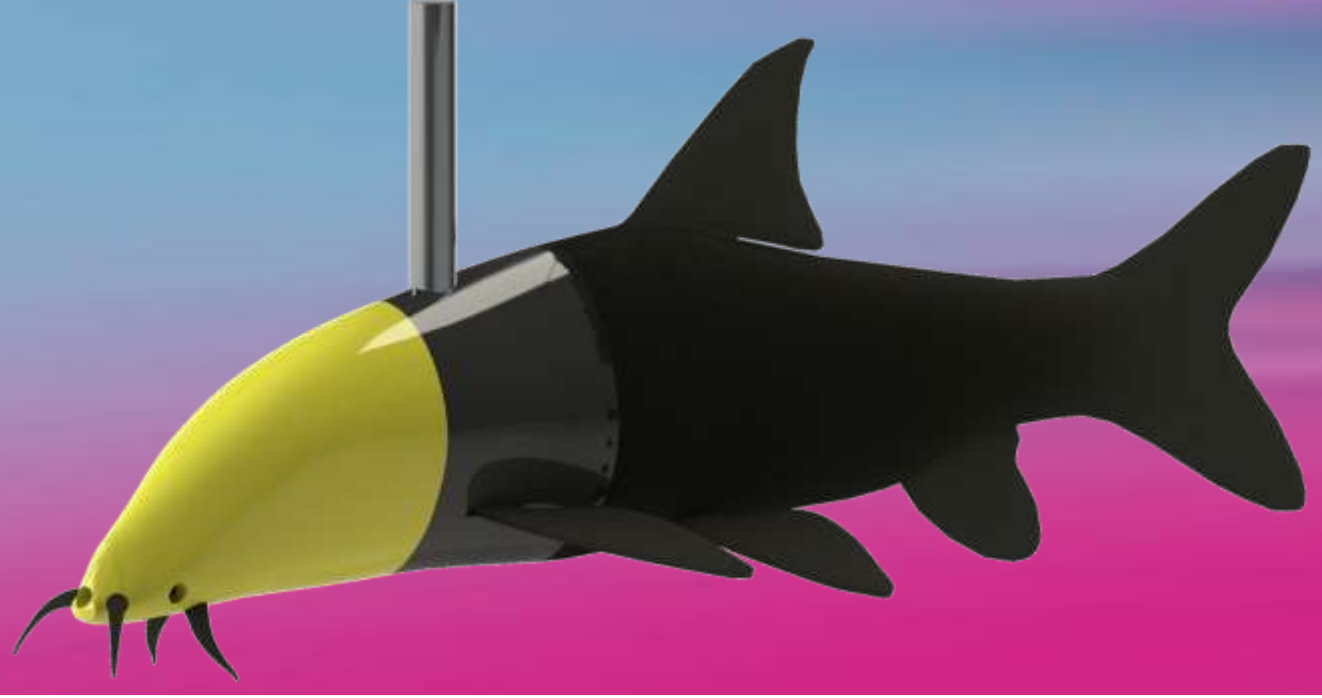

COMPARISON OF NEAR-BODY FLOW FIELDS OF A GUDGEON AND NACA0013 PROFILE

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FLOW FIELDS AROUND STREAMLINED BODIES

- Flow fields
  - velocity
  - pressure
  - acceleration

- Lateral line mechano-receptors
  - Superficial neuromasts (< 20 Hz)
  - Canal neuromasts (< 200 Hz)

- Active sensing space
  - 3D spatial distance around fish

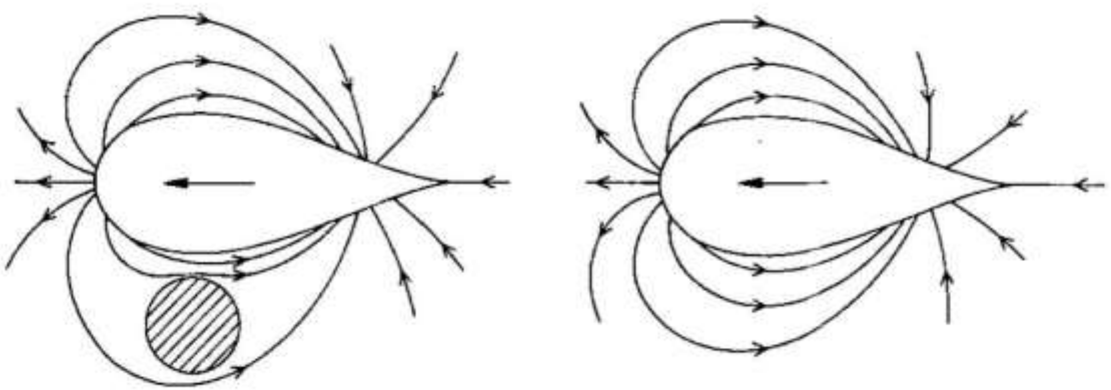

Fig 1: Schematic diagram of the current flow around a gliding fish[1]

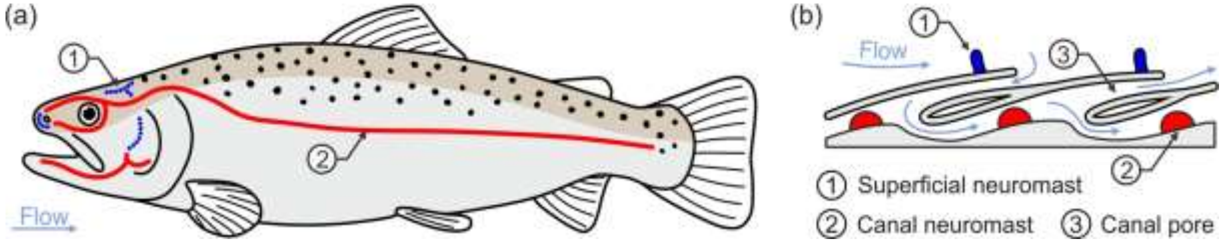

Fig 2: Representation of lateral line along the body of fish from head to tail region[2]

[1] *El-S.Hassan. Mathematical analysis of the stimulus for the lateral line organ. Biological Cybernetics 1985; 52: 23-36*
[2] *Tuhtan, J. A., Strokina, N. , Toming G. et al. Hydrodynamic Classification of Natural Flows Using an Artificial Lateral Line and Frequency Domain Features. Proceedings of the 36th IAHR World Congress 2015*

BOUNDARY LAYER AROUND STREAMLINED BODIES

Boundary layer characteristics

- Strong viscous effects at fish swimming Reynold number ($10^2<Re<10^5$)
- Boundary layer thickness gradually grows along the body length and changes from laminar to turbulent
- Boundary layer thickness is influenced by the Reynold number (Re). Higher Re tends to result in a thinner boundary layer
- Pressure remains constant across the boundary layer whereas the velocity alters abruptly

Why boundary layer around fish is important?

- Acts as a high pass filter attenuating low-frequency stimuli[2]

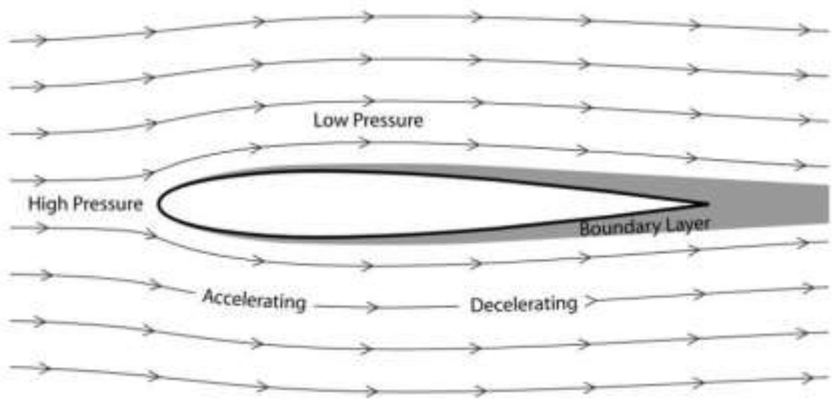

Fig 3: Flow field around a gliding fish or other streamlined bodies. On the surface of fish, a thick boundary layer forms due to viscous effects [1].

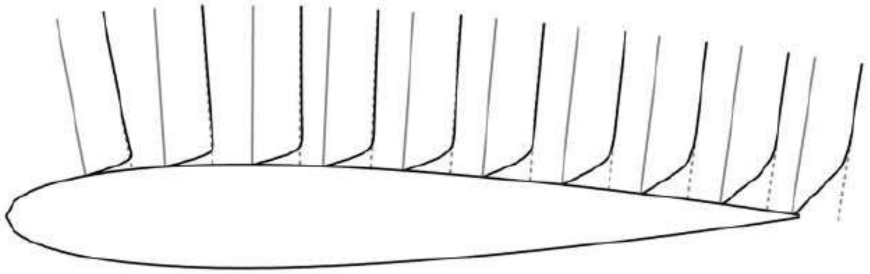

Fig 4: CFD boundary layer velocity profiles of flow around a revolved 3D body based on a NACA 0013 aerofoil at Re 6000 [1].

[1] Windsor SP, McHenry MJ. The influence of viscous hydrodynamics on the fish lateral-line system. Integrative and Comparative Biology. 2009 08;49(6):691-701
[2] McHenry MJ, Strother JA, van Netten SM. Mechanical filtering by the boundary layer and fluid–structure interaction in the superficial neuromast of the fish lateral line system. Journal of Comparative Physiology A. 2008 09;194(9):795-810

NACA 0013 AEROFOIL

- Streamlined body optimized to reduce drag and efficient flow around it
- It is symmetrical, meaning its upper and lower surfaces are identical
- The axisymmetric body of revolution based on a NACA 0013 aerofoil is commonly used as fish analogy [1,2].

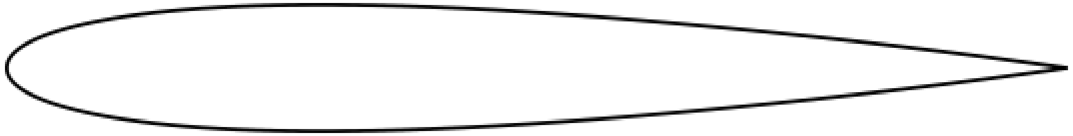

Fig 5: 2D NACA 0013 airfoil of total length 15 cm (NASA/Langley LS(1))

Fig 6: 3D axisymmetric body of NACA 0013 aerofoil representing fish

[1] Windsor SP, Norris SE, Cameron SM, Mallinson GD, Montgomery JC. The flow fields involved in hydrodynamic imaging by blind Mexican cave fish (Astyanax fasciatus). Part I: open water and heading towards a wall. Journal of Experimental Biology. 2010 11;213(22):3819-31
[2] Hassan, E. S. (1992a). Mathematical description of the stimuli to the lateral line system of fish derived from a three-dimensional flow field analysis - I The cases of moving in open water and of gliding towards a plane surface. Biological Cybernetics, 66(5), 443–452

RESEARCH QUESTIONS

- Can the NACA 0013 airfoil serve as an effective approximation for the flow fields observed around realistic fish geometries?
- Does the boundary layer thickness around the NACA 0013 airfoil resemble that around a fish-shaped body?
- Can the NACA 0013 airfoil be employed as a representative model for ecological research related to fish?

METHODOLOGY

- Developing three-dimensional CAD models for a NACA 0013 airfoil and a gudgeon fish
- Conducting RANS simulations at two different velocities for both bodies
- Performing an analysis of the flow fields surrounding both bodies to identify potential divergence.

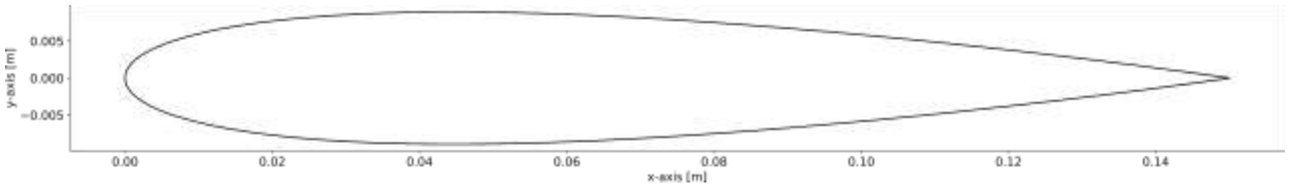

Fig 7: 2D NACA0013 airfoil of with total body length of 15 cm (NASA/Langley LS(1))

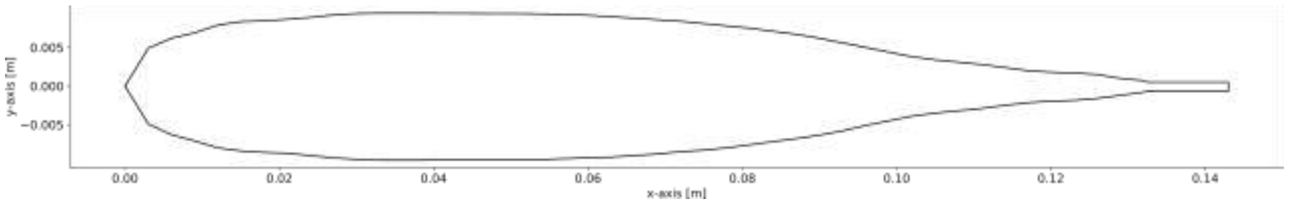

Fig 8: 2D Gudgeon body profile in xy-plane preserving the same body length of 15 cm

Tab 1: Channel specifications and inlet flow velocities

Channel dimensions	Mean flow velocity $\bar{U}$ $[ms^{-1}]$	Flow rate Q $[ms^{-3}]$	Reynold Number Re	Froude Number Fr
LxWxH	0.25	$1.41x10^{-3}$	$3.74x10^{4}$	0.21
28x7.5x7.5 cm	0.55	$3.09x10^{-3}$	$8.24x10^{4}$	0.45

NUMERICAL MODEL

Computational fluid dynamics (CFD) Model

- **OpenFOAM-v2112** framework
- Rectangular domain
- RANS models implementation
  - *Spalart Allmaras*
  - *Near wall modelling*
  - *Fully resolved $y^+<1$*
- Unstructured mesh with *cfMesh*
  - *Hexahedral*
  - *Polyhedral*
- *Mesh and time sensitivity analysis*

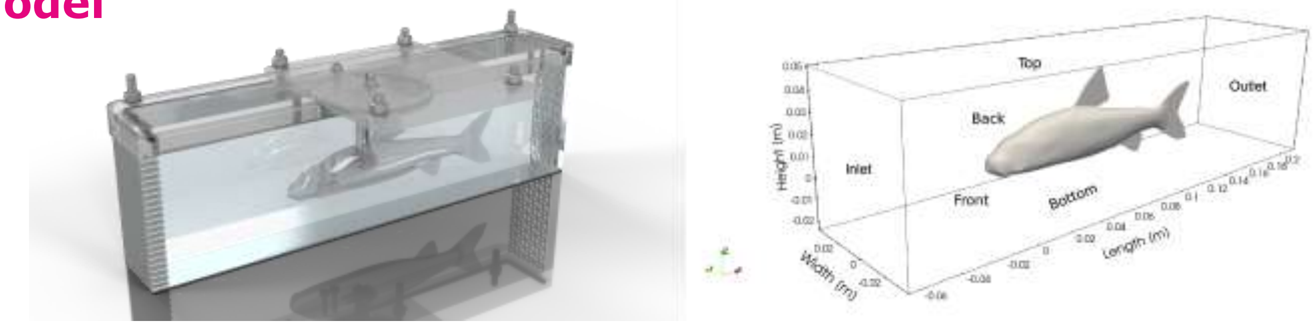

Fig 9: Generation of a three-dimensional model of the domain containing the fish, while explicitly defining the boundaries.

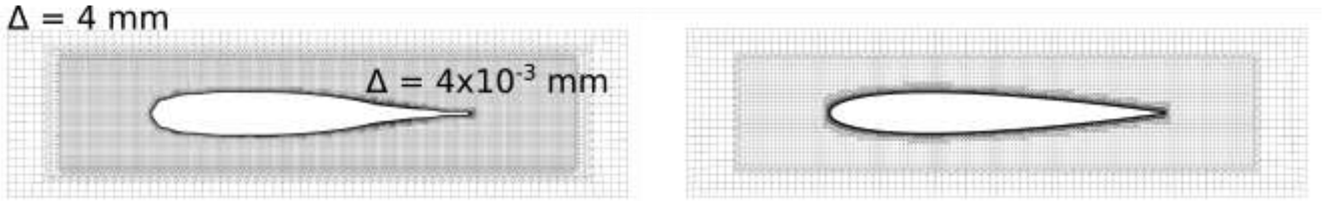

Fig 10: 2D planar view of domain discretized around the Gudgeon and NACA 0013 aerofoil into an unstructured mesh

BOUNDARY LAYER THICKNESS

Boundary layer thickness comparison b/w Gudgeon and NACA0013

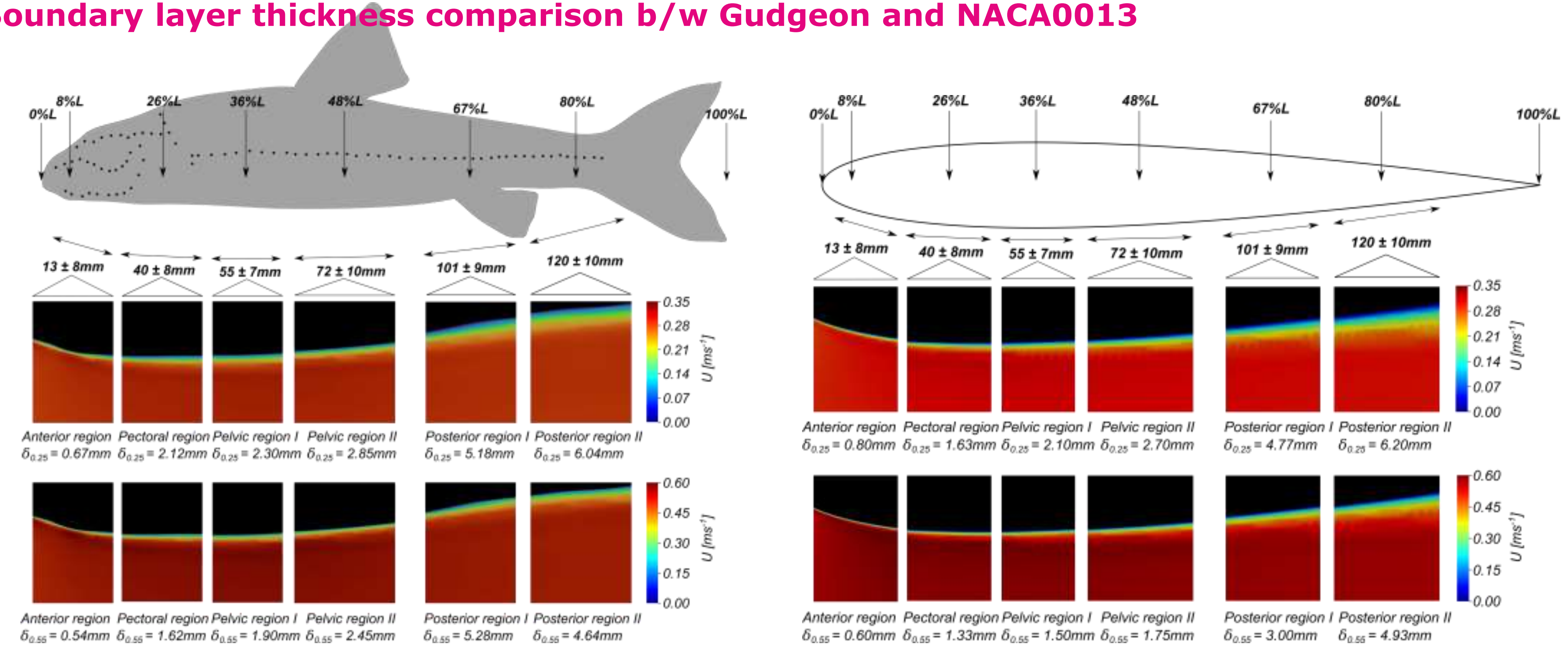

Fig 11: The layout of canal neuromasts along the body of a gudgeon fish[1]. The fish body is classified into multiple regions i.e., anterior, pectoral, pelvic and posterior. Bottom: 2D planar view (z=0) of velocity fields around the gudgeon fish model at both free stream velocities representing the boundary layer thickness[2] in respective regions.

[1] Schmitz A, Bleckmann H, Mogdans J. The lateral line receptor array of cyprinids from different habitats. Journal of Morphology. 2014 04;275(4):357-70.
[2] Schlichting H, Gersten K. Boundary-Layer Theory. Springer-Verlag Berlin Heidelberg; 2000

VELOCITY PROFILES

Normal velocity distribution at the surface

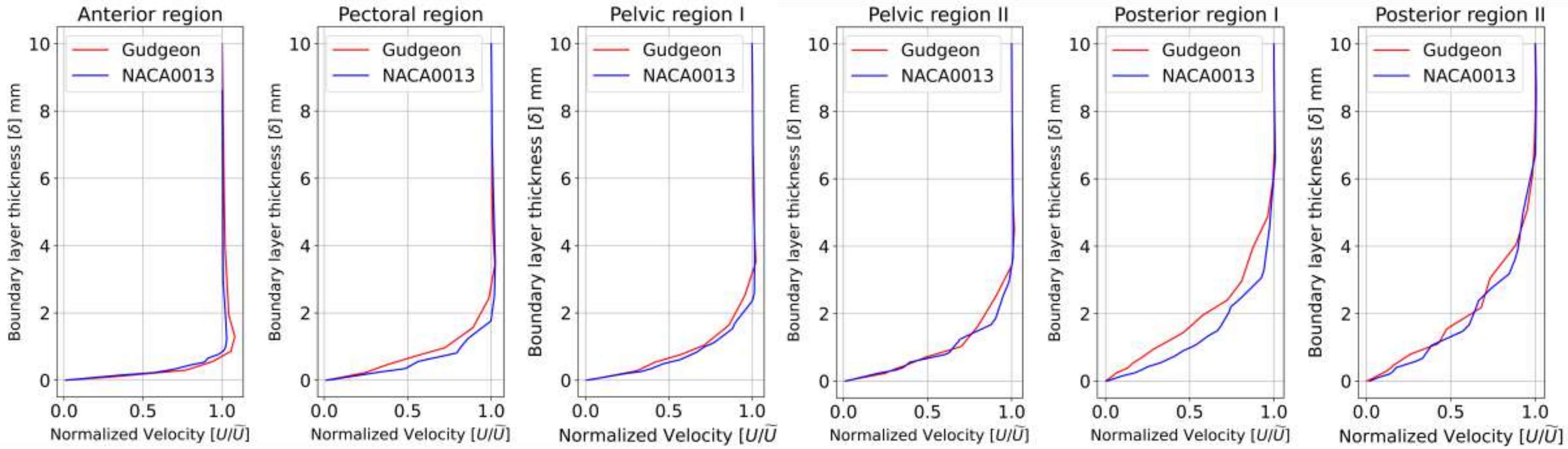

Fig 12: Boundary layer velocity profiles in respective regions around the gudgeon and NACA0013 at U_{inlet}=0.25 ms^{-1}

CONCLUSION

- *The boundary layer thickness of a gudgeon body marginally differentiates from that of the NACA0013 model*
- *Both models exhibited thinner boundary layers in the anterior region*
- *The mean flow velocity around head region of gudgeon body is slightly higher than the NACA0013 model due to the protuberant organs*
- *The minor differences in the flow field around both geometries indicate that using simplified fish-like bodies would be a suitable approximation of the fish for boundary layer studies*
- *It reveals that the thickness of the boundary layer is reduced in the region characterized by a high concentration of neuromasts i.e., the initial 20% of the body length.*

RECOMMENDED READINGS

- El-S.Hassan. Mathematical analysis of the stimulus for the lateral line organ. Biological Cybernetics 1985; 52: 23-36
- Tuhtan, J. A., Strokina, N. , Toming G. et al. Hydrodynamic Classification of Natural Flows Using an Artificial Lateral Line and Frequency Domain Features. Proceedings of the 36th IAHR World Congress 2015
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Thank you