Cycling Aerodynamics

Clearing the air
Learning objective

Become an educated user of aerodynamic information

- Importance of aerodynamics
- Aerodynamics 101
  - The basics of flow
- Wind Tunnels
  - How they work
  - Cycling test protocol
- Wind tunnel test results
  - Equipment
  - Rider position

Active learning
Quiz #1 – Energy cost of drag

Estimate the percentage of the cyclist’s energy used to overcome the air resistance at racing speed (48 kph or 30 mph). Assume the wind isn’t blowing.

- 0 – 25%
- 26 – 50%
- 51 – 75%
- 76 – 100%
Quiz #1 – Energy cost of drag

- 0 – 25%
- 26 – 50%
- 51 – 75%
- 76 – 100%

Aerodynamic Drag
~ 90%, ~ 2/3 is the rider!

Rolling Resistance ~ 10%
Drive Train Loss < 1%
Energy cost of drag

Alpine Skiing ~ 40-80%

Running ~ 6-14%

XC Skiing ~ 20-25%

Bobsled ~ 50%

Speed Skating ~ 90%
Let’s assume a 5% drag reduction

<table>
<thead>
<tr>
<th>Olympic Event</th>
<th>Time Savings</th>
<th>Place</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycling M ITT (46.8 km)</td>
<td>0.8 sec</td>
<td>4th</td>
</tr>
<tr>
<td>Speed Skating W (5 km)</td>
<td>0.8 sec</td>
<td>3rd</td>
</tr>
<tr>
<td>Alpine Downhill M</td>
<td>0.4 sec</td>
<td>4th</td>
</tr>
<tr>
<td>XC Skiing W (30 km)</td>
<td>0.3 sec</td>
<td>3rd</td>
</tr>
<tr>
<td>Running M (10 km)</td>
<td>0.2 sec</td>
<td>4th</td>
</tr>
</tbody>
</table>
Aerodynamics 101

The basics of flow

Kim B. Blair PhD
Vice President
Air flow around objects

Bernoulli’s Equation (conservation of energy)

\[ P + \frac{1}{2} \rho V^2 = C \]

- \( P_s \) = static pressure
- \( \rho \) = Density of the fluid
- \( V_\infty \) = Free-stream velocity
- \( C \) = Constant

Streamline
- Flow of fluid around an object

Drag
- Net force on an object due to the pressure difference

Image by MIT OpenCourseWare.
Boundary layer

Boundary Layer
- Thin layer of fluid on the surface of the object
  - Friction of the surface
  - Viscosity of the fluid

Streamlines of constant air-speed

Image by MIT OpenCourseWare.
Boundary layer behavior

Boundary Layer Changes Along the Surface

- Laminar
  - Low skin friction
  - High probability of separation

- Turbulent
  - High skin friction
  - Low probability of separation

- Separated
  - Highest total drag

A large wake = pressure drop = drag

Effect of body shape

Shape

Drag

Skin Friction Drag
Pressure Drag

$C_D = 2.0$

$C_D = 1.2$

$C_D = 0.12$

dia. = 0.1
Reducing drag

- Use streamlined shapes

- Trip the flow for blunt objects

Images removed due to copyright restrictions.
See image 55 and 56 from *An Album of Fluid Motion* by Milton Van Dyke.

- In all cases, minimize the separation
Reducing drag

<table>
<thead>
<tr>
<th>Rules of Thumb</th>
<th>Skin Friction</th>
<th>Separation</th>
<th>Boundary Layer</th>
<th>Surface</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Less Important</td>
<td>More Important</td>
<td>Less Important</td>
<td>Rough</td>
</tr>
<tr>
<td></td>
<td>More Important</td>
<td>Less Important</td>
<td>Laminar</td>
<td>Smooth</td>
</tr>
</tbody>
</table>

Interaction Effects

- Two “slow” objects make one “fast” one
- Subtle changes in shape of objects can make large changes in aerodynamics
Wind Tunnel Testing
Wright Brothers Memorial Wind Tunnel
WBWT schematic

- Diffuser
- Motor, Fan
- Safety Screen
- Settling Chamber
- Diffuser
- Turning Vanes
- Test Section
- Contraction
- Control Room

Courtesy of the Wright Brothers Wind Tunnel. Used with permission.
WBWT test section

Courtesy of the Wright Brothers Wind Tunnel. Used with permission.
Wind tunnel balance

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Mounting the bike

Requirements

• Safety
  – Ease of rider access

• Interface to the balance
  – No other contacts

• Interface to the bike
  – Changes in bike alignment = changes in data

• Minimize airflow interference
  – Interaction of mount and bike

• Yaw capability
  – Crosswind study

• Ground plane
  – Avoid boundary layer build-up
WBWT Bike Mounting System

Brian Hoying, SB 2003

- Adjustable for wide range of bikes
- Wide attachments

- Front wheel
  - Driven

- Rear wheel
  - Driven
  - Power controlled

Test with or without rider

Courtesy of Brian Hoying. Used with permission.
Fairings

Ground Plane

Courtesy of the Wright Brothers Wind Tunnel. Used with permission.
The most important slides today!!!

Wind direction

- How fast do you ride a 40K on a windless flat course?
- How fast do you ride a 40K with a tailwind?
- How fast do you ride with a crosswind?

Conclusions?
The most important slides today!!!

Wind direction

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Conclusions?

YOU (almost) ALWAYS “SEE” A HEADWIND
- Apparent wind
The most important slides today!!!

Wind direction

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Conclusions?

YOU (almost) ALWAYS “SEE” A HEADWIND

- Apparent wind

YOUR ENERGY GOES INTO OVERCOMING THE APPARENT WIND

- The wind the bicycle sees
The most important slides today!!!

Forces in tunnel axes – measured in tunnel

- \( D_w \) – in the direction of the wind
- \( S_w \) – perpendicular to the wind

Forces in bike axes – calculated

- \( D_b \) – opposing the motion of the bike
- \( S_b \) – perpendicular to the motion

Related through the yaw angle

- \( D_b = D_w \cos \psi - S_w \sin \psi \)
- \( S_b = D_w \sin \psi + S_w \cos \psi \)
- \( D_b = D_w \) and \( S_b = S_w \) at \( \psi = 0 \), pure headwind

Always want bike axis data

- When looking at data, be sure you know which axes it represents
Example: Disc Wheel at yaw angle in tunnel

• The wind “sees” the projection of the wheel in the tunnel
  
  – $D_w$ for disc $>> D_w$ for spoke wheel
  
  – $D_b$ for disc $<< D_b$ for spoke wheel

• Which wheel will reduce your TT time?
Data acquisition

Data acquisition and calculations

• 1000 Hz sampling, average over 30 or 60 seconds
  – Average over pedaling cycle

• Instantly reduce data
  – Change test plan as data is collected
  – Efficient use of tunnel time

• Convert to standard conditions
  – Small variations in wind speed, air temperature and humidity = small changes in results
  – We are measuring small changes
Operator interface

Courtesy of the Wright Brothers Wind Tunnel. Used with permission.
Rider feedback

Slide back 2 cm on saddle

Courtesy of the Wright Brothers Wind Tunnel. Used with permission.
A typical test

Courtesy of the Wright Brothers Wind Tunnel. Used with permission.
Wind Tunnel Test Results

Equipment
Equipment testing

Aero weenies look at $/second
  • Weight weenies look at $/gram

Generic rider
  • 160 lbs, 225 W, “good” aero position
  • Math model of 40 K TT

Compare individual changes
  • Details like cable routing, etc.
  • Aero frame vs. round tube frame
  • Dialed aero position vs. good position
  • Aero helmet vs. road helmet
  • Aero wheels (Deep/Disc) vs. standard
  • New aero bottle vs. bottles on frame
Quiz #2 – Performance improvement

1. Details
2. Frame
3. Position
4. Helmet
5. Wheels
6. Bottle

Seconds Saved Over 40K TT
Quiz #2 – Performance improvement

1. Details

- Details
- Frame
- Position
- Helmet
- Wheels
- Bottle

Seconds Saved Over 40K TT

Quiz #2 – Performance improvement

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3.
4.
5.  
6.  
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   • Frame
   • Position
   • Helmet
   • Wheels
   • Bottle

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Seconds Saved Over 40K TT

Quiz #3 – Now rank the value

1. Details
2. Frame
3. Position
4. Helmet
5. Wheels
6. Bottle

Cost in $/sec saved

Quiz #3 – Now rank the value

1. Details
2. 
3. 
4. 
5. 
6. 

- Details
- Frame
- Position
- Helmet
- Wheels
- Bottle

Cost in $/sec saved
Quiz #3 – Now rank the value

1. Details
2. Bottle
3. Frame
4. Position
5. Helmet
6. Wheels
7. Bottle

Cost in $/sec saved

- Details
- Frame
- Position
- Helmet
- Wheels
- Bottle
Quiz #3 – Now rank the value

1. Details
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3. Helmet
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5. 
6. 

- Details
- Frame
- Position
- Helmet
- Wheels
- Bottle

Cost in $/sec saved

- 1
- 2
- 3
- 4
- 5
- 6

Quiz #3 – Now rank the value

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2. Bottle
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6. 

- Details
- Frame
- Position
- Helmet
- Wheels
- Bottle

Cost in $/sec saved
Quiz #3 – Now rank the value

1. Details
2. Bottle
3. Helmet
4. Position
5. Frame
6. Details
   Frame
   Position
   Helmet
   Wheels
   Bottle

Cost in $/sec saved

Quiz #3 – Now rank the value

1. Details
2. Bottle
3. Helmet
4. Position
5. Frame
6. Wheels

- Details
- Frame
- Position
- Helmet
- Wheels
- Bottle

Cost in $/sec saved
Wind Tunnel Results

Rider Position

Kim B. Blair PhD
Vice President
Riders Tested

CSC
- Ivan Basso
- Carlos Sastre

Liberty Seguros
- Luis Leon Sanchez,
- Alberto Contador

TIAA-CREF
- Bryan Smith
- Timmy Duggan
- Taylor Tolleson

Team Psycho
- Steve Lyons
Ivan Basso

Time in the tunnel
   • 3.5 hours

Drag reduction
   • 11%

Position changes
   • Saddle up 1.5 cm
   • Angled aerobars up 5 degrees from ground plane
Ivan Basso

Before

After

Courtesy of the Wright Brothers Wind Tunnel. Used with permission.
Cycling News: May 6, 2004

- Riis told the Danish media that he expects that the results of the test will enable Basso to improve his time trial by up to 3 minutes in a 40-50 kilometre race – an incredible 3-4 seconds per kilometre. "We can gain a lot of time through these tests."

**2003 Final ITT**
- Basso 22nd place

**2004 Final ITT**
- Basso 6th place
- Time difference within 2% of predicted improvement

**2005**
- Dominated ITT events at 2005 Giro
- 2nd overall at the Tour de France
Carlos Sastre

Time in the tunnel
- 3 hours

Drag reduction
- 17%

Position changes
- Saddle 2 cm forward and 1.5 cm up
- Hands 1.5 cm forward on aerobars
- Straight extensions parallel to ground plane

Courtesy of the Wright Brothers Wind Tunnel. Used with permission.
Alberto Contador

Time in the tunnel
- 1 hour

Drag reduction
- 5% (helmet, apparel)

Position changes
- Head angle

Equipment
- Aero helmet prototypes
- Skinsuit prototypes

Courtesy of the Wright Brothers Wind Tunnel. Used with permission.
Luis Leon Sanchez

Time in the tunnel
• 1 hour

Drag reduction
• 2.5%

Position changes
• Angled aerobars downward

Courtesy of the Wright Brothers Wind Tunnel. Used with permission.
Taylor Tolleson

Time in the tunnel
- 80 minutes

Drag reduction
- 7.3%

Position changes
- Aerobars angled downward 15 degrees
- Narrower elbows
- Moved hands forward 2 cm
Bryan Smith

Time in the tunnel

• 1 hour

Drag reduction

• 2%

Position changes

• Seat height up 1.5 cm
• Angle bars up 3-5 degrees
• Aerobars down 1-2 cm
• Shorten aerobars 1.5 cm

Courtesy of the Wright Brothers Wind Tunnel. Used with permission.
Timmy Duggan

Time in the tunnel
  • 1 hour

Drag reduction
  • 12%

Position changes
  • Slide back on saddle (~ 1 cm) and rotate pelvis forward
  • Bar angle up 5 deg
  • Head looking down a bit (tail in air)
  • Bar and seat height optimal

[Image courtesy of Roxanne King.]
Conclusions
Conclusions

Aerodynamics is important
  • 5% change means big results

Be wary of published aerodynamic data
  • No consistency in reporting data

Consider value for equipment
  • $/sec. of drag
  • Can drive sales of lower price point equipment

Rider position
  • 5% improvement is “easy” to get
  • No right answer for every rider