Estimation of the drag force: a neuronal approach

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Context

- **Aerodynamic drag = 80-90% of resistive forces**

- **Effective Frontal Area (ACd) : $F = 0.5\ ACd\ \rho\ v^2$**
- **ACd should be reduced so must be quantified**

- **Existing Method :**
  - Wind tunnel
  - Dynanometric measurement
  - Deceleration + Linear regression
  - **Recently 3D digitilization + CFD**

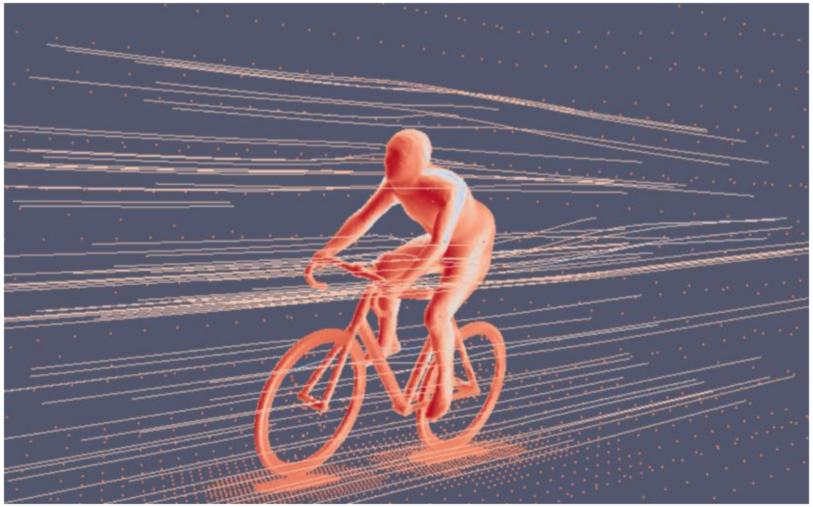
3D + CFD

- **Cyclist Digitalization**

- **Set-up : 4 RGB-D Sensors**

3D + CFD

- **CFD solver : OpenFoam**



➔ **Drag force from simulation**

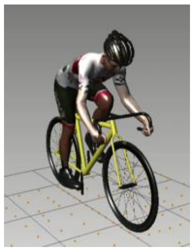
- **Excellent agreement with wind tunnel experimental data**

3D + CFD

- **Low operating and equipment costs**
- **Measuring conditions closer to real world**
- **Many experiments are possible :**
  - Simulating different wind conditions
  - Simulating different cyclist speeds
  - Assessing different equipments (helmet,wheel, …)
  - Simulating team pursuit
  - **But CFD simulations are time consuming**

Our proposal

- 3D + CFD



3D models

→ **CFD simulation** →

Drag force

Simulation time
= some **hours**

- 3D + neural network

3D models

→ **Neural network** →

Drag force

Processing time
= some **seconds**

Neural network inputs

- **Inputs = body parametric model + bike model + wind**
  - Parametric body model produced by our 3D scanning device
  - Model is composed of:
    - Anatomical features (morphology)
    - Pose features (posture)
  - Bike dimensions
  - Wind speed and direction

➔ **70 (posture) + 10 (morphology) + 50 (bike) = 130 parameters**

➔ Too much parameters ➔ Over-fitting

Neural network inputs

- Dimension reduction

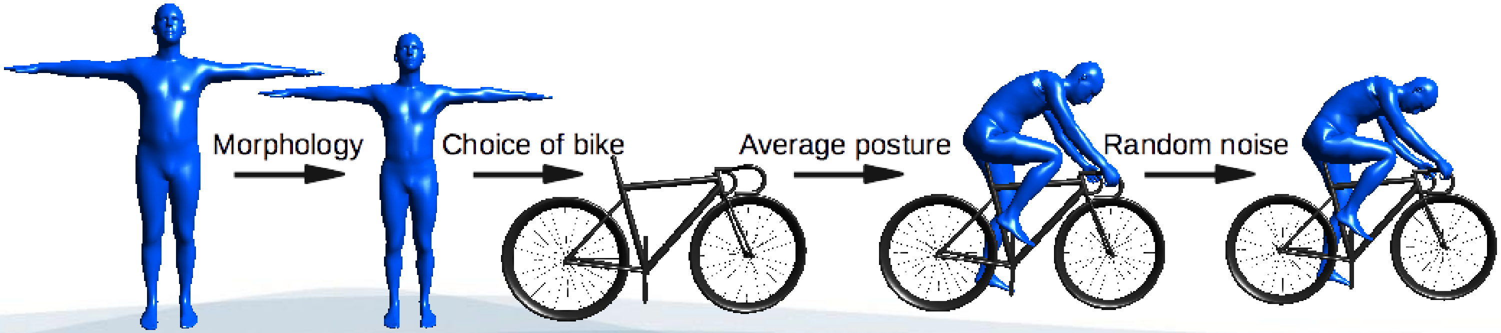
- Morphology : gender + 4 most significant parameters
- Bike description:
  - Saddle height
  - Crank angle
  - Handle bar height
  - Horizontal distance between bottom bracket and handle bar
- Posture description:
  - Hand pose (top, brake or down)
  - Average left and right shoulder torsion
  - Average left and right elbow flexion
  - Head and back flexion.
- Wind speed and direction

➔ **16 parameters**

Dataset for learning

- Creating a cyclist model

- Morphology : randomly chosen
- Bike description:
  - Bike frame chosen according to the resulting body size
  - Saddle height, handle bar height and stem randomly altered around the nominal values
  - Crank angle randomly chosen
- Posture description:
  - Hand pose randomly chosen
  - Body model placed on the bike
  - Head flexion, spine flexion, elbow flexion and shoulder torsion randomly modified



Dataset for learning

- One sample

- A cyclist model
- Wind speed and direction randomly chosen

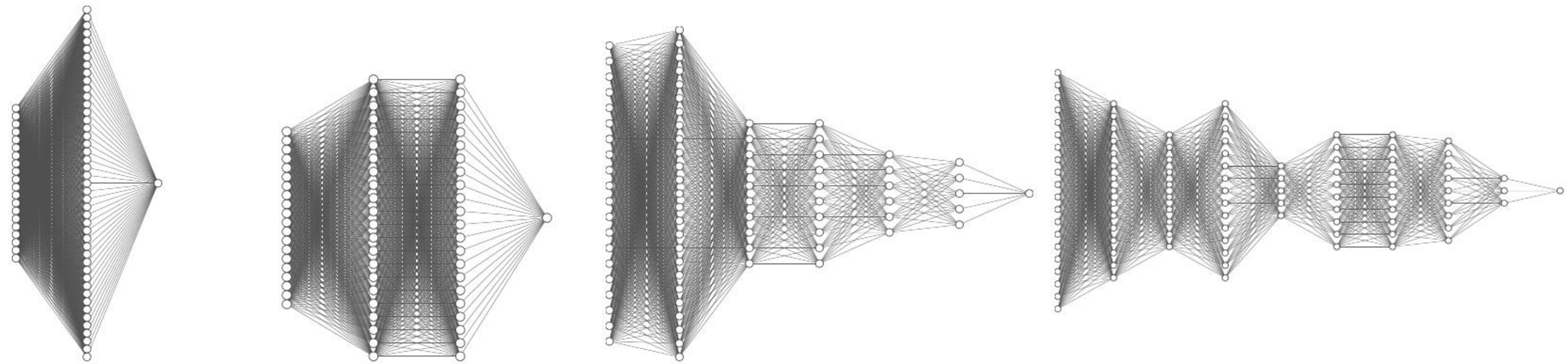
- **Inputs : 16 parameters**
- **Output : drag force from OpenFoam simulation**

- Dataset:

- 100 000 samples
- From 11 000 differents cyclist models
- Several wind directions and speeds ranging from 20 to 60 km/h.
- 1/3 of the data corresponds to a headwind

Neural network

- **MLP architectures**



(a) 1 hidden layer (b) 2 hidden layers (c) 5 hidden layers (d) 8 hidden layers

- **LeakyReLU activation functions + linear activation function**

➔ solving the problem of vanishing gradient

Results (1)

- **Evaluation**

  – 25% of the data kept for validation (cross validation)

  – Metric = RMSE :

$$MSE = \frac{1}{n} . \sum_{i=1}^{n} (Y_i - \hat{Y}_i)^2 \qquad RMSE = \sqrt{MSE}$$

- **Best architecture**

  – Architecture with 25, 10, 10, 6 and 5 neurons in 5 hidden layers

  – Difference between the “neural” (prediction) and CFD (output of the solver) drag forces = **0,95 Newton**

- **Encouraging results**

  BUT we need an indicator of the expected error on real data

  (synthetic data does not include all the small variations seen in the real world)

Results (2)

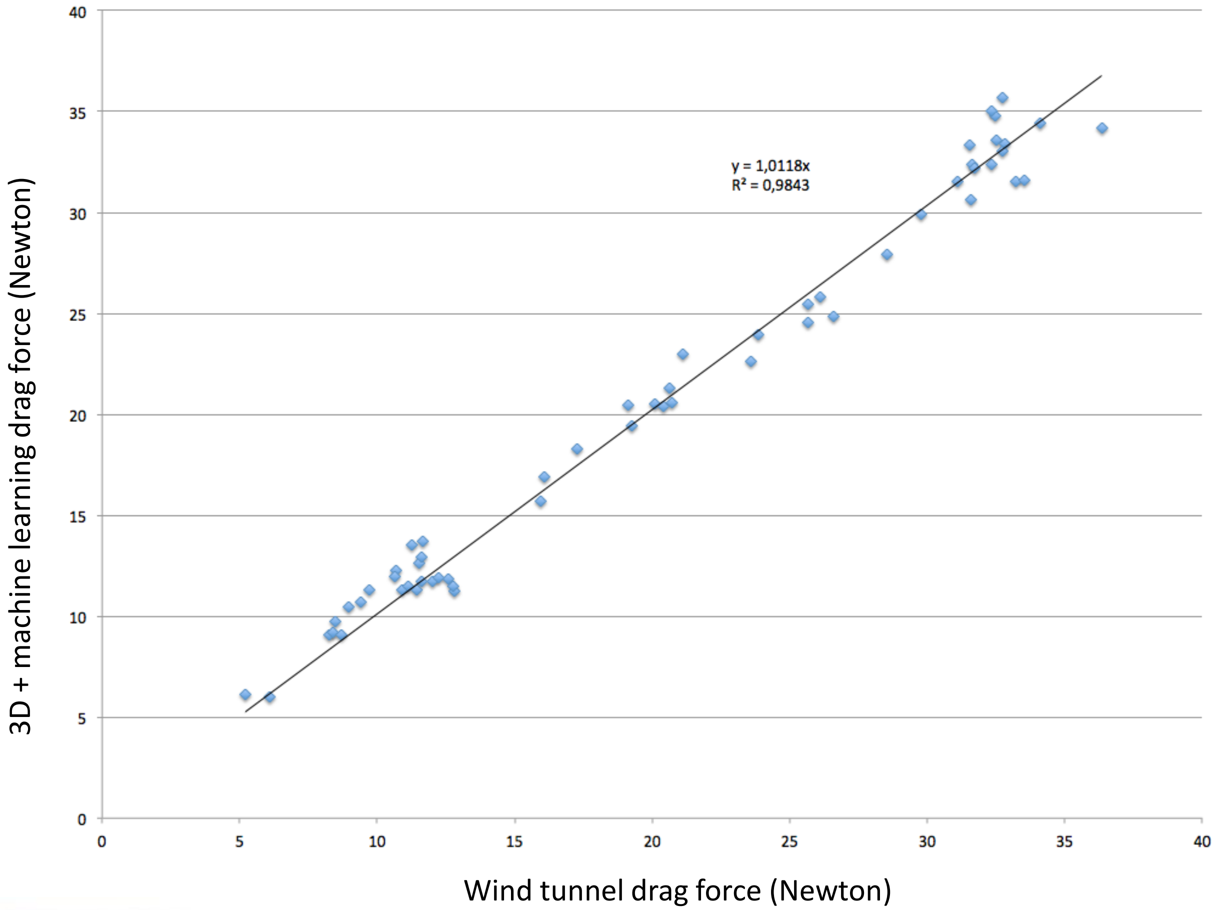
- **Comparison wind tunnel / 3D + neural network**

Correlation = **0,984**

Proportionnality = **1,01**

RMSE = **1,2 Newton**

Only headwind



Conclusion

- **Machine learning-based technique**

  ➔ **Fast approximation of a time-consuming CFD simulation**

- **Results**
  - Good approximation of CFD simulation (RMSE = 1,7 Newton)
  - Good approximation of wind tunnel measurements (RMSE = 1,2 Newton)

  ➔ **Promising method !**

- **Future works**
  - Validation for winds from all directions
  - Taking into account the shape of the equipments (helmet, wheels, ...)
  - Replacement of the CFD part of our drag force measurement system

Questions ?