Objectives

- Apply sports biomechanics approach to swimming
- Be able to differentiate characteristics of different swimming styles
- Review fundamental concepts on fluid dynamics - buoyancy, lift vs. drag
- Learn about dolphin skin and swim suits
- Create a comprehension how all works together
Contents

1. Introduction: four main swim styles
2. What we can see: characterisation of the four styles
3. Fluidodynamics principles
   - drag
   - lift
   - about surfaces and adjacent materials
4. Simple calculations
5. Finetuning of swim style understanding (?)
6. Summary

Videos

4 swimming styles & ....
Starting time

start depends on horizontal and vertical impulses produced on the block
speed in air greater than speed in water: optimise time in the air.
however, too much height in the start produces greater downward speed which must be stopped in the water → appears to slow the swimmer down
grab vs sprint starts: grab is faster off the blocks, but sprint start → greater impulse (what is the objective of the start?)

- beware of “first out of the blocks” syndrome
- when to start stroking? When your glide speed drops to your swimming speed

\[ I = m \times v \]
Stroke length

Propulsive forces:
- lift forces – from sculling actions
- drag forces – from pull action
- legs contribute to propulsion in whip and dolphin kicks, but less so in flutter kick

Resistive forces:
- form drag – X-C area (viewed from the front)
- surface drag – typically small, reduced by flutter kick. Also by speed suits
- wave drag – caused by lifting water above surface level
  (minimise rolling and vertical motion of the body)
Basic propulsion instructions

“new water”
Hand to move into still water and accelerate it (generate a force against it)
hand must move in a 3 dimensional curve
if the hand moves in a straight line backwards, it cannot accelerate as much water!

“lift”
additional force can be gained by pitching the hand so that it acts as a wing (producing lift as well as drag)
this is called ‘sculling’

Factorial Model of Swimming, cont’d

Diagram showing the decomposition of swimming time into starting time, stroking time, turning time, and their subcomponents such as average turn time, number of turns, glide time in, turn time, glide time out, and turn technique.
Turns

turns take between 20 - 35% of race time!
the longer the race the more important turns become
Observational research has shown that a 'piked' turn is faster than a 'tucked' turn

Physics principles needed for swimming

Need to stay at the surface
Need to produce propulsive forces
Need to minimise resistive forces

Definitions and concepts
Application to swimming
Definition of a “Fluid”

A fluid is any substance that tends to flow or continuously deform when acted upon.

Gases and liquids - fluids with similar mechanical behavior.

-- but compressible vs. incompressible

Relative Velocity

Velocity of a body with respect to the velocity of something else such as the surrounding fluid.

The velocity of a body relative to a fluid influences the magnitude of the forces exerted by the fluid on the body.
Other important Fluid Properties

Fluid Density - mass per unit volume (i.e., 1 g/ccm), \( \rho = 1 \, \text{g/cm}^3 \)

Fluid Viscosity - internal resistance of a fluid to flow (oil vs water)

In addition:
Temperature & atmospheric pressure affect both above

Forces exerted by fluids: Buoyancy

- in water, the buoyant force equals the weight of the volume of water displaced.
- the "centre of buoyancy" is at the centre of mass of the volume of water displaced
Will a body float or not???

A body will float only if:

\[ \text{Wt of body} \leq \text{Wt of an equal amount fluid} \]

This can also be stated as:

\[
\frac{\text{Weight of body}}{\text{Weight of an equal amount of fluid}} \leq 1
\]

termed: "Specific Gravity of Body"

Specific gravity of a body

Effects of:
1. Volume of air in lungs
2. Age (very young or very old)
3. Females vs Males
4. Body composition
Forces exerted by fluids: Buoyancy

- weight: Always vertically downward!!!
- Archimedes’ principle: magnitude of buoyant force on a given body = weight of the fluid displaced by the body

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Pressure approach

\[ P_x = \rho \times h_x \]
In a wave ...

A circular shape is a bad body surfer...

Wave Drag = energy loss

- motion at the interface of body and fluid causes waves, takes energy and slows down the swimmer/boat/etc.
- But you can use waves! In swimming, the lane markers are designed to reduce wave motion between lanes
Drag

Drag = resistance force - slowing the motion of a body moving through fluid

Drag force:

\[ F_D = \frac{1}{2} C_D \rho A_P v^2 \]

\( F_D \) = drag force; \( C_D \) = coefficient of drag; \( \rho \) = fluid density, \( A_P \) = projected area of body or surface area of body oriented \( \perp \) to fluid flow; \( v \) = relative velocity of body with respect to fluid

Examples of Coefficient of Drag

A

\[ C_D = 0.26 \]

B

\[ C_D = 0.36 \]

C

\[ C_D = 1.20 \]
Factors affecting Drag

\[ F_D = \frac{1}{2} C_D \rho A_F v^2 \]

\( C_D \) = affected by shape & orientation of body to relative to fluid flow

\( \rho \) = medium density - e.g., air density decreases with altitude 1968 Olympic Games in Mexico City (2250m) - many world records set!

\( v \) = greatest effect!!! “Theoretical square law” - if e.g., cyclist at double speed; other factors remain unchanged: drag force opposing increases 4 times!!!!

Form Drag

form drag depends on the cross-sectional area presented to the flow

’sstreamlining’ is an attempt to minimize form drag

sometimes you want to maximize form drag:

- oar blade
- sailing downwind
What is Form Drag???

Separation of flow from boundary and subsequent re-uniting of the divergent paths causes a "pocket" to be formed behind moving body.

Pocket has "lower pressure" versus "high pressure" resulting from oncoming airflow striking the front of the body.

Whenever a pressure differential exists, a force is directed from the region of high pressure to the region of low pressure = FORM DRAG ( = $C_D$)

An example: streamlining (short)
Laminar vs Turbulent flow

Laminar - flow in parallel layers
Turbulent - flow with violent intermixing of fluid

Affected by:
1. form of body
2. relative velocity
3. surface roughness of body

Modifying boundary layer turbulence

you can reduce drag by reducing turbulence
a rough patch on the surface will reduce the separation angle and thus reduce drag

Images of a ball in a wind tunnel. On the right, the ball had sand glued to the front of it. Notice the separation angle change.
Speed suits

many sports now use suits which incorporate rough patches designed to reduce the separation angle and decrease the drag

What is surface drag?

Example: water rushes past an object, layer of water in contact with object is slowed down due to forces the object's surface exerts on it - that layer of air slows down the layer of air next to it etc. ....

Boundary layer: region within which fluid velocity is diminished due to shearing resistance caused by boundary of moving body

Depending on velocity & nature of body, the boundary layer becomes unstable & turbulent - i.e., change from laminar to turbulent flow!
Surface Drag

Surface drag depends on the smoothness of the surface and the velocity of flow. Shaving in swimming - big effect???
Other examples of sports to decrease surface drag....???

A note on the technological advancement of the swimsuits
The Perfect Material

In the past: Hairless skin better than suit
Human skin: Too porous, turbulence too high
Shark skin: Scales spaced very closely together
   Hydrophobicity, turbulence control → Drag resistance “slice the water.”
Fastskin I and II developed by Speedo
Coverage: Eventually from feet to hands
Oxygen bubbles along stitches

The Perfect Shape

Following three years of research that included input from NASA, tests on more than 100 different fabrics and suit designs, and body scans of more than 400 elite swimmers, Speedo has launched its most hydro-dynamically advanced - and fastest - swimsuit to date.
- February 14th, 2008
Extreme tight fit: Streamline body shape - reduce (bad) vibrations.
FINA hits the brakes - but too late
Intention: Ban all hi-tech suits before WC 2009
Failed to address 136 enquiries
-> all suits were allowed
Super materials: 100% Polyurethane, Hydrofoil

Restrictions by FINA - 1st Jan 2010
Surface covered: Men swimsuit shall not extend above the navel nor below the knee and for women shall not cover the neck or extend past the shoulders nor shall extend below the knee.

Type of material: The material used for swimsuits can be only "Textile Fabric(s)" defined for the purpose of these rules as material consisting of, natural and/or synthetic, individual and non consolidated yarns used to constitute a fabric by weaving, knitting, and/or braiding.

Additional rules for: surface treatment, flexibility, variety of materials, thickness, buoyancy, permeability, construction etc.
World Records Never To Be Broken?

FINA: Records set at WC 2009 will stand.

"Though the changes won’t go into effect at the world championships that begin Sunday in Rome, they will hang over the competition, seemingly wagging a finger at every world-record setter wearing a suit that will never be allowed again in a major swimming championship."

- The Washington Post, July 2009

~ 130 WR's broken since launch of high-tech suits

Magnus Effect

If a ball spins in flight, it will drag some of the air close to the surface with it. This creates an area of high pressure and an area of low pressure on opposite sides of the ball. This pressure imbalance will make the ball curve in flight.

[Diagram showing Magnus Effect]

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An example: streamlining

Consider a "foil" shape - fluid flows over the curved side & is accelerated while on the flat side it remains virtually unchanged

This difference in velocity of flow creates low pressure on curved side & high pressure on flat side

Remember that force is directed \( \perp \) to foil from area of high pressure to area of low pressure..... causing "lift" = more effective!!!

Now! Do the stroke!
•Freestyle stroke (butterfly is very similar)

Breaststroke pattern - relative to the a) swimmer and b) pool
virtually no ‘pull’ in breaststroke
scull out, then scull in
LIFT forces from L & R limbs add to propulsion in
sculling motion
DRAG forces cancel in sculling motion

Lift and Drag Forces on a Discus
(Wind v = 25 m/s)

Angle of Attack
(Degrees) | Lift (N) | Drag (N) | Lift/Drag
--- | --- | --- | ---
0 | 0.000 | 0.036 | 0.000
10 | 0.135 | 0.047 | 2.890
20 | 0.331 | 0.128 | 2.579
30 | 0.348 | 0.254 | 1.371
40 | 0.264 | 0.297 | 0.890
50 | 0.268 | 0.380 | 0.705
60 | 0.214 | 0.466 | 0.459
70 | 0.148 | 0.511 | 0.290
80 | 0.079 | 0.525 | 0.151
90 | 0.000 | 0.551 | 0.000

Angle of attack – angle btw longitudinal axis of a body & direction of fluid flow
Need to take some drag into account to enable "lift"!
Back to swimming reality: Relationships between stroke length and frequency

SF for freestyle, butterfly and breaststroke are similar and greater than for backstroke as race distance increases, SL increases, SF decreases and speed decreases differences in ability are due primarily to stroke length, with better swimmers having greater SLs
to increase speed in the short term (i.e., on the day) increase stroke frequency
to increase speed in the long term (i.e., over the season) train to increase stroke length

Summary

Factor (subjective) model - be aware of the complexity of mechanical factors in swimming resistive and propulsive forces - what are they, and how can you maximise propulsive and minimise resistive forces starts - a case of optimising distance in the air plus distance in the glide strokes - how do the principles of 'new water' and 'lift' influence stroke shape? understand the relationships between SL and SF turns - play a much more important part in races over 100m that most swimmers realise. Turn practice is essential!
Points to remember

Forces exerted by fluids

- **buoyancy** - magnitude and location (+ effect on floating position)
- **Bernoulli’s Principle** - increased velocity of flow results in decreased pressure
- **lift & drag forces**
  - result from objects being in a fluid flow.
  - The drag force is aligned with the flow and the lift force is perpendicular to it.
  - Maximum lift at 45°, zero lift at 0° and 90°.
- **Form drag** depends on the X-C area presented to the flow and geometry
  - important in streamlining and minimizing frontal area
- **Surface drag** is comparably small but may be decisive

Acapulco ...

or what I left out...

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