward force exerted by a fluid that opposes the weight of an immersed object [12]
- Archimedes' Principle: Any object, wholly or partially immersed in a fluid, is buoyed up by a force equal to the weight of the fluid displaced by the object

- Depends on the volume and density of the swimmer
- Body Composition and
- Air in Lungs - increases buoyancy!
- Staying Afloat!
- Achieving optimal buoyancy to ensure efficient forward motion with minimal resistance
- Centre of Buoyancy vs. Centre of Mass

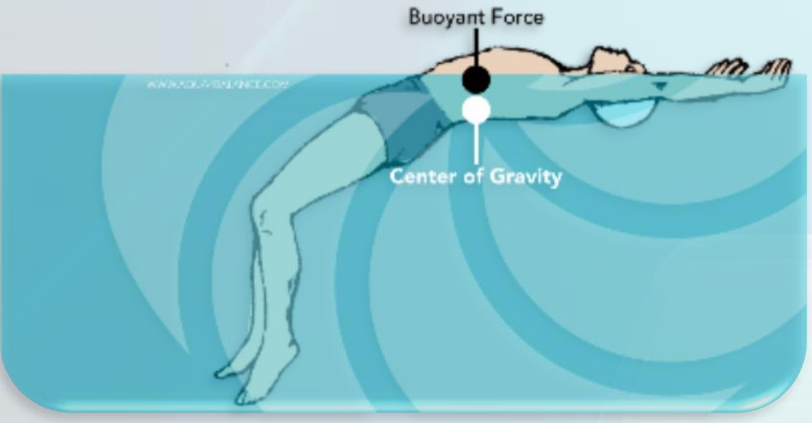


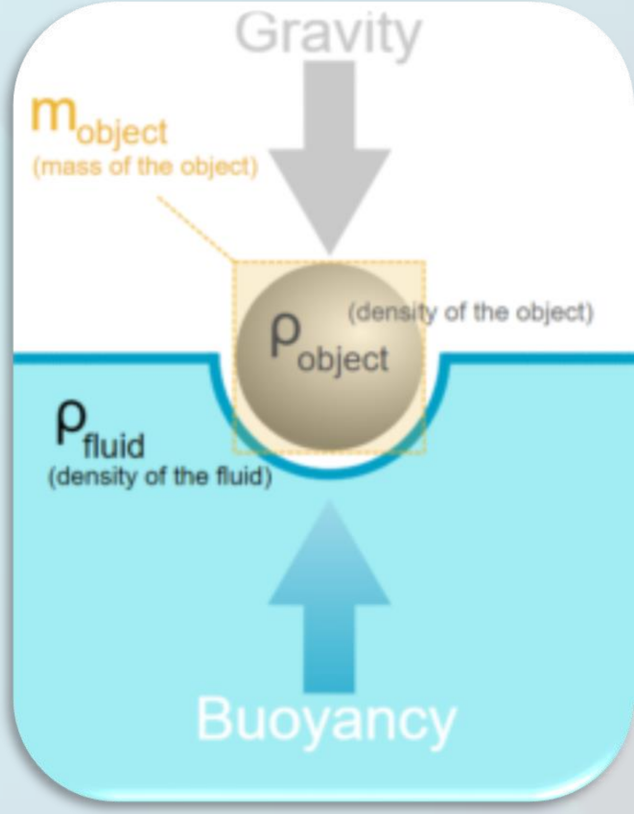
[11] Source: https://isaacphysics.org/concepts/cp_buoyancy_archimedes?stage=all
[12] Source: https://en.wikipedia.org/wiki/Buoyancy

[13] Source: https://www.pngegg.com/en/png-eqrrn

Gravity's Role [14]

- Gravity's Pull: Every swimmer, regardless of body composition, is continuously pulled downward by gravity. This force gives the swimmer weight in water.
- Sinking motion increases drag and leads to inefficient swimming
- Counteracting Gravity/Interplay with Buoyancy



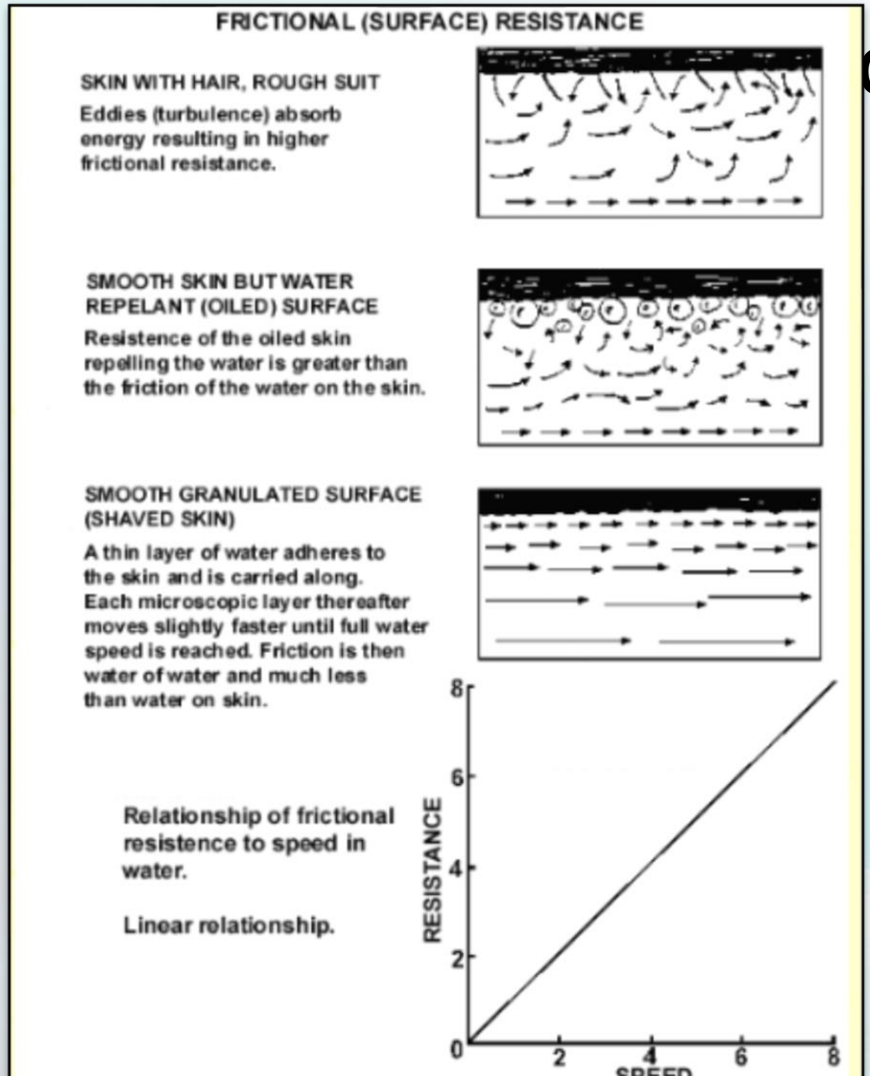


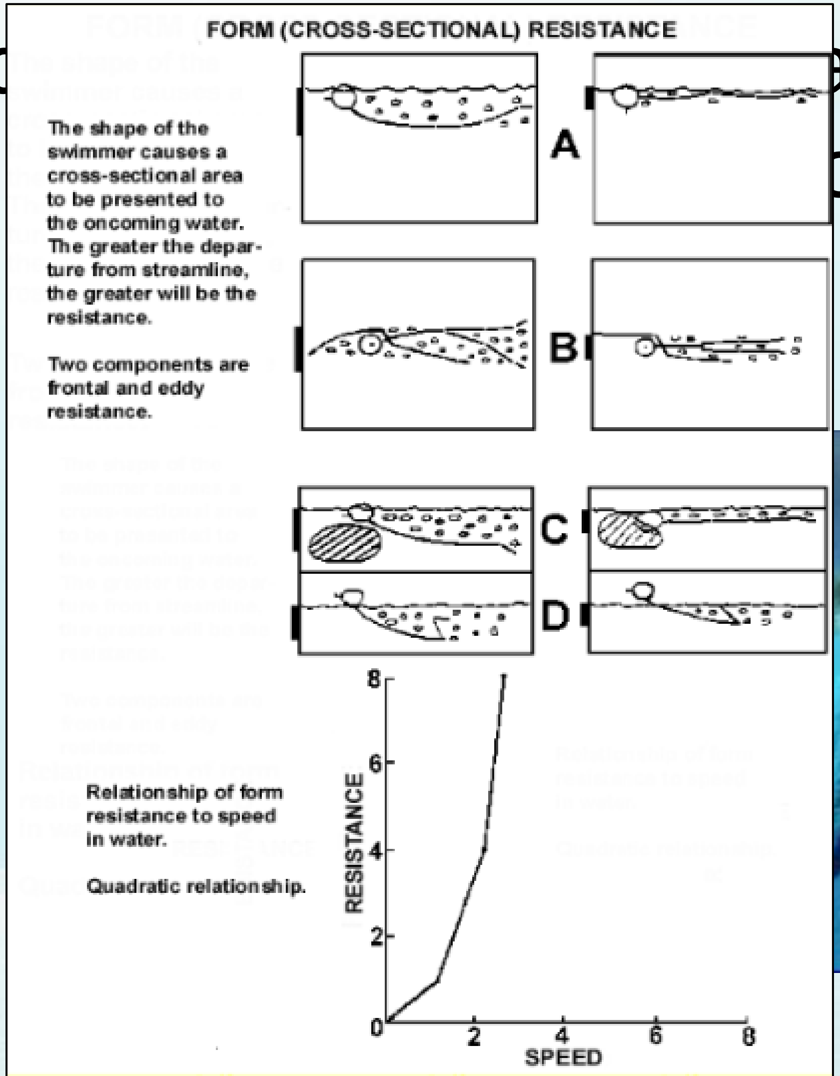
[12]

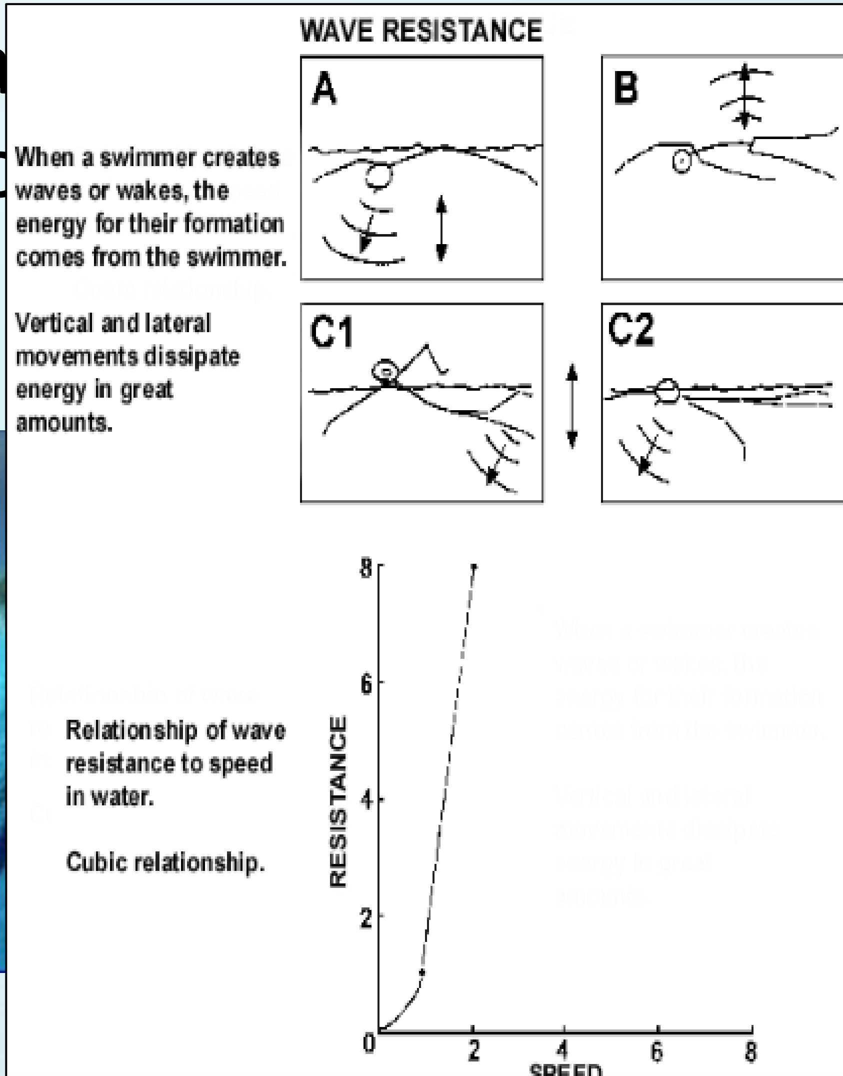
[14] Source: https://coachsci.sdsu.edu/swim/bullets/float36.htm

Drag Forces (fluid resistance) in Swimming

[16] Source: https://coachsci.sdsu.edu/swim/bullets/forces4.htm

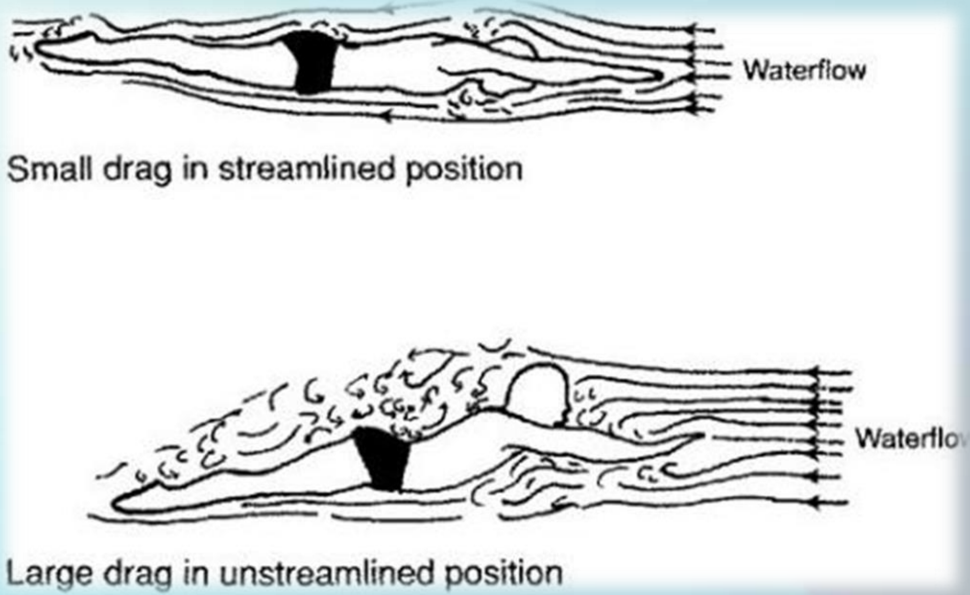






Drag forces

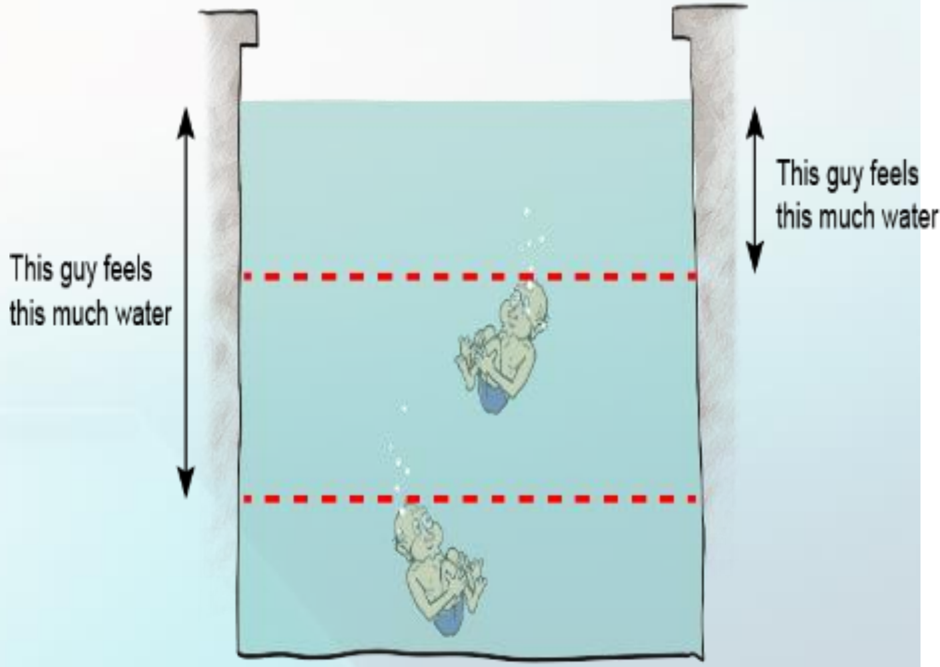
- How swimmers minimize these forces:
  - Streamlined Position
  - Smooth Technique
  - Cap and Swimsuit Design
  - Depth Consideration

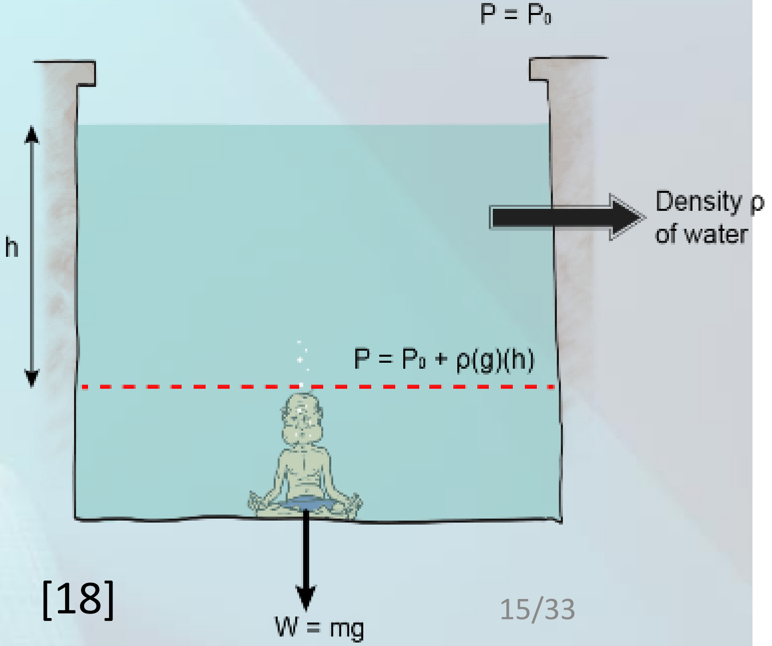


[17] Source: https://360swim.com/blog/streamline-explained-how-forces-influence-swimming

Pressure in Fluids [18], [19]

- Force per unit area exerted on an object's surface in a fluid
- Hydrostatic Pressure in Swimming
- Swimmers feel different pressures on various parts of their body
- When pushing off walls or the pool floor, swimmers can use the pressure gradient as an advantage, gaining speed
- As swimmers move, they create dynamic pressure differences around their bodies, influencing drag and propulsion.
- Faster movement increases dynamic pressure





[18]

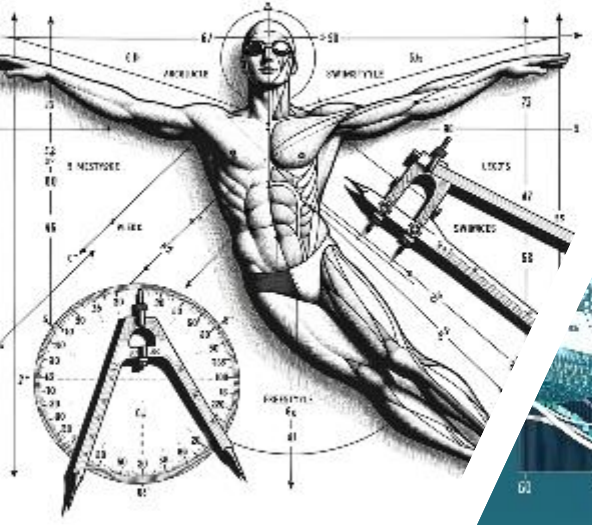
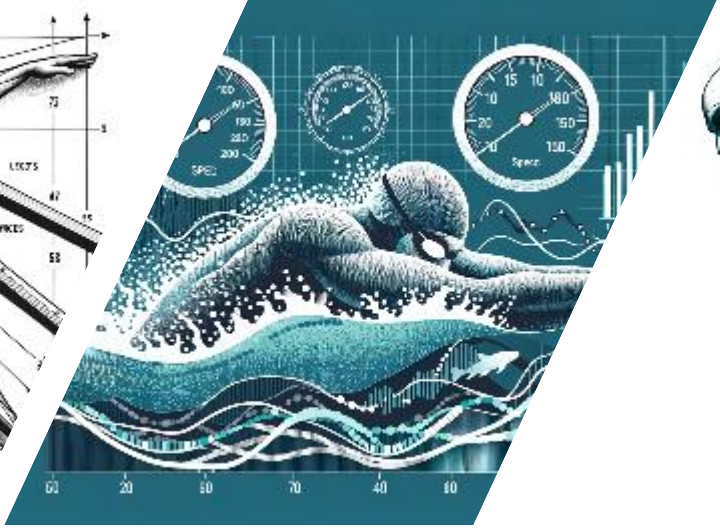
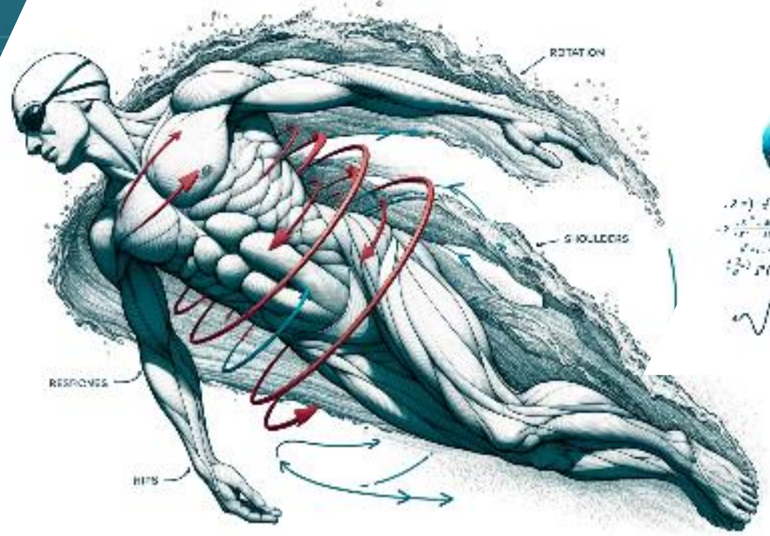
[18] Source: https://www.shmoop.com/study-guides/physics/fluids/hydrostatic-equilibrium
[19] Source: https://simple.wikipedia.org/wiki/Fluid_pressure

Energy

- Potential and Kinetic Energy
- Swimming requires energy for propulsion and to overcome drag forces!
- Energy Sources
  - ATP (Adenosine Triphosphate): Primary energy currency in muscles. Sourced from carbohydrates, fats, and, to a lesser extent, proteins. [20]
  - Oxygen: Muscles use oxygen to help break down glucose and fat to produce ATP.
- Muscles contraction and movement
- Heat Transfer: Body loses heat in water, affecting energy efficiency & stamina.
- Energy efficiency and conservation of energy!

[22]

[20] Source: https://www.ncbi.nlm.nih.gov/books/NBK553175/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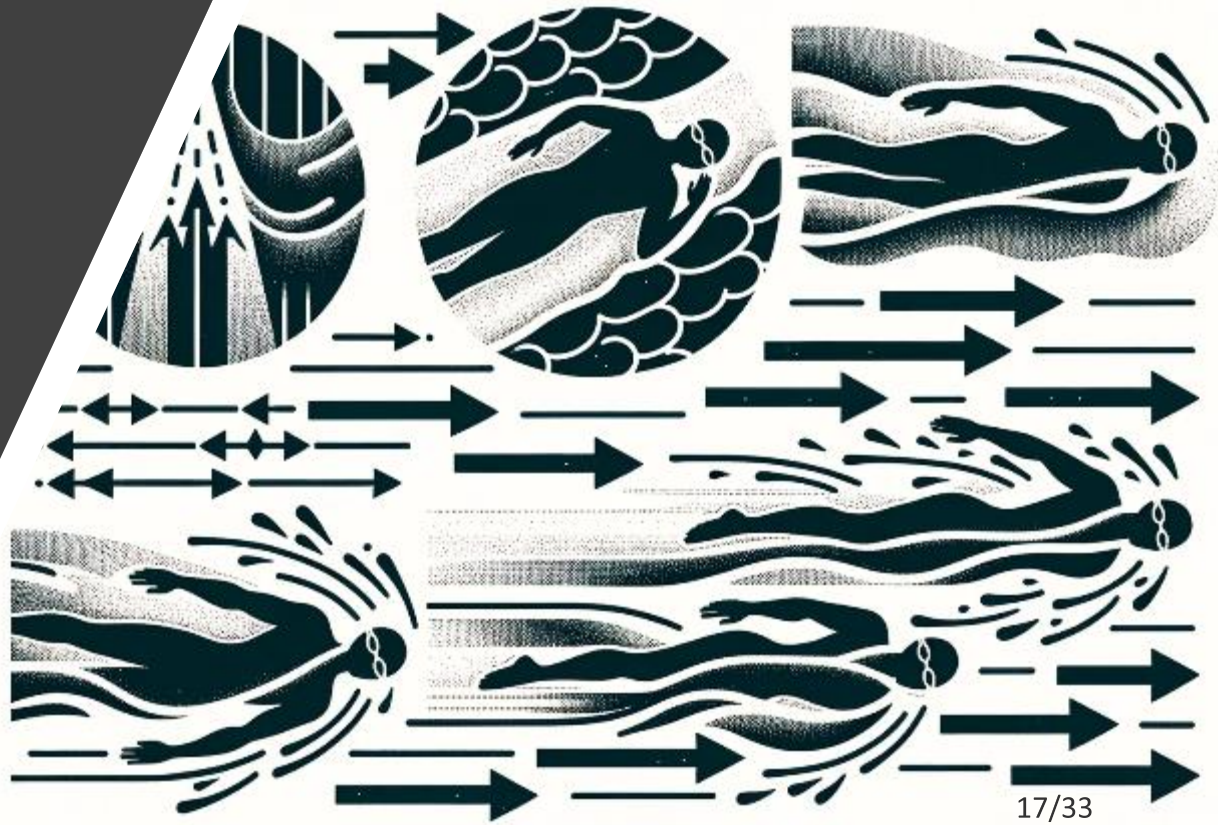
Kinematics of Swimming [21]

- Kinematics focuses on the description of motion without concern for the forces causing it.
- Swimmer’s Body Position and Angles
- Stroke Rate & Stroke Length
- Velocity and Acceleration
- Swimmer's Body Motion

[21] Source: https://www.intechopen.com/chapters/19665



Mechanics of Varied Swimming Techniques | Deep Dive

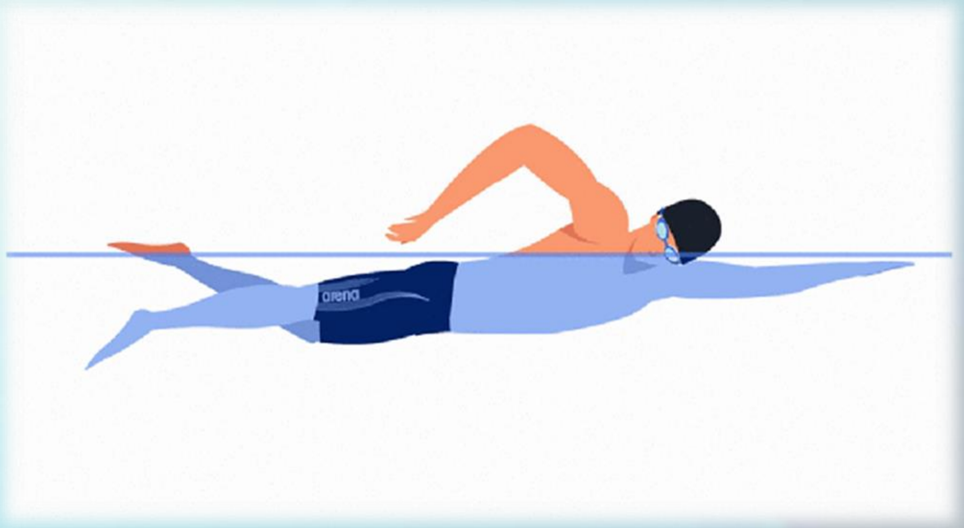
The Physics of Different Swimming Strokes

- Freestyle (Front Crawl)
- Backstroke
- Breaststroke
- Butterfly
- *Starts and turns

[23] Examplary images Source: google.com

Front Crawl (Freestyle)

- Fluid Dynamics:
  - Water as a medium: Resistance & Flow
- Forces:
  - Propulsion: Arm pull & leg kick
  - Buoyancy
  - Drag
- Energy Efficiency
- Kinematics: Speed, direction, and acceleration

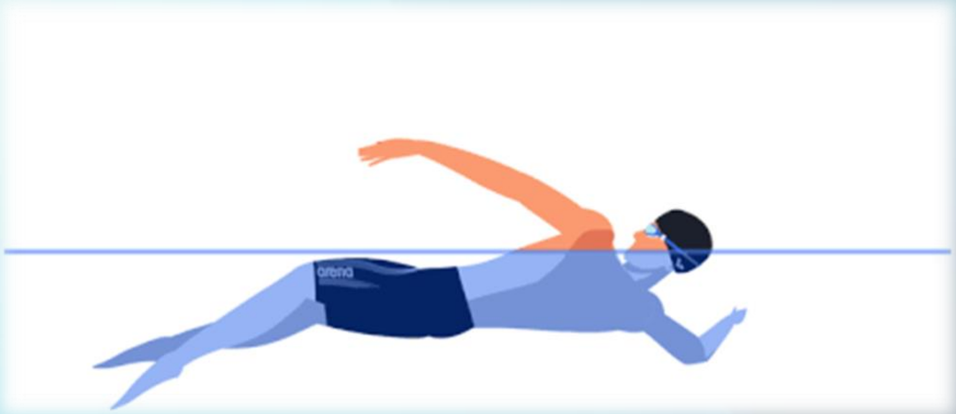


[24]

[24] Source: https://blog.arenaswim.com/en/training-technique

Backstroke

- Fluid Dynamics:
  - Water flow: Resistance and Streamline
- Forces:
  - Propulsion: Upsweep & downbeat kick
  - Buoyancy: horizontal posture and core stability.
  - Drag: Surface area optimization, body rotation
- Energy:
  - Conservation: Rotational body movement, breathing
- Kinematics:
  - Motion aspects: Rotational speed, arm sweep, and leg kick dynamics



[24]

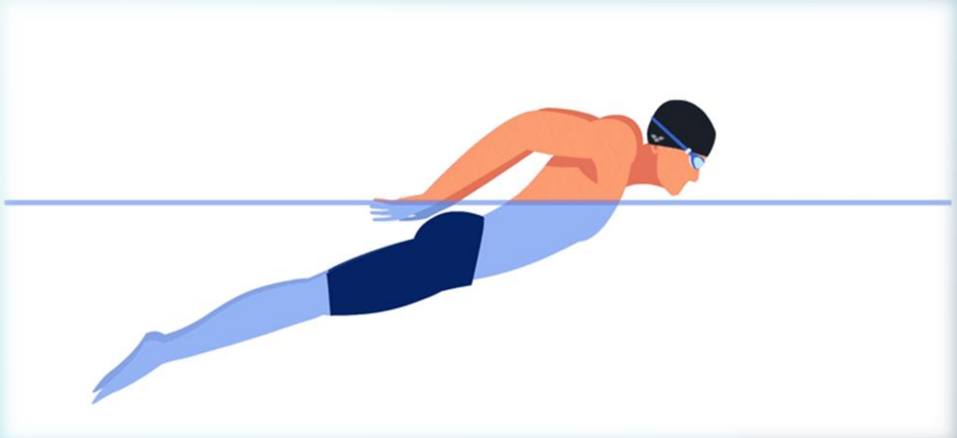
Breaststroke

- Fluid Dynamics:
  - Whipping motion: Creating vortices
- Forces:
  - Propulsion: Leg "whip" and arm scull
  - Buoyancy: Chest-driven floatation
  - Drag: Maximized during glide & minimized in streamline
  - Gravity: Role in pull-down and body bobbing
- Energy Harnessing: Through a cyclical stroke pattern
- Kinematics:
  - Body undulation & coordinated motion

[24]

Butterfly

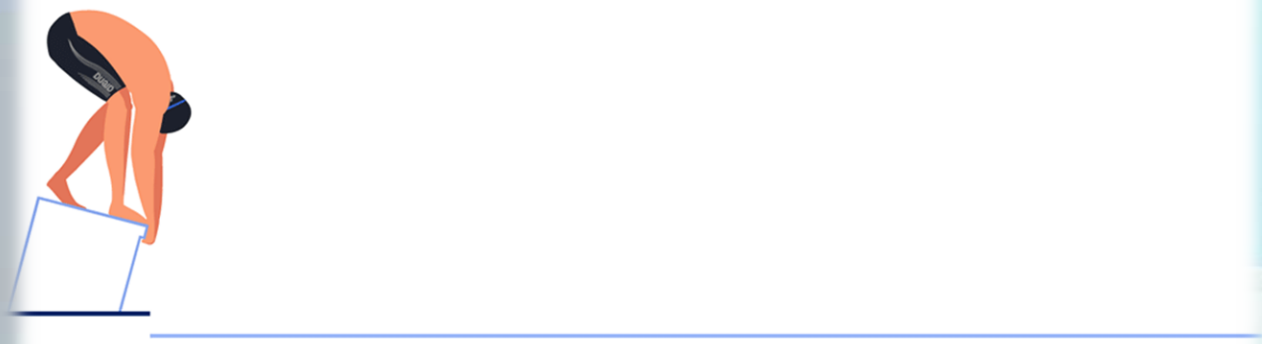
- Fluid Dynamics:
  - Synchronized double-arm pull, Propulsion vortex
- Forces:
  - Propulsion: Dolphin kick & arm pull
  - Buoyancy: Body undulation & lung capacity
  - Drag: Minimized in streamlined surge
  - Gravity: Continuous vertical oscillation [24]
- Kinematics Wave-like motion: Full body coordination



Starts Diving Off the Blocks

- Kinematics:
  - Optimal angle: 45° for max distance
- Forces:
  - Propulsion: Leg drive & arm swing
  - Gravity: Pulls swimmer downward
  - Buoyancy: Transition from air to water
  - Drag: Streamlined entry minimizes
- Energy:
  - Quick transitions = less energy loss
- Wake: During race starts, the collective wake of multiple swimmers can create a notably turbulent environment, affecting the initial phase of the race.

[24]

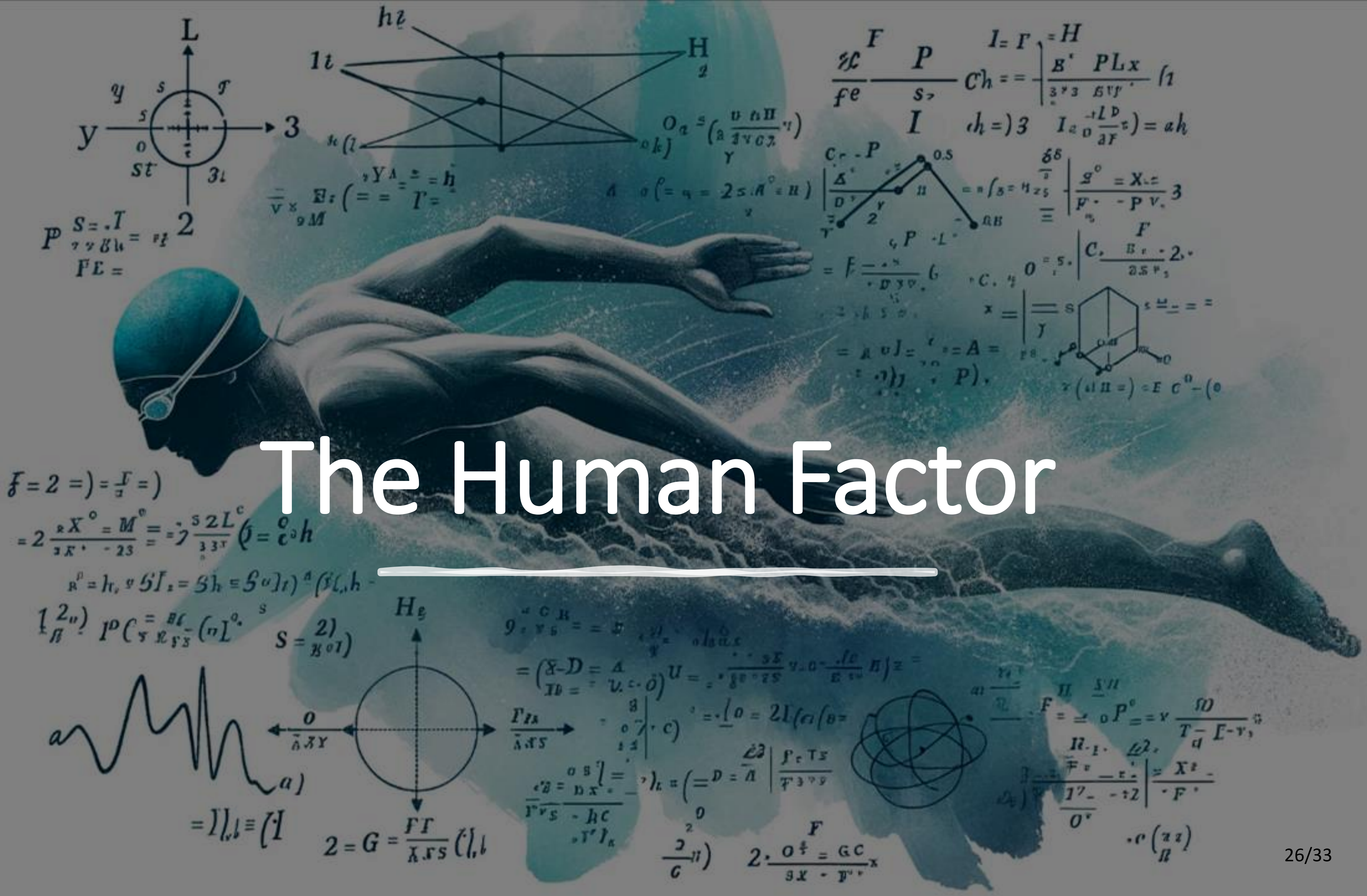


Wall Turns

- Momentum:
  - Conserve speed into & out of turn
- Rotational Kinematics:
  - Optimal flip angle & speed
- Forces:
  - Wall push-off: Maximize propulsion
  - Drag: Minimized with streamlined exit
- Energy:
  - Efficiency: Quick turn = less energy loss
- Wakes: Similarly, during finishes, especially in close races, wakes can merge and influence the final approach to the wall.

[24]

The Human Factor



[22]


[22]

Biomechanics in Swimming [21]

- Body Position and Streamlining
  - Horizontal positioning & head-spine-hips alignment.
- Muscle Mechanics and Power Generation
  - Power stems from coordinated muscle actions.
  - Core strength
  - Arms and legs generate propulsive forces.
- Kinesiology of Swimming Strokes
  - Unique movement patterns for each stroke
  - Flexibility and Muscle length-tension

Muscles [25] [26]

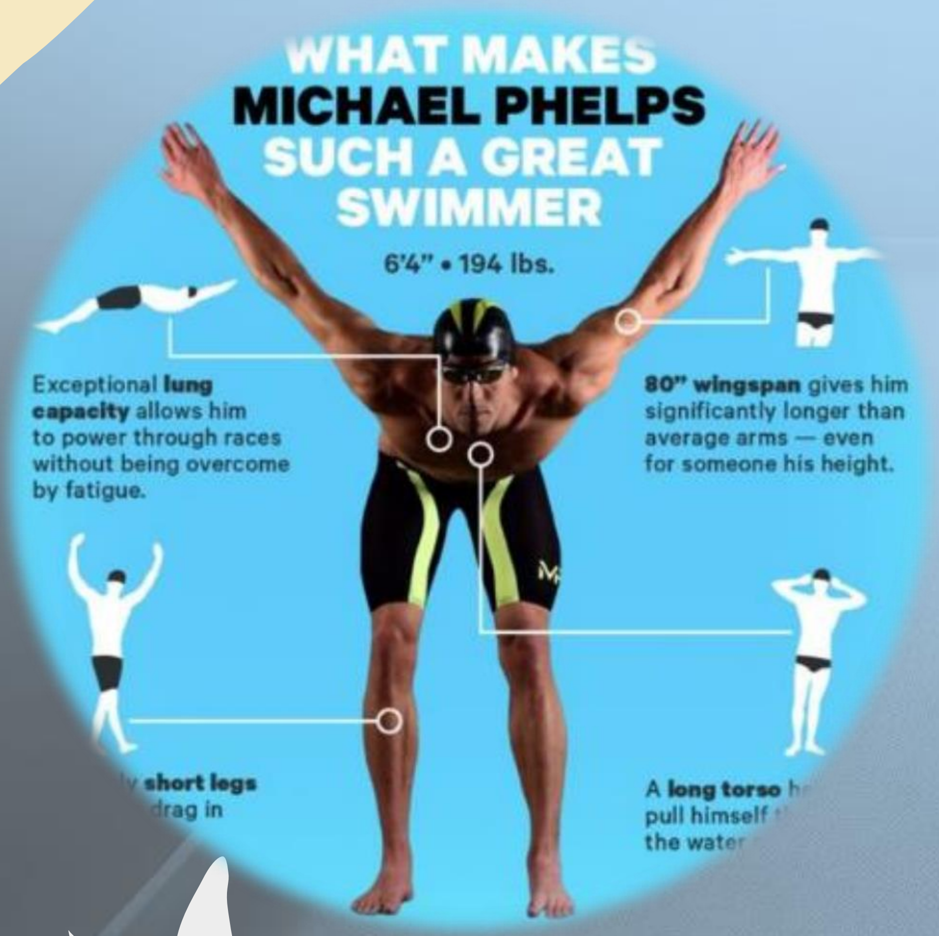
- Fast-Twitch (Type II): Speed & Power | Slow-Twitch (Type I): Endurance & Stamina
- ATP Production: Cellular Energy for Stamina & Speed.
- Oxygen Utilization: Sustained Energy | Anaerobic Respiration: Explosive Events.
- Energy Transfer: Kinetic Chain Movements | Technique: Maximize Efficiency.

Breathing Dynamics [26]

- Oxygen Need vs Streamline Maintenance

- Oxygen Requirement: Muscles need oxygen for optimal performance.
- Streamlined Position: Every head lift or turn can introduce drag.
- Bow wave!
- Breathing Patterns and rhythm e.g. bilateral breathing

Body Build



[27]

- Tapered Shape body
- Limb Length
- Torso and Chest Size
- Shoulder Width

- Body Mass, Body Density and Distribution
- Joint flexibility

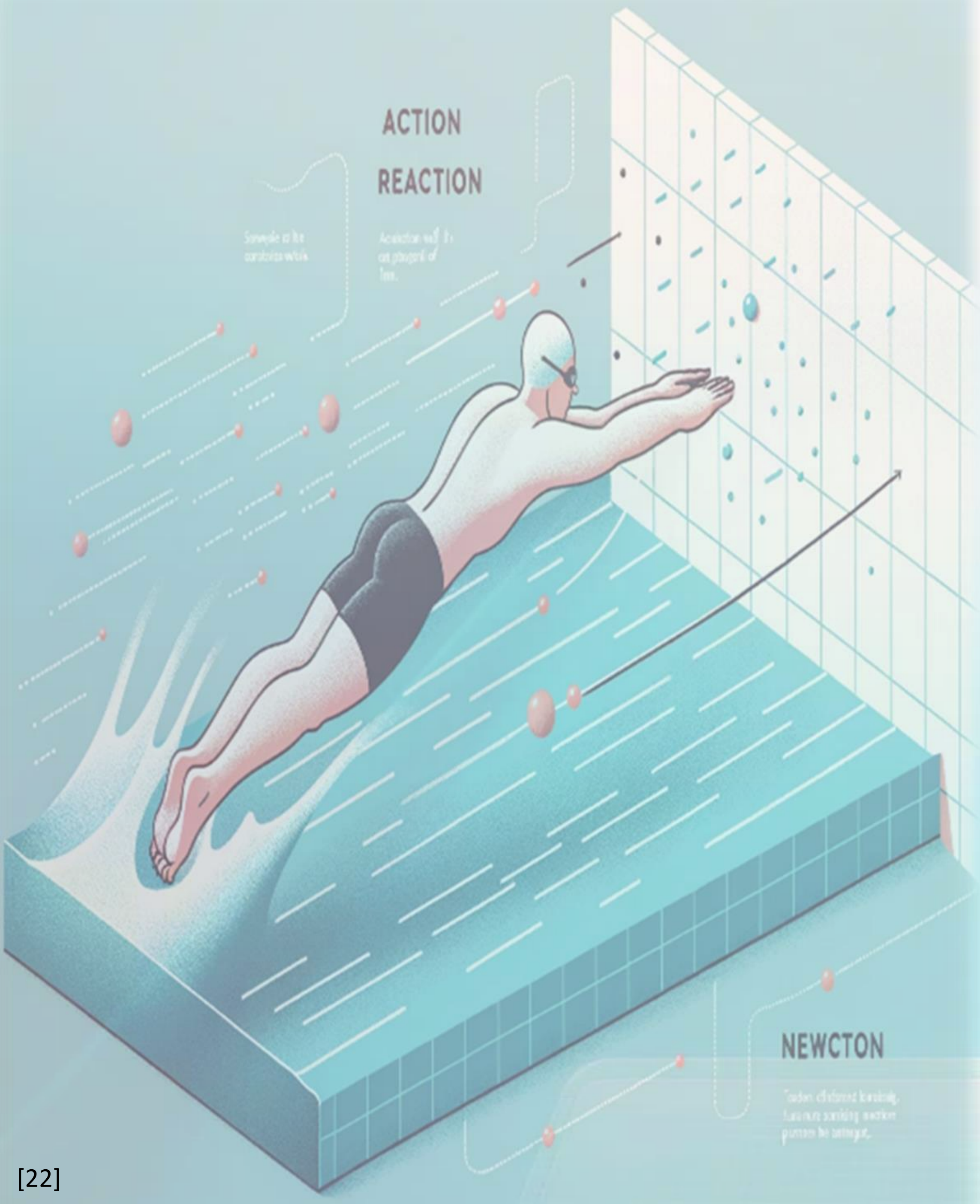
- Hip Rotation
- Foot Size and Arch

External Factors

External Factors

- Swimsuit Tech
- Pool Design
- Water Properties
- Varied Environments

[28]



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Conclusions

- Influence of Physics on Performance
- Fluid Properties, Hydrodynamics, Forces - relevant to swimming
- Nature of the Medium: Swimming is unique as it engages with water, a medium 800 times denser than air
- Harmony of Forces: Every stroke, turn, and dive is a calculated response to the forces of buoyancy, gravity, and drag
- Stroke Techniques & Physics
- Impact of Biomechanics and External Factors in Swimming

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THANK YOU

Questions, Comments?