Experimental evaluation of the repeatability of wind tunnel measurement of cyclist's drag

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Context

- **Aerodynamic drag = 80-90% of resistive forces**
- **Drag should be reduced so must be quantified**
- **Existing Method :**
  - Dynanometric measurement
  - Deceleration + Linear regression
  - Recently 3D digitilization + CFD

  - **Wind tunnel = gold standard**
    - **repeatability**
    - **accuracy**

Context

- **Problem : the repeatability of rider's position**

- **A rider is NOT a mannequin :**
  - Unable to **maintain** perfectly a position
  - Unable to **reproduce** perfectly a position

  ➔ **Small variations in position**

➔ **Overall repeatability of wind tunnel drag measurements**

> Pure repeatability of wind tunnel measurements

Context

- **For wind tunnel cyclist's drag measurements :**

  repeatability in real procedures = overall repeatability

- **Overall repeatability is not known (to the best of our knowledge)**

- **We will evaluate the repeatability :**
  - for two wind speeds
  - with/without pedaling movements
  - while staying still on the bike or getting on after getting off

Experimental data

- **Aero Concept Engineering's facility in Magny-Cours (France)**
  - single return closed-circuit wind tunnel
  - width: 2.3 m, height: 2.2 m, length: 4,75 m
  - 6-components balance (500Hz for 15 seconds)
  - air temperature, wind speed and atmospheric pressure

- **Data processing:**
  - averaging the values given by the balance
  - computing effective frontal area (to compensate for changes in air parameters):

$$AC_d = \frac{2F}{\rho V^2}$$

Experimental data

- **Measurements of the drag of a bike alone**
- **Measurements of the drag of a cyclist**
  - height: 1.85 m, weight: 71 kg
  - constant position (brake hoods)

Series	Pedaling	Holding a static position	Get off an get on the bicycle	Wind speed	Number of measurements
Bike 1	NO	YES	NO	60	12
Bike 2	NO	YES	NO	80	12
1	NO	for 3 minutes	NO	50	5
2	NO	for 5 minutes	NO	30	10
3	NO	for 10 minutes	NO	30	5
4	NO	for 10 minutes	NO	50	5
5	NO	NO	YES	30	10
6	NO	NO	YES	50	10
7	YES	NO	YES	30	20
8	YES	NO	YES	50	20

Results

- **Statistics**
  - mean
  - unbiased standard-deviation
  - relative amplitude (difference between maximum and minimum values divided by the average value in %)

Series	Mean	Standard deviation (10e-3)	Relative amplitude (%)
Bike 1	0,099	0,416	1,051
Bike 2	0,099	0,073	0,252
1	0,320	1,856	1,459
2	0,337	3,554	3,285
3	0,347	9,589	6,733
4	0,340	6,522	4,686
5	0,356	7,979	7,218
6	0,325	6,336	6,261
7	0,383	11,259	10,066
8	0,355	5,725	6,179

Results

- **Drag measurement of a stationnary object**

  ➔ **highly repeatable**

Series	Bike 1	Bike 2
Wind speed	60	80
Number of measurements	12	12
Mean	0,099	0,099
Standard deviation (10e-3)	0,416	0,073
Relative amplitude (%)	1,051	0,252

Results

- **Drag measurement of a cyclist holding a static position**

  ➔ **correct repeatability but decreases quickly with time**

Series	1	2	3	4
Pedaling	NO	NO	NO	NO
Holding a static position	for 3 minutes	for 5 minutes	for 10 minutes	for 10 minutes
Get off an get on the bicycle	NO	NO	NO	NO
Wind speed	50	30	30	50
Number of measurements	5	10	5	5
Mean	0,320	0,337	0,347	0,340
Standard deviation (10e-3)	1,856	3,554	9,589	6,522
Relative amplitude (%)	1,459	3,285	6,733	4,686

Results

- **Drag measurement of a cyclist in real conditions**

➔ **poor repeatability and great measurement amplitudes**

Series	5	6
Holding a static position	YES	YES
Get off an get on the bicycle	YES	YES
Wind speed	30	50
Number of measurements	10	10
Mean	0,356	0,325
Standard deviation (10e-3)	7,979	6,336
Relative amplitude (%)	7,218	6,261

Results

- **Drag measurement of a cyclist in real conditions (pedaling)**

➔ **poor repeatability and great measurement amplitudes**

Series	5	6	7	8
Holding a static position	YES	YES	Pedaling	Pedaling
Get off an get on the bicycle	YES	YES	YES	YES
Wind speed	30	50	30	50
Number of measurements	10	10	20	20
Mean	0,356	0,325	0,383	0,355
Standard deviation (10e-3)	7,979	6,336	11,259	5,725
Relative amplitude (%)	7,218	6,261	10,066	6,179

Results

- **Drag measurement of a cyclist in real conditions (pedaling)**

➔ **measured drag significantly greater than in static case**

Series	5	6	7	8
Holding a static position	YES	YES	Pedaling	Pedaling
Get off an get on the bicycle	YES	YES	YES	YES
Wind speed	30	50	30	50
Number of measurements	10	10	20	20
Mean	0,356	0,325	0,383	0,355
Standard deviation (10e-3)	7,979	6,336	11,259	5,725
Relative amplitude (%)	7,218	6,261	10,066	6,179

Conclusion

- **Global repeatability of wind tunnel drag measurements**
- **Results**
  - Good repeatability for stationary object (bike)
  - Correct repeatability when cyclist holds position for a short time
  - Poor repeatability in real conditions (pedaling or not)
    = when cyclist gets off and gets on the bike between two measurements
  - Great measurements amplitudes (> 6%)
  - Drag measurements while pedaling greater than in static case (≈8 %)

Conclusion

- **Measuring small differences in cyclist drag (<10 %)**

  is highly questionable !

- **Two solutions:**
  - working with mannequins
  - greatly increasing the number of measurements
- **Lack of repeatability comes from the cyclist's inability to maintain or reproduce his position**

➔ **Conclusions should be valid for any measurement technique**

Questions ?