# Cycling Aerodynamics

*Clearing the air*

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**Kim B. Blair PhD**
**Vice President**

# 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%
- X 76 – 100%

**Aerodynamic Drag**

**~ 90%, ~ 2/3 is the rider!**

**Rolling Resistance ~ 10%**

**Drive Train Loss < 1%**

# Energy cost of drag

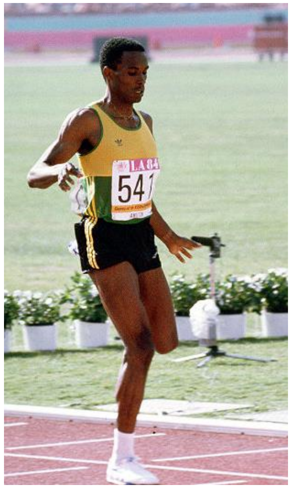


Image courtesy of Letartean.

Image courtesy of Val Gardena.

**Alpine Skiing ~ 40-80%**

**XC Skiing ~ 20-25%**

**Running ~ 6-14%**


**Bobsled ~ 50%**

**Speed Skating ~ 90%**

# Let's assume a 5% drag reduction

| Olympic Event (Distance) | Time Savings Sec/km | Place Difference |
|---|---|---|
| Cycling M ITT (46.8 km) | 0.8 sec | 4th |
| Speed Skating W (5 km) | 0.8 sec | 3rd |
| Alpine Downhill M | 0.4 sec | 4th |
| XC Skiing W (30 km) | 0.3 sec | 3rd |
| Running M (10 km) | 0.2 sec | 4th |

# Aerodynamics 101

*The basics of flow*

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# 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

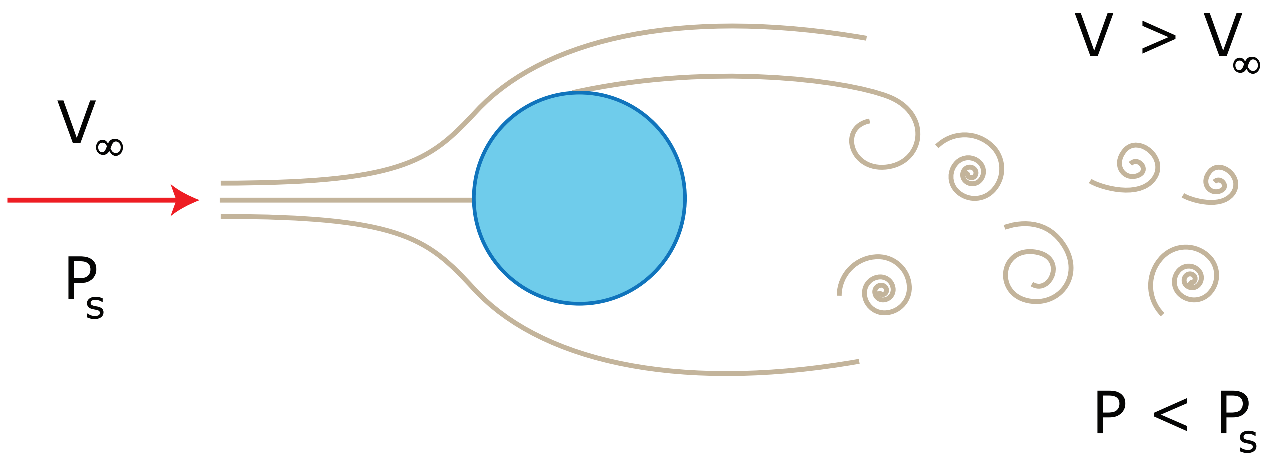



Image by MIT OpenCourseWare.

# 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**

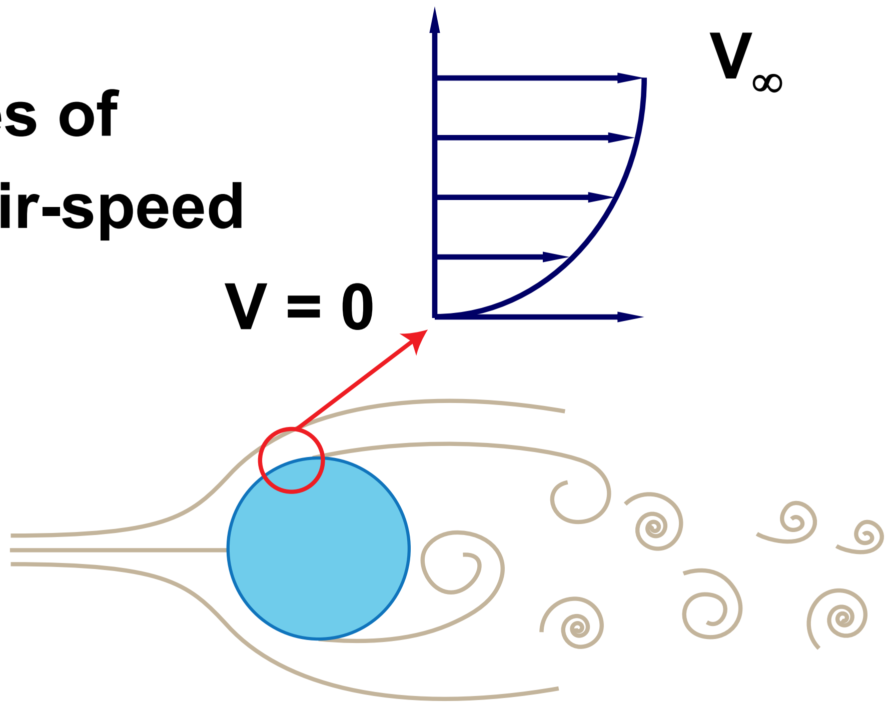
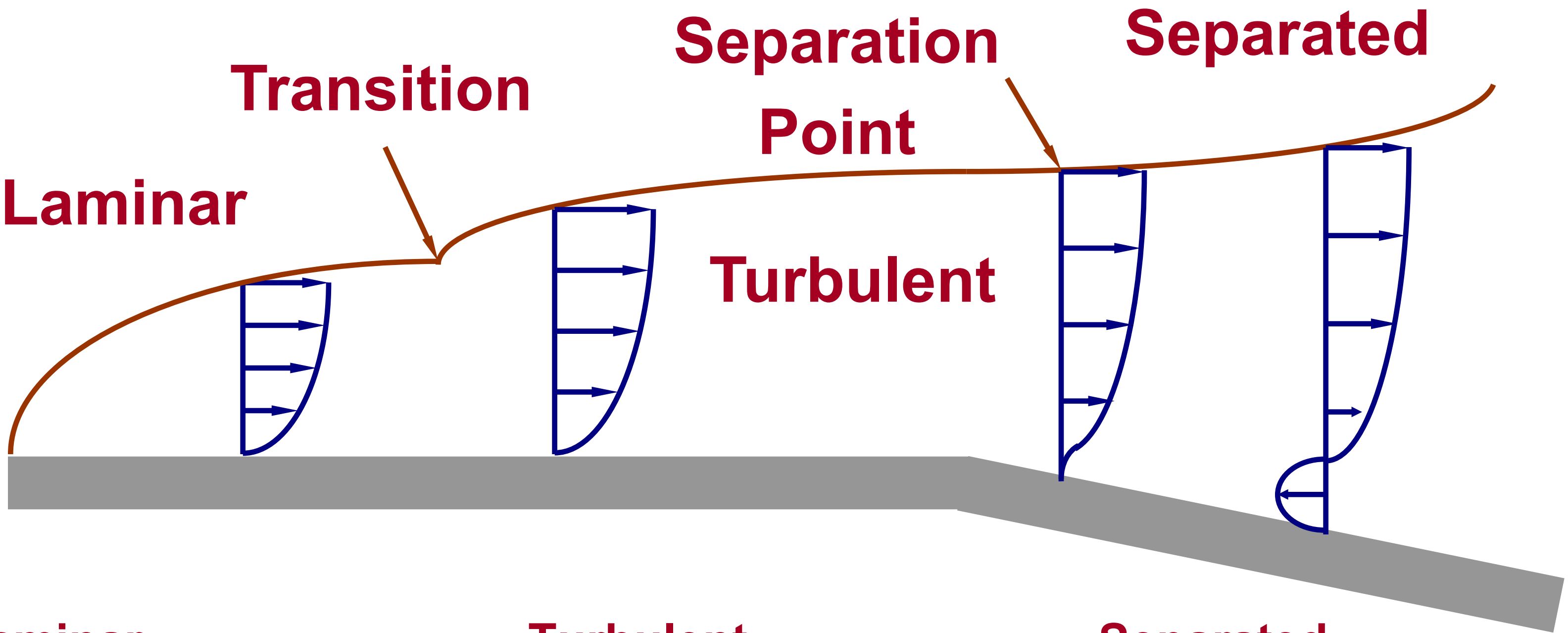



Image by MIT OpenCourseWare.

# Boundary layer behavior

## Boundary Layer Changes Along the Surface



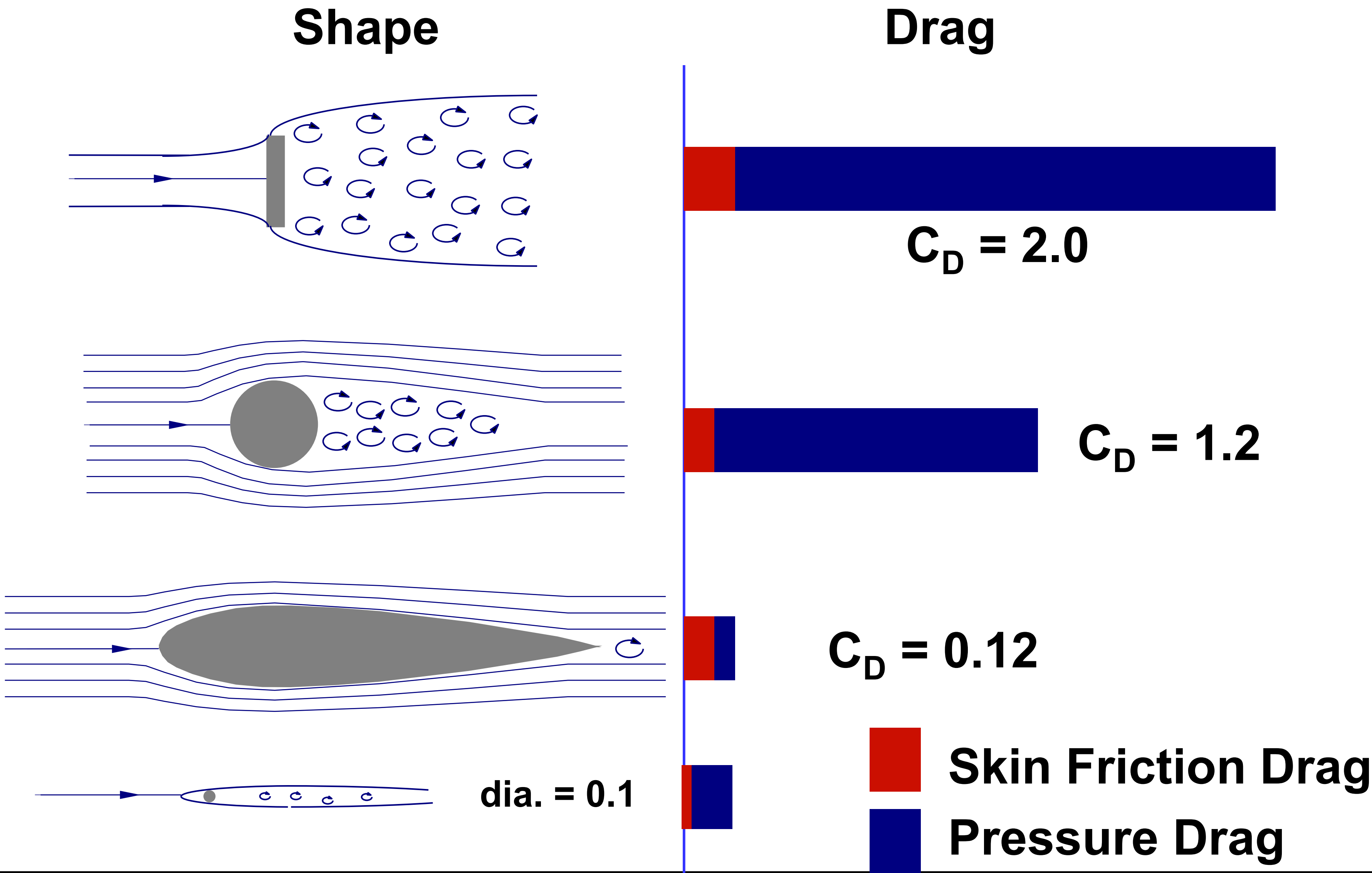

**Laminar**
Low skin friction
High probability of separation

**Turbulent**
High skin friction
Low probability of separation

**Separated**
Highest total drag

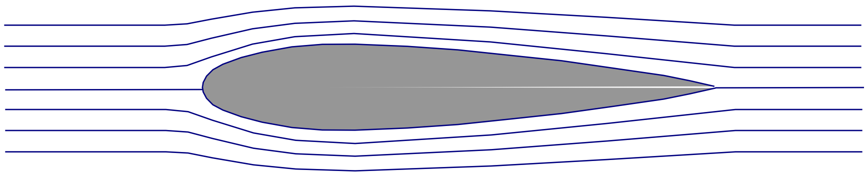
**A large wake = pressure drop = drag**

# Effect of body shape



# Reducing drag

- Use streamlined shapes



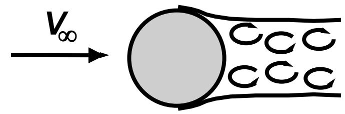
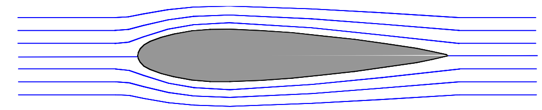
- Trip the flow for blunt objects

Images removed due to copyright restrictions.

See image 55 and 56 from *An Album of Fluid Motion* by Milton Van Dyke.
Parabolic Press, 1982.

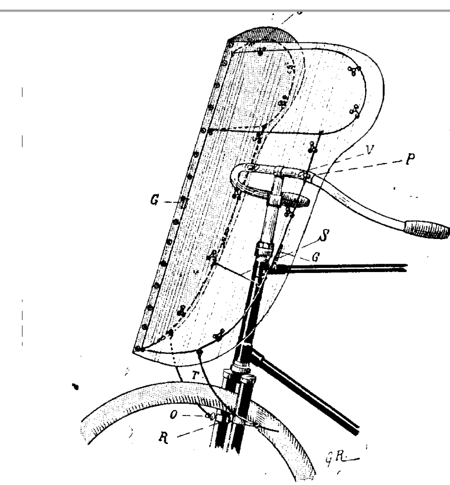
- In all cases, minimize the separation

# Reducing drag

| Rules of Thumb |  |  |
|---|---|---|
| Skin Friction | Less Important | More Important |
| Separation | More Important | Less Important |
| Boundary Layer | Turbulent | Laminar |
| Surface | Rough | Smooth |

## Interaction Effects

- Two "slow" objects make one "fast" one
- Subtle changes in shape of objects can make large changes in aerodynamics



*Manuale del Ciclista*, Galante, A., Milan 1894

# Wind Tunnel Testing

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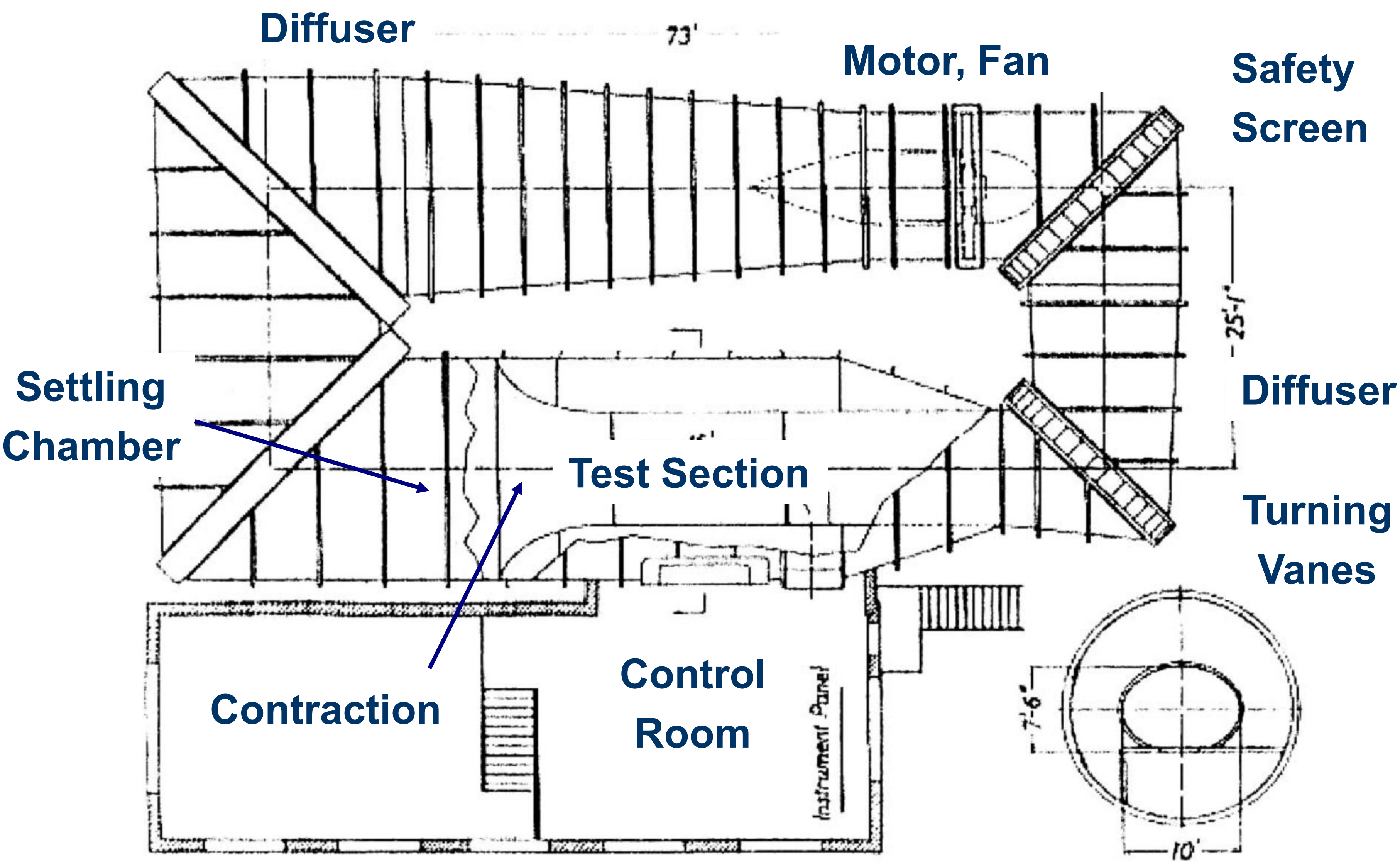
**Vice President**

# Wright Brothers Memorial Wind Tunnel

# WBWT schematic

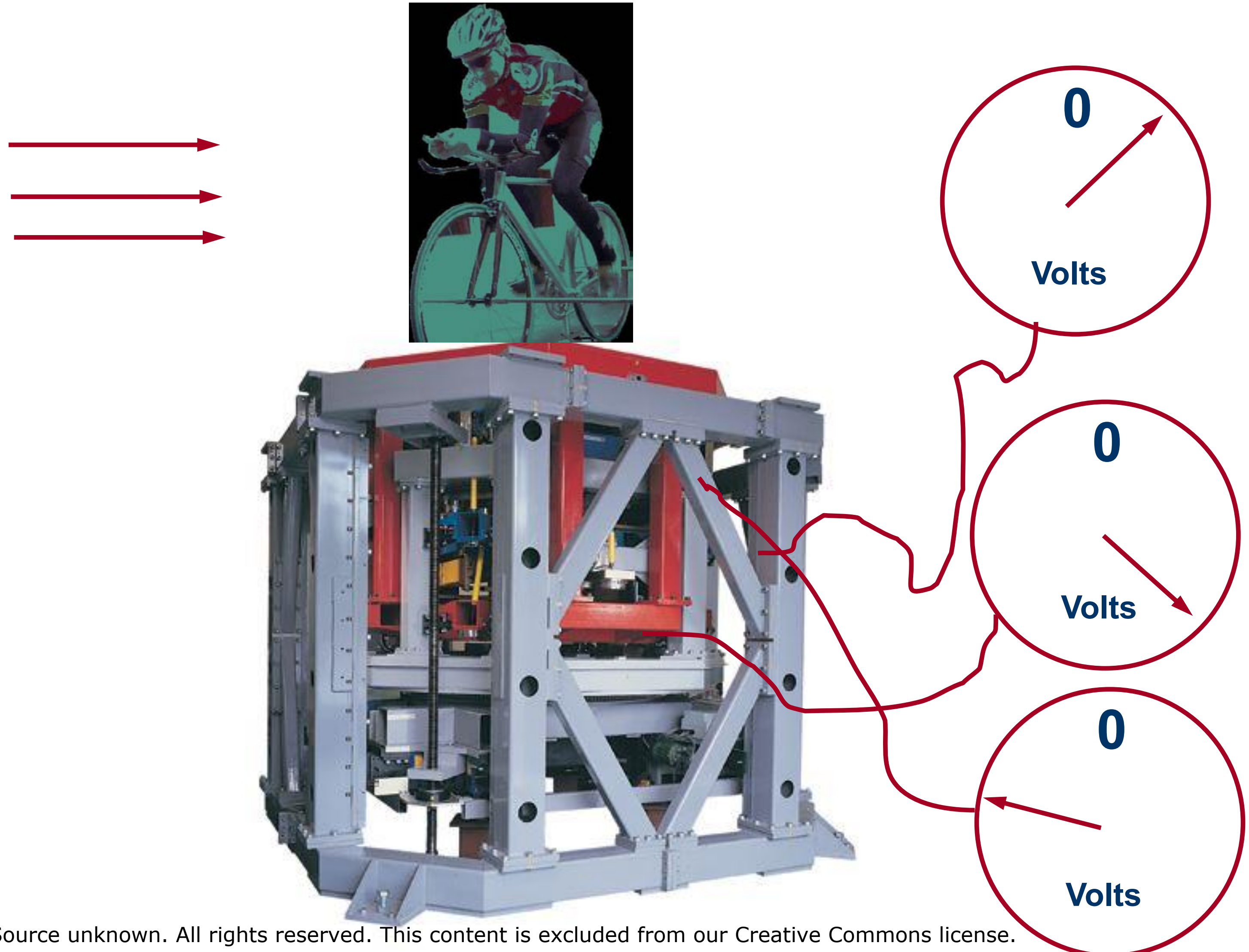



Courtesy of the Wright Brothers Wind Tunnel. Used with permission.

# WBWT test section


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

# Wind tunnel balance



# Mounting the bike

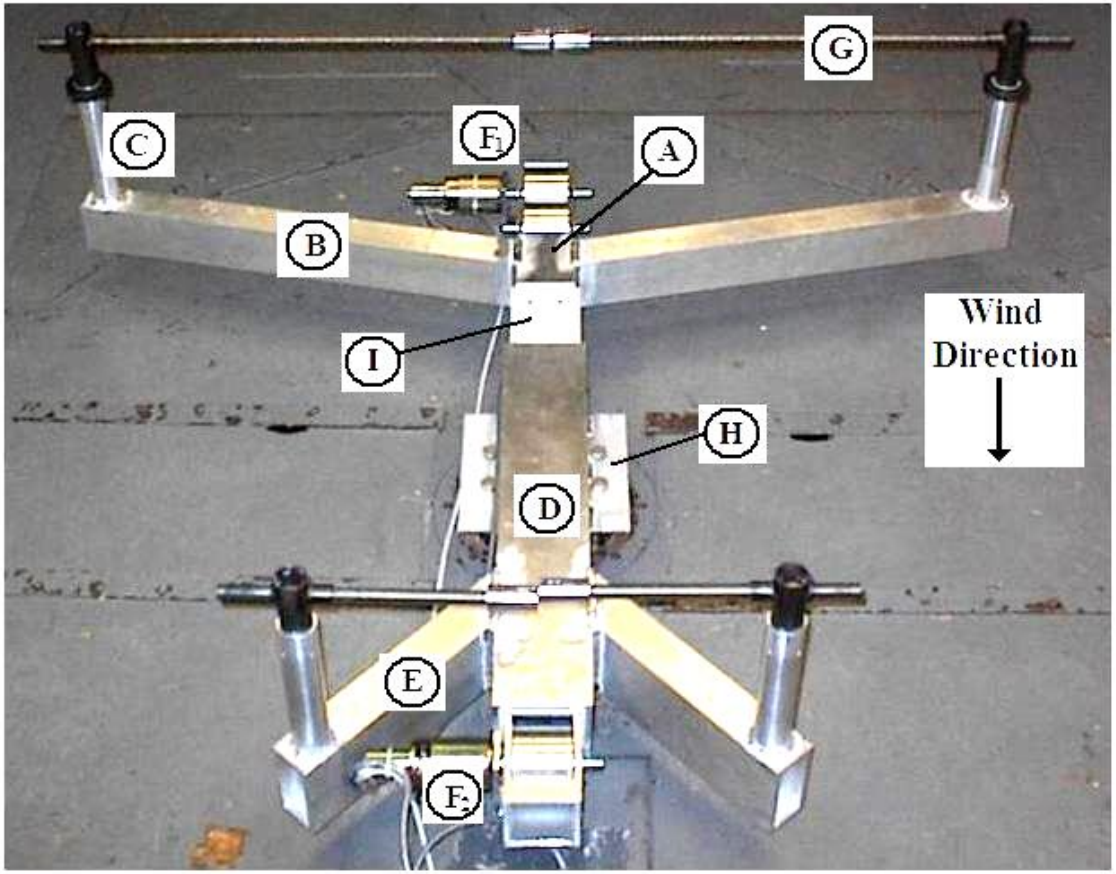
## Requirements

- 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




Courtesy of Brian Hoying. Used with permission.

- Front wheel
  - Driven
- Rear wheel
  - Driven
  - Power controlled

**Test with or without rider**

# WBWT

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

- How fast do you ride a 40K on a windless flat course?
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## Conclusions?

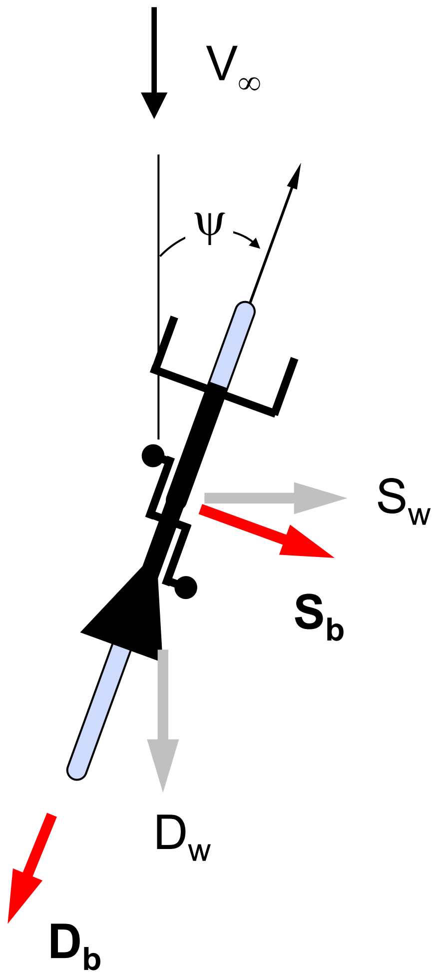
## YOU (almost) ALWAYS "SEE" A HEADWIND

- 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

# The most important slides today!!!

## Example:  Disc Wheel at yaw angle in tunnel

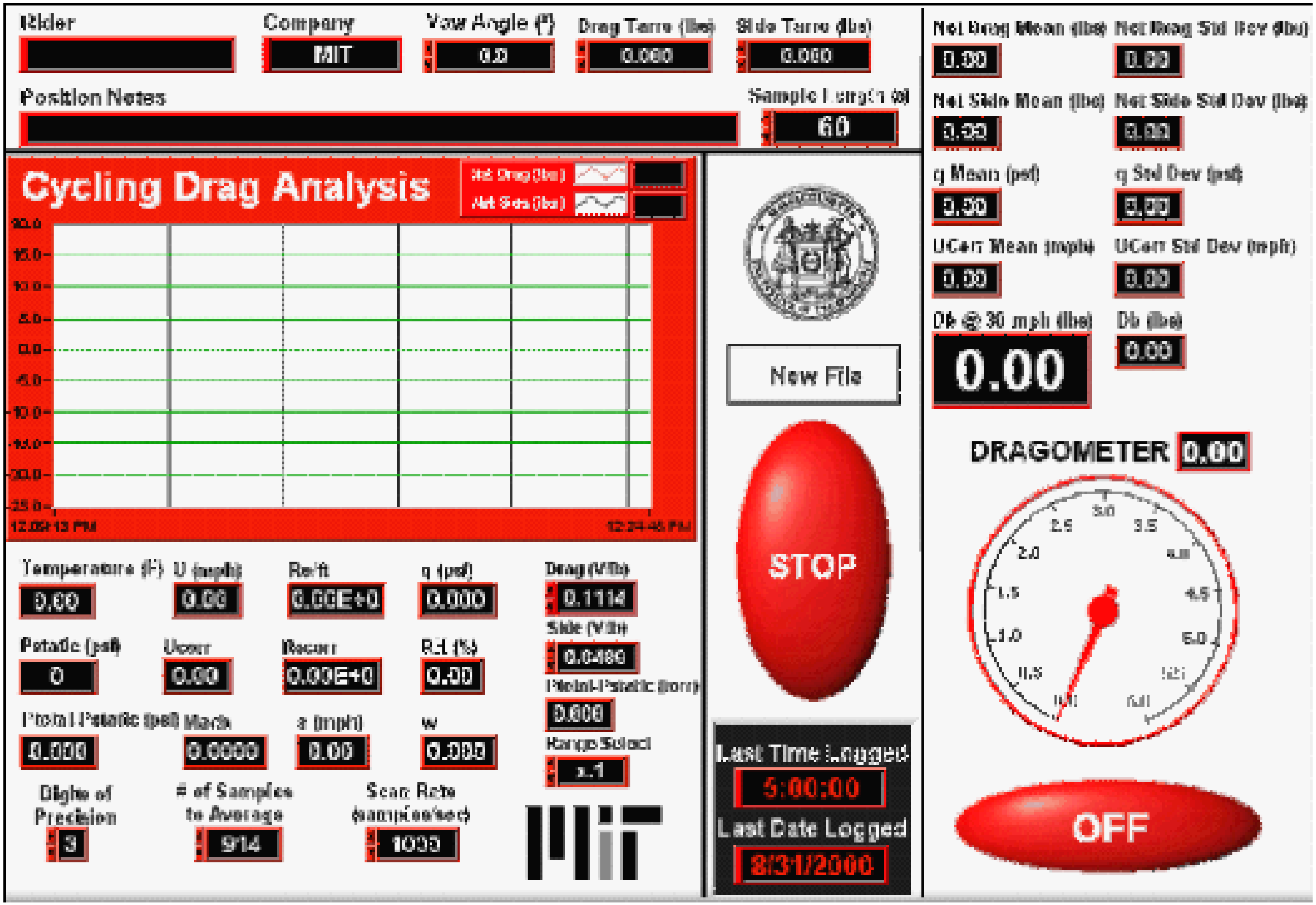
- The wind “sees” the projection of the wheel in the tunnel
  - $D_w$ for disc >> $D_w$ for spoke wheel
  - $D_b$ for disc << $D_b$ for spoke wheel
- Which wheel will reduce your TT time?

# Data acquisition

## Data acquisition and calculations

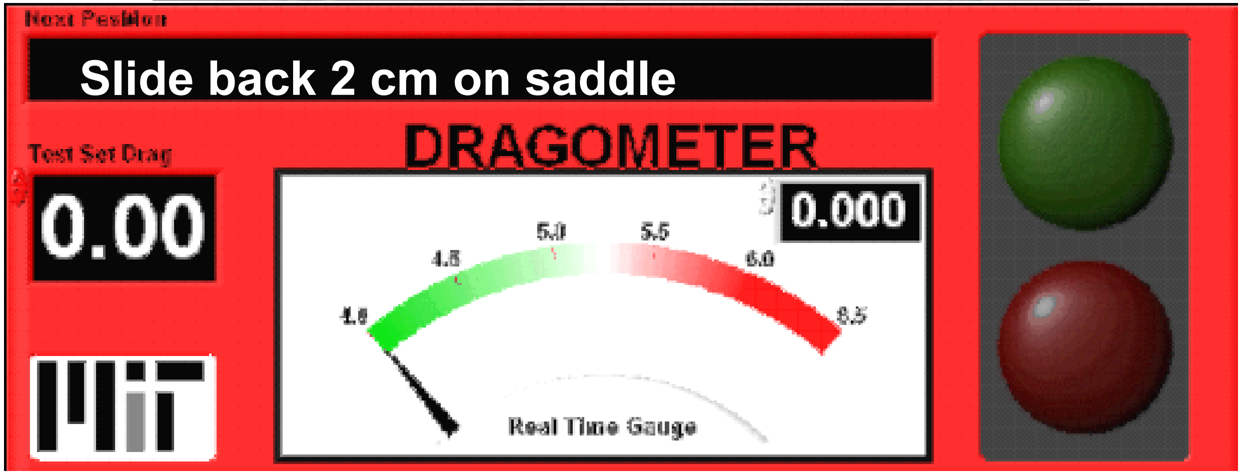
- 1000 Hz sampling, average over 30 or 60 seconds
  - Average over pedaling cycle
- Instantly reduce data
  - Change test plan as data is collected
  - Efficient use of tunnel time
- Convert to standard conditions
  - Small variations in wind speed, air temperature and humidity = small changes in results
  - We are measuring small changes

# Operator interface




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

# Rider feedback




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*

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**Vice President**

# 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

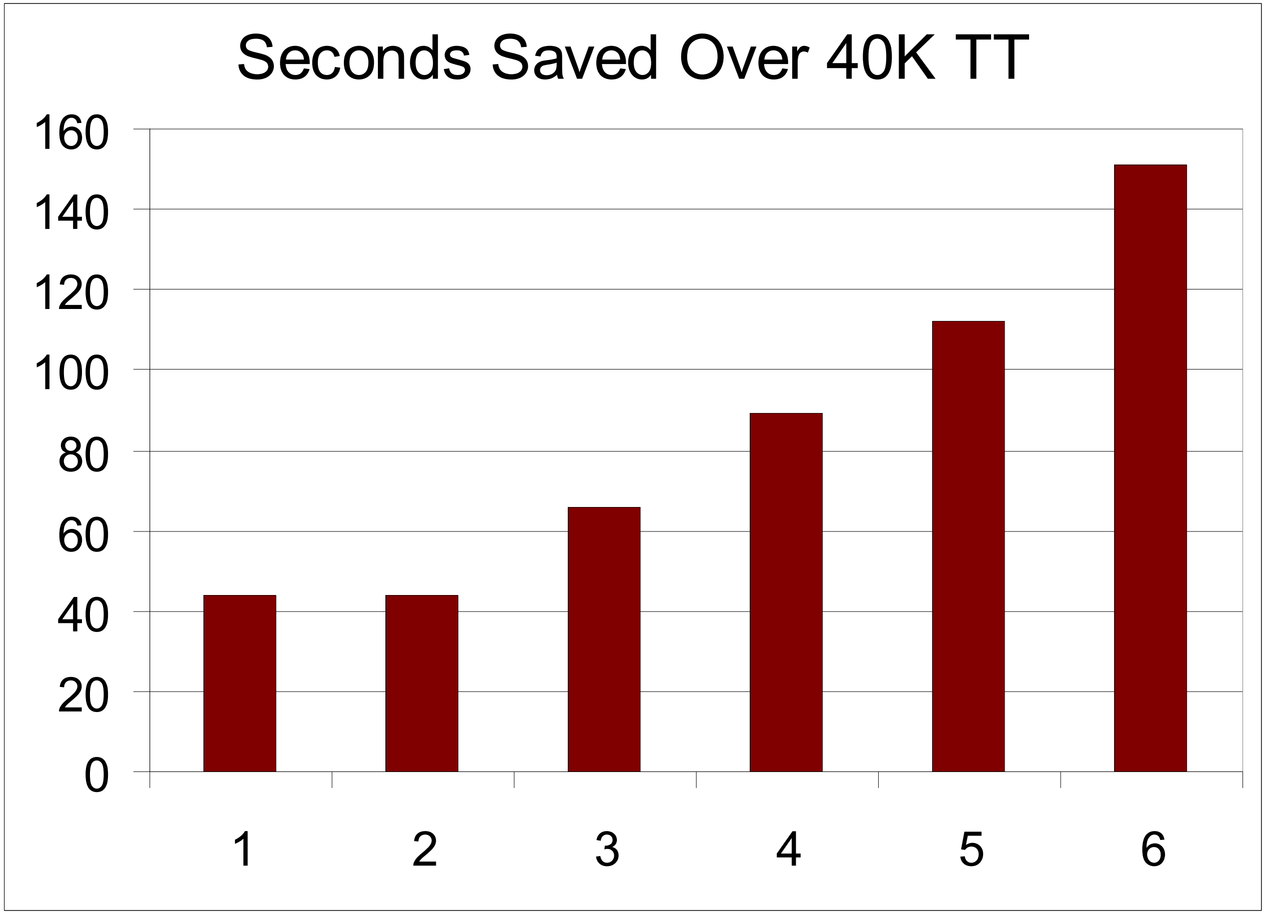
## Compare individual changes

- 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.
2.
3.
4.
5.
6.

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



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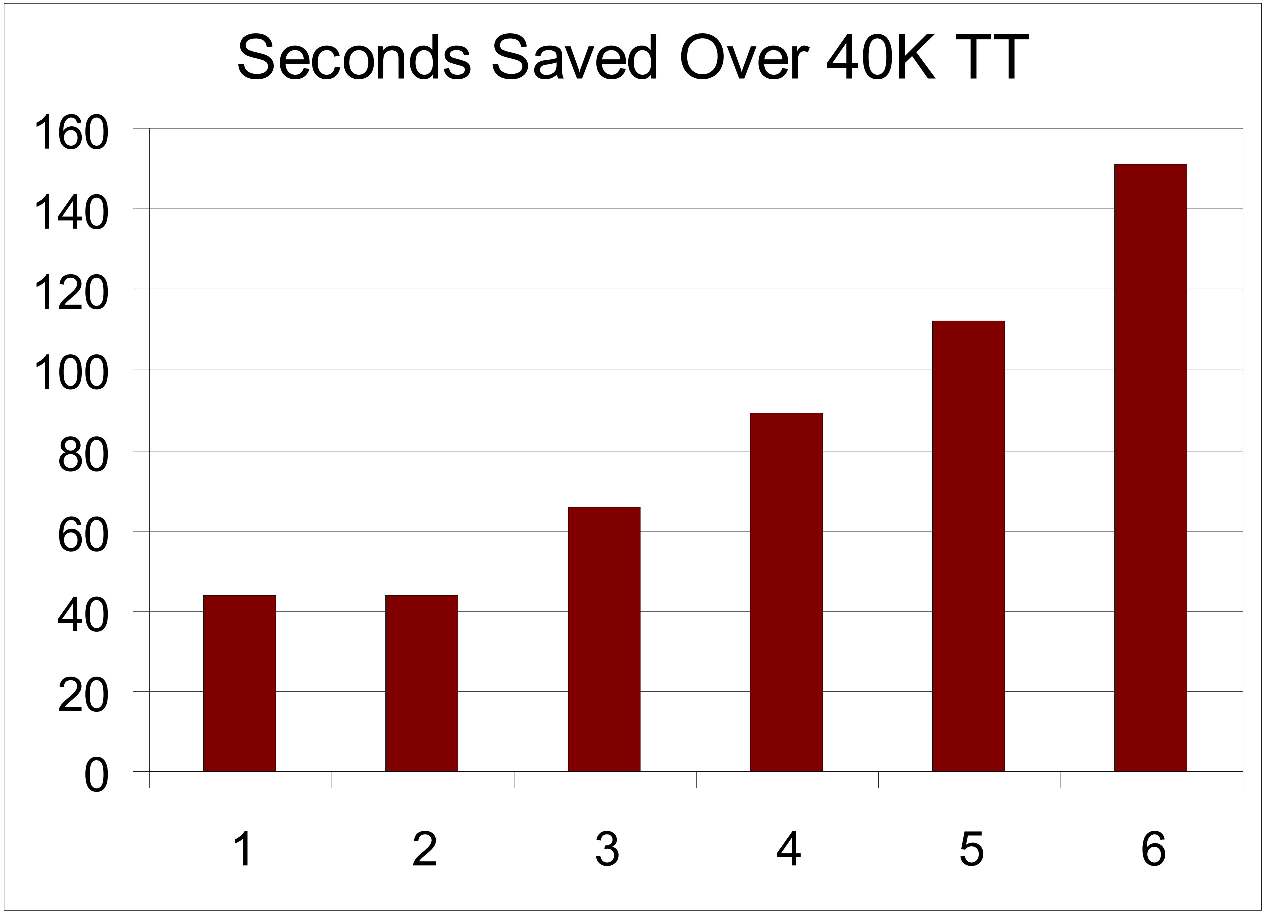


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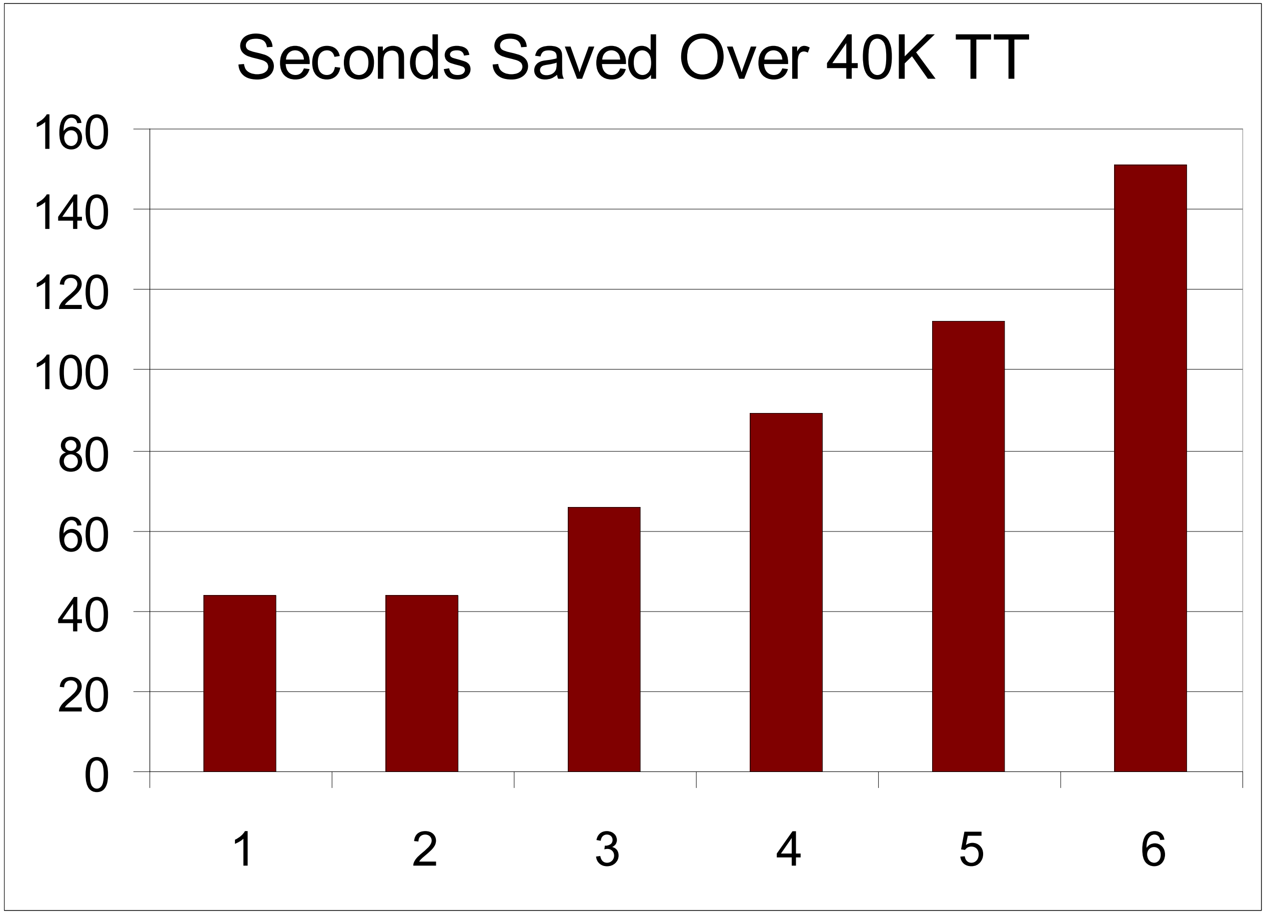

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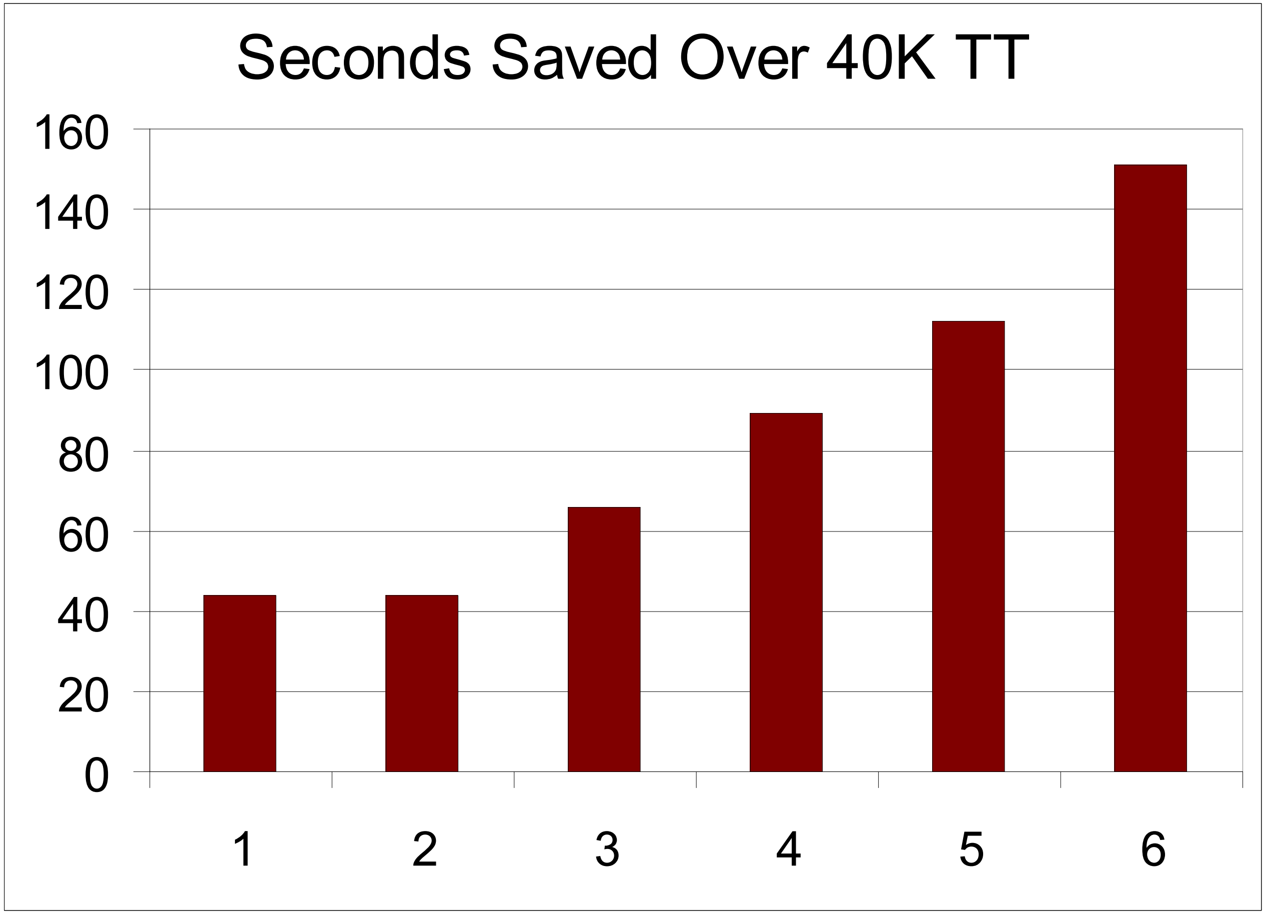

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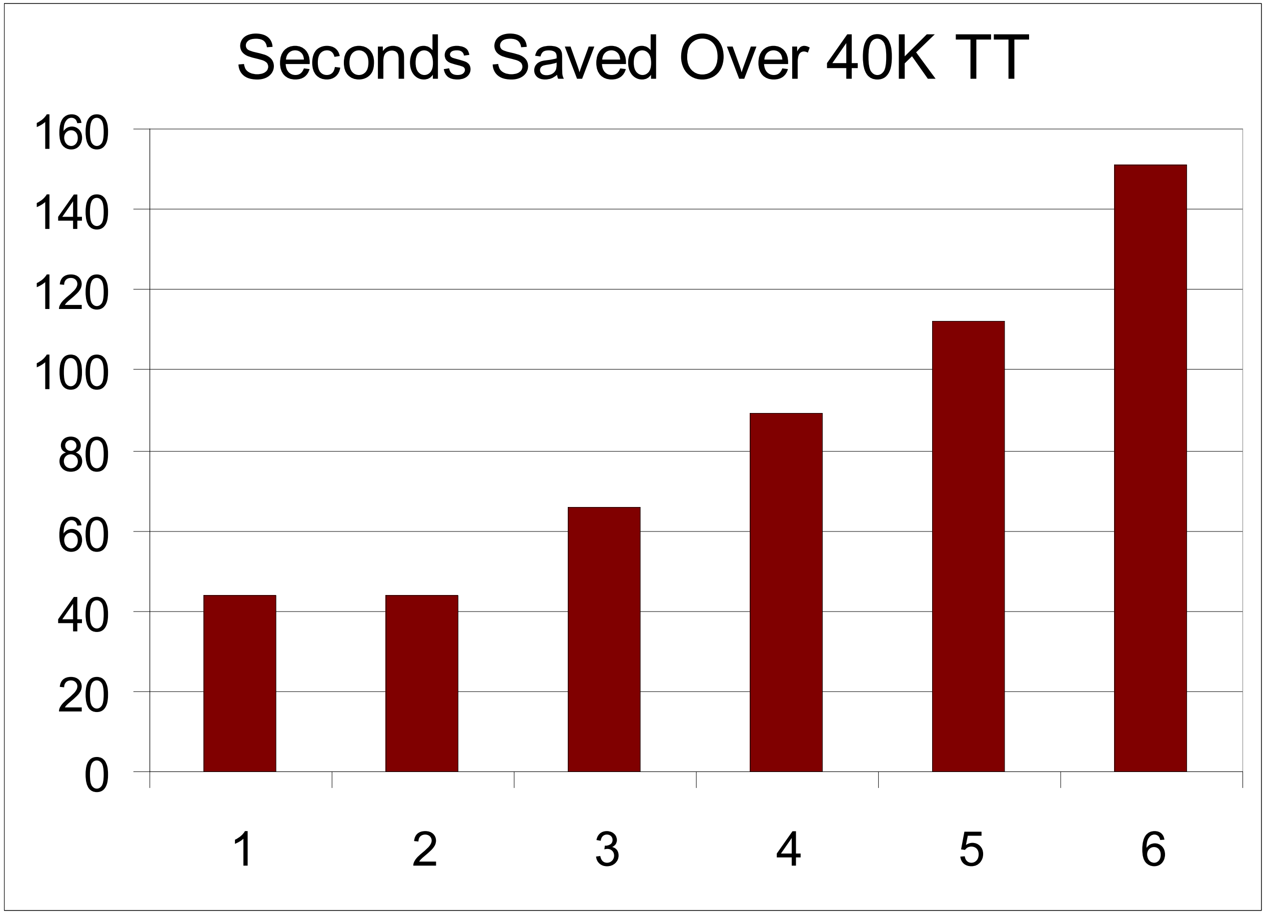

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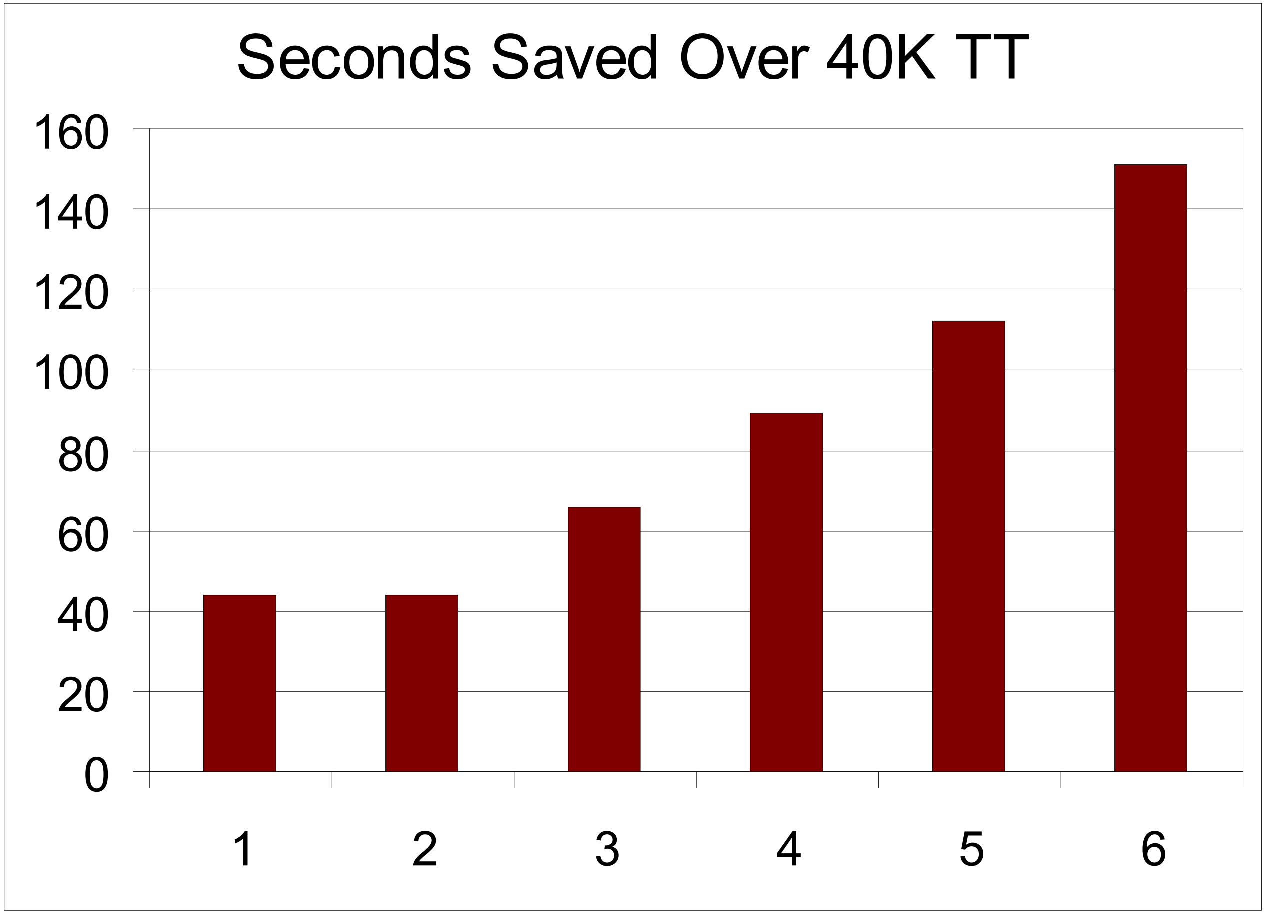

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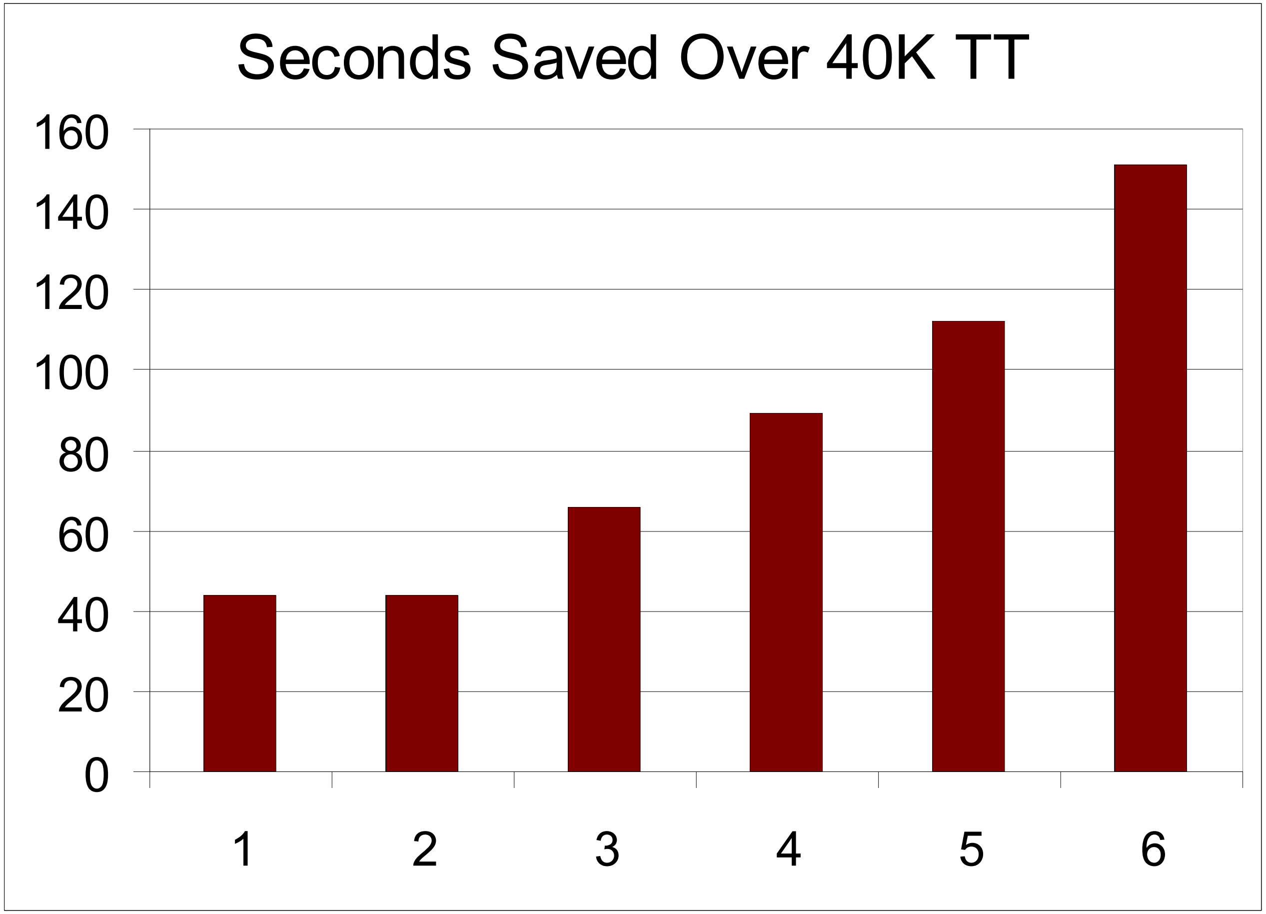

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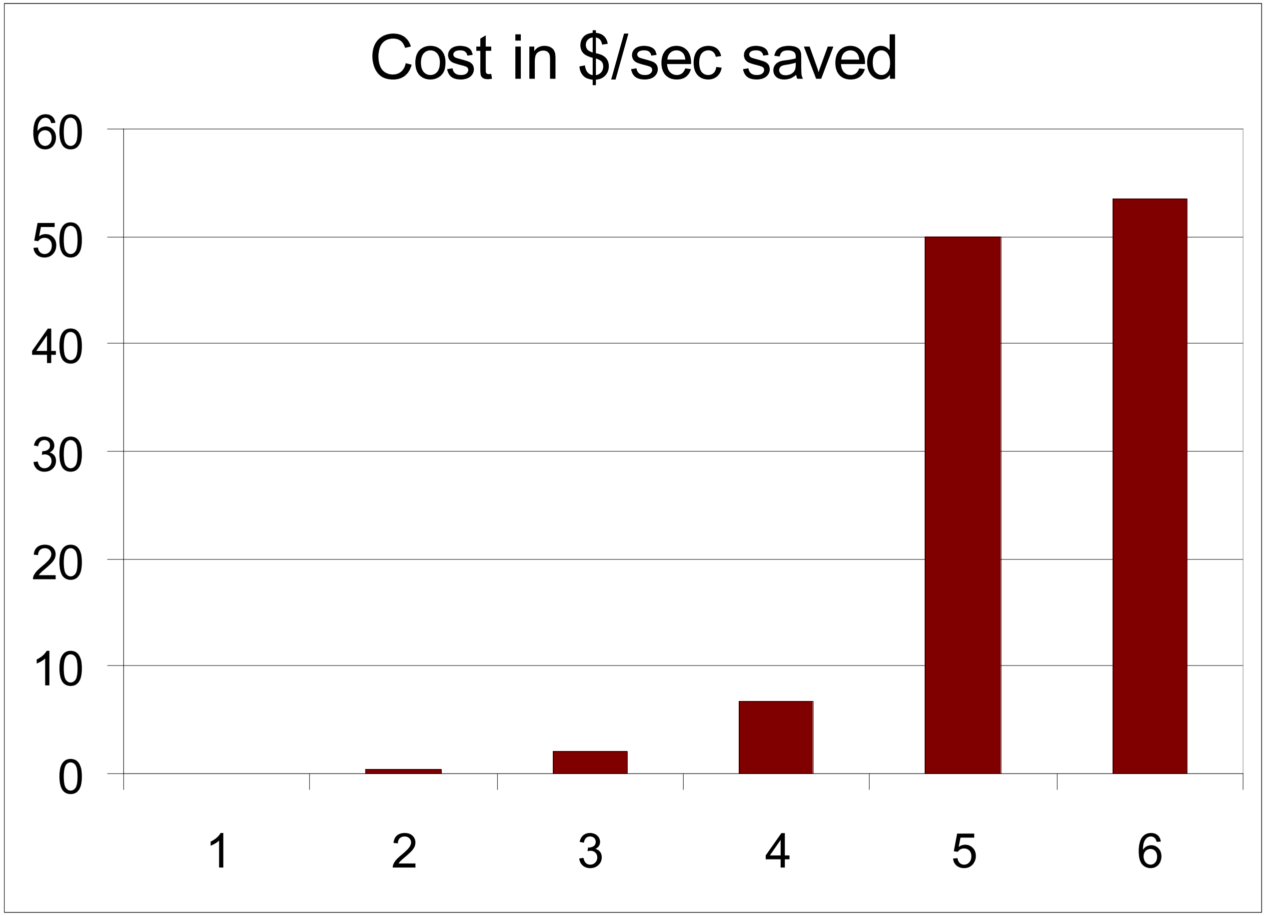

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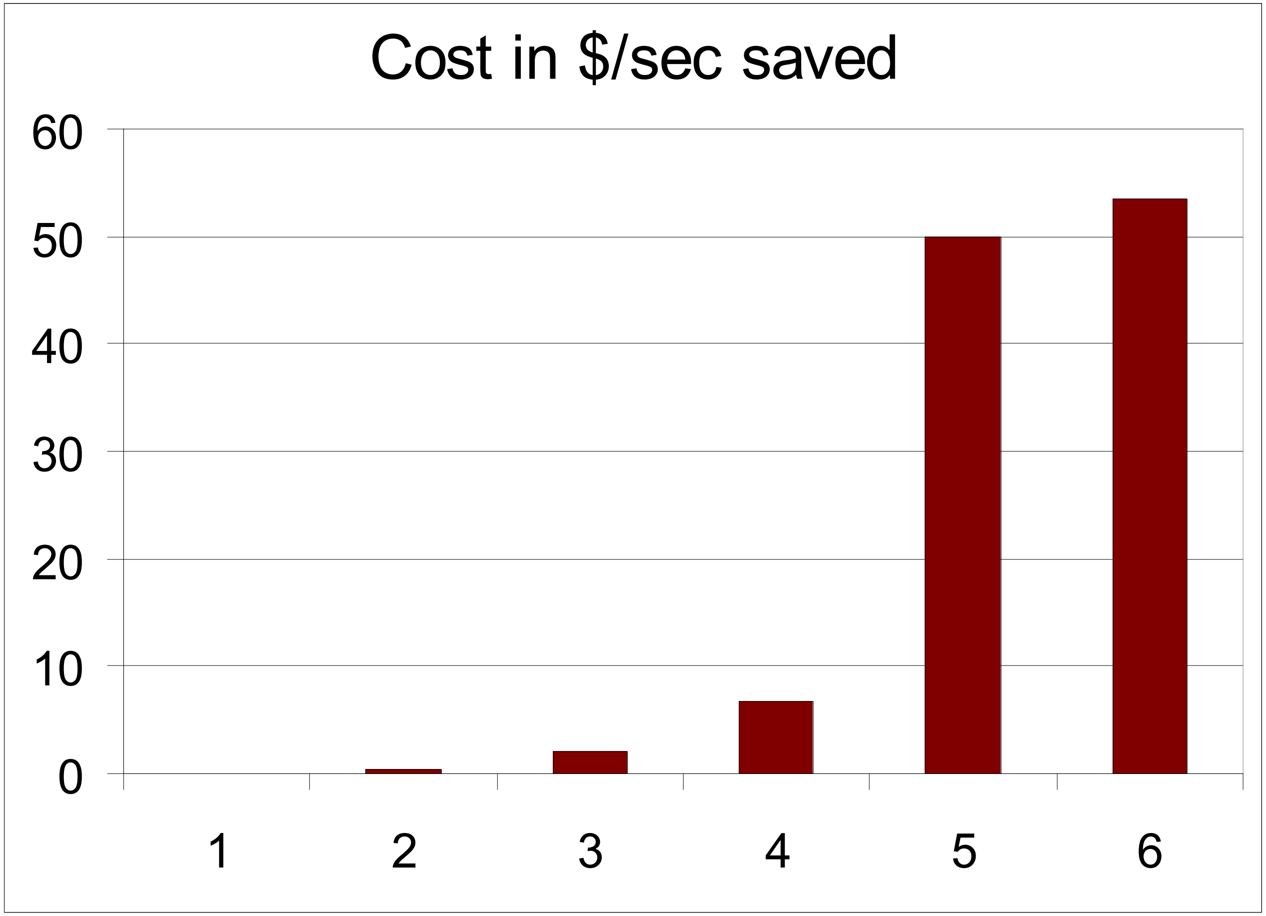

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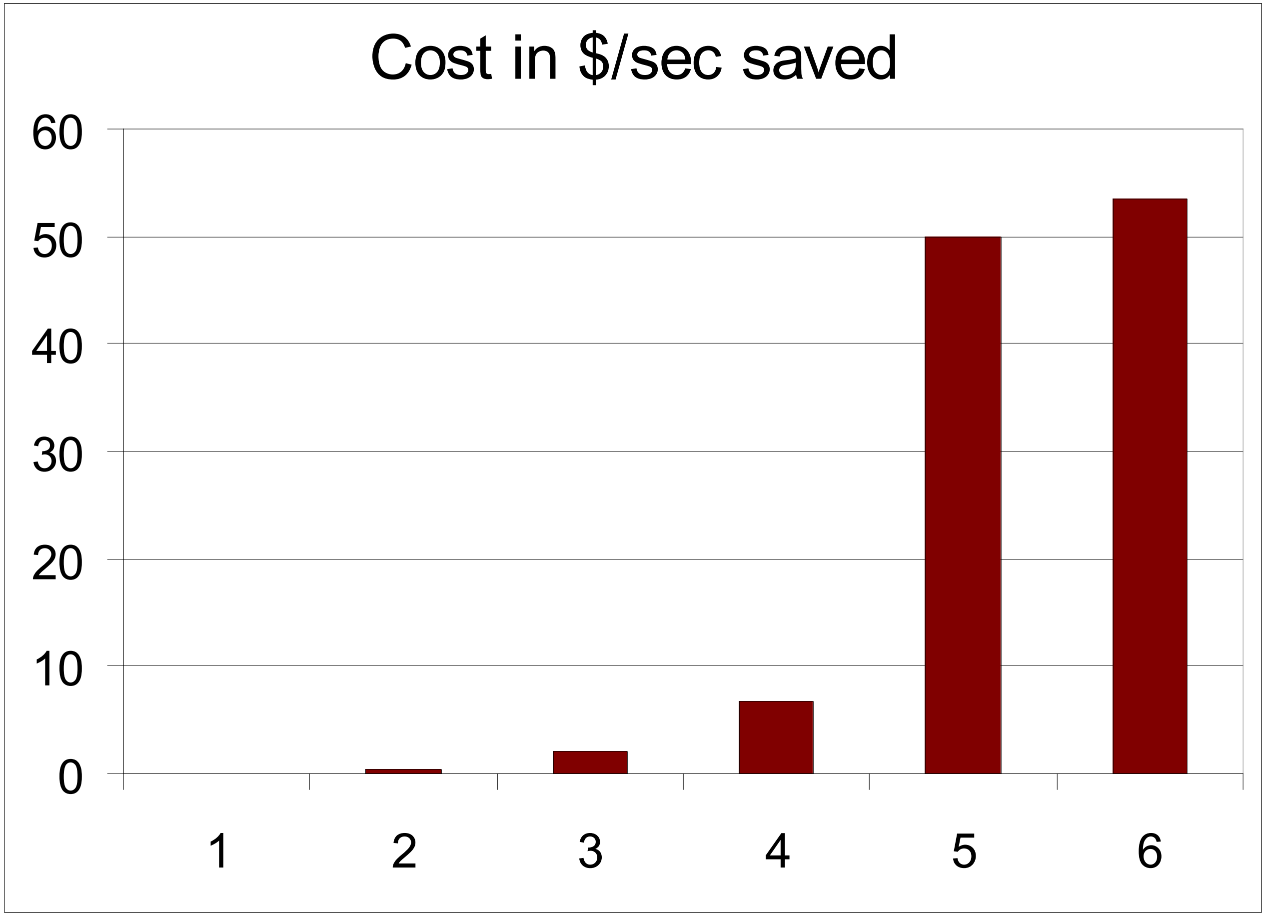

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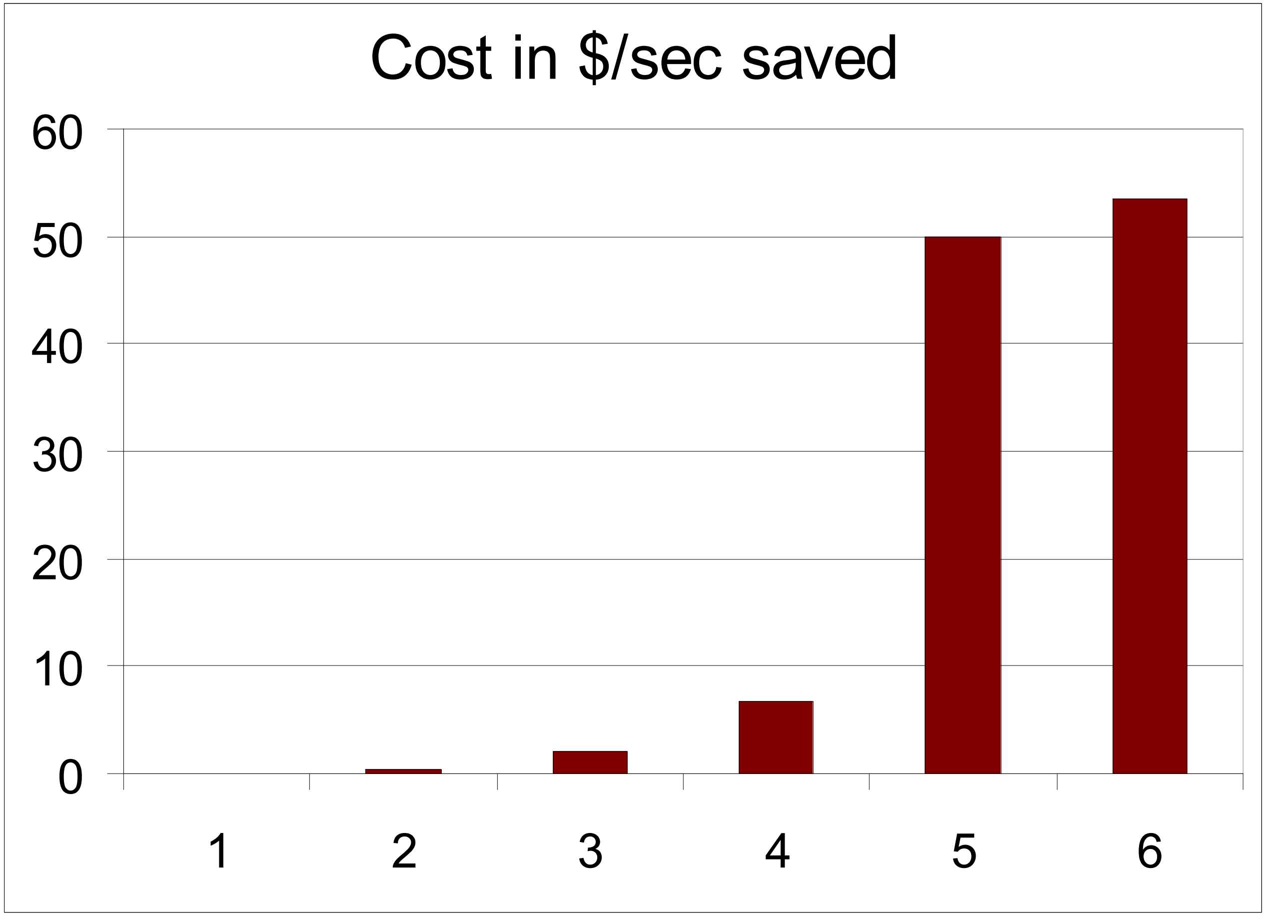

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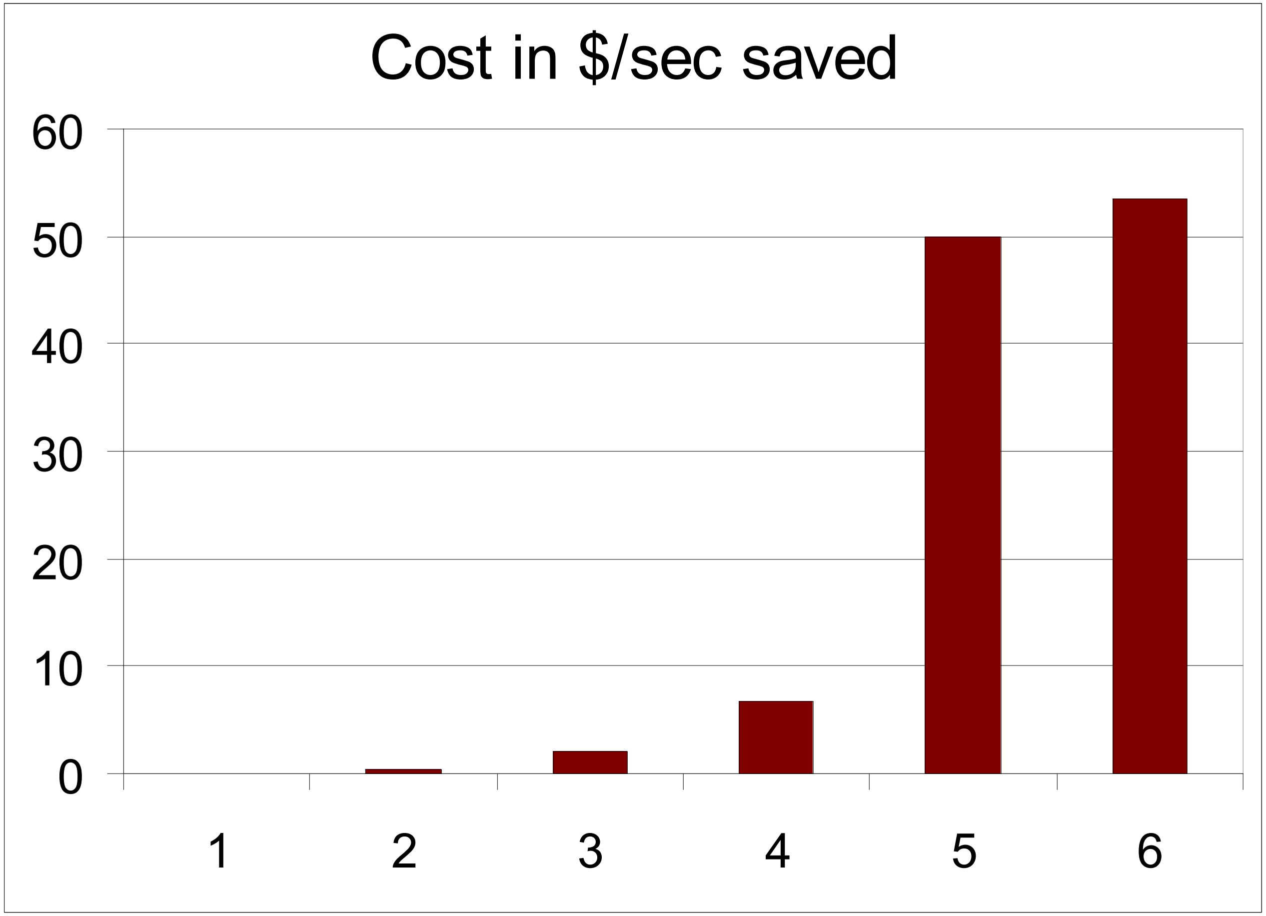

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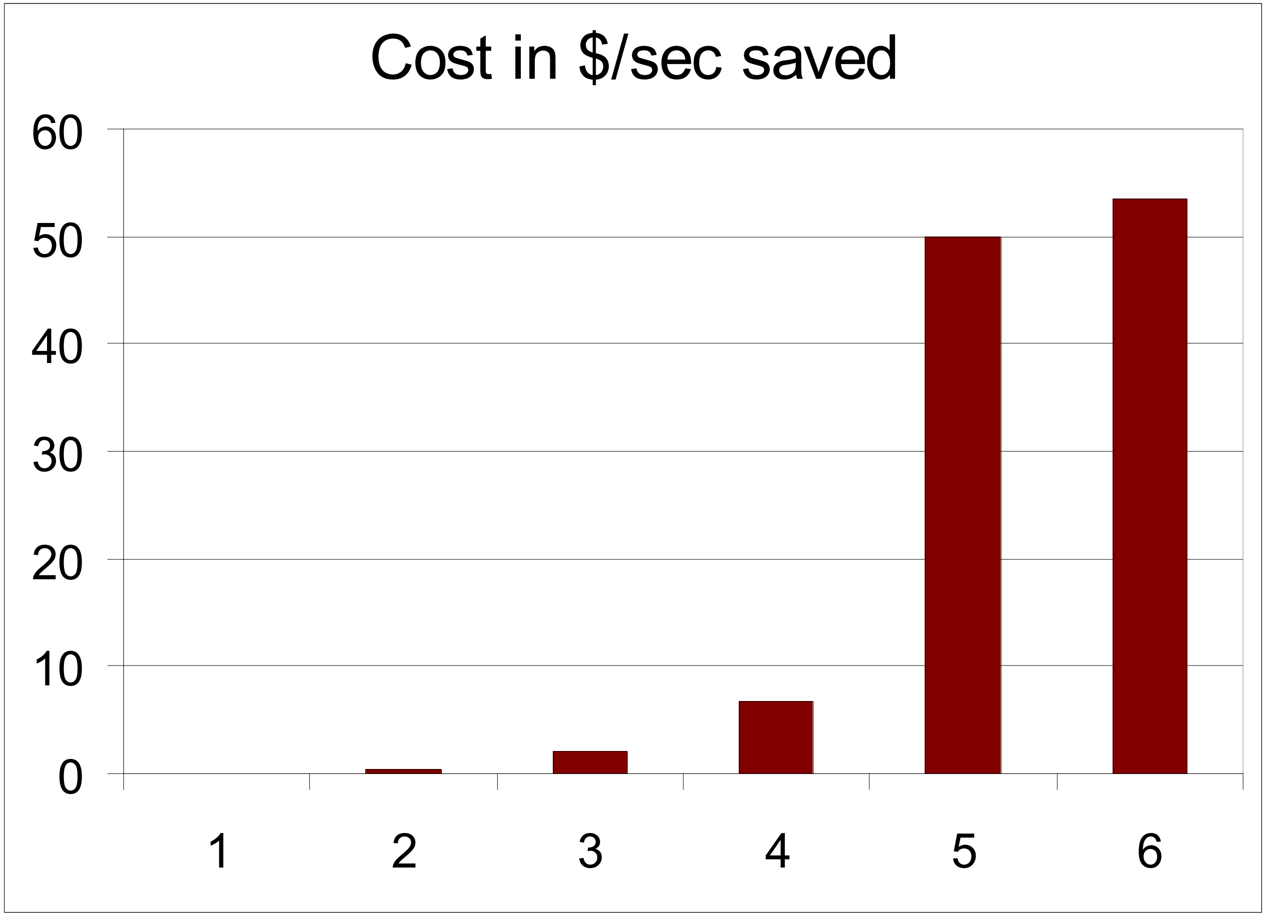

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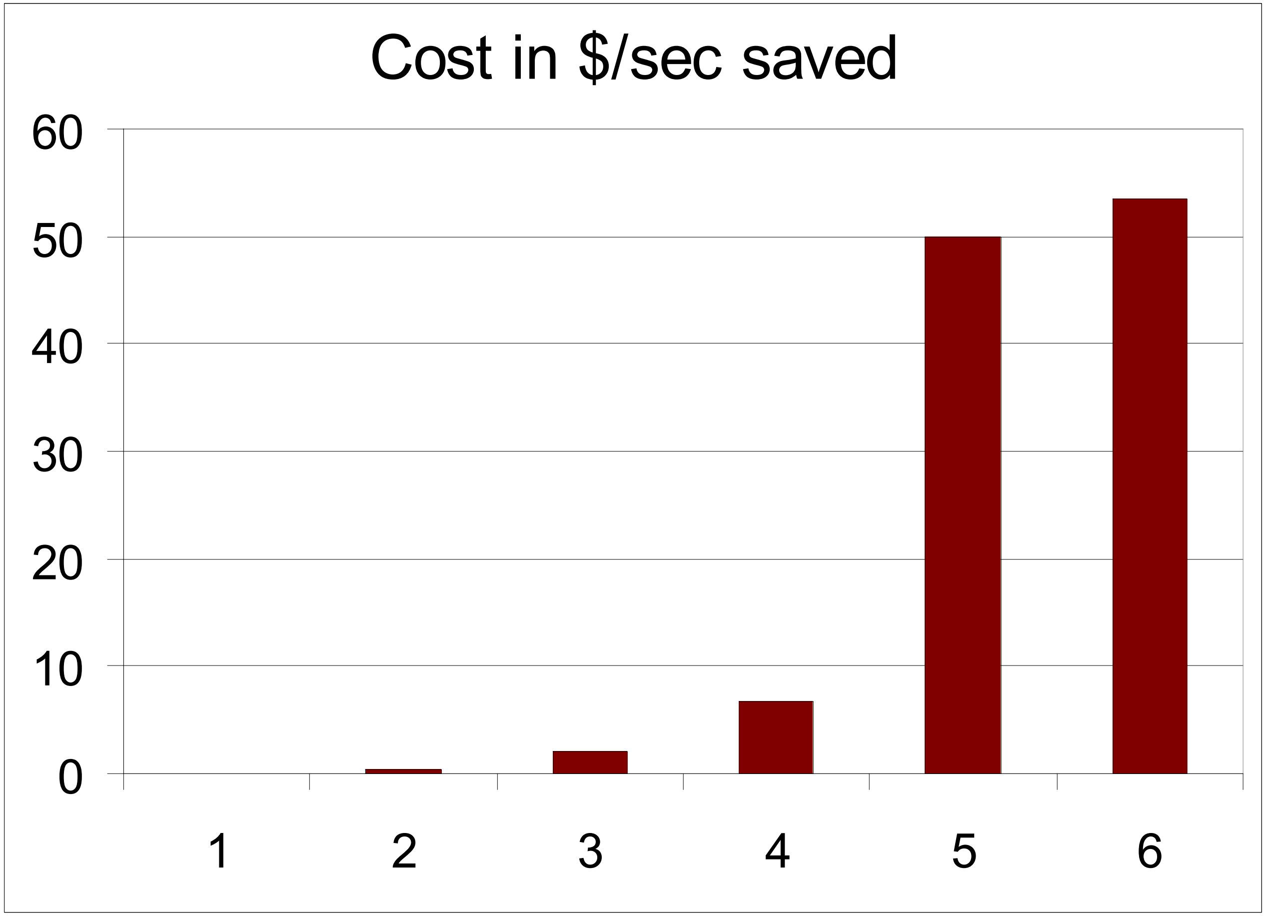


# Wind Tunnel Results

*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%

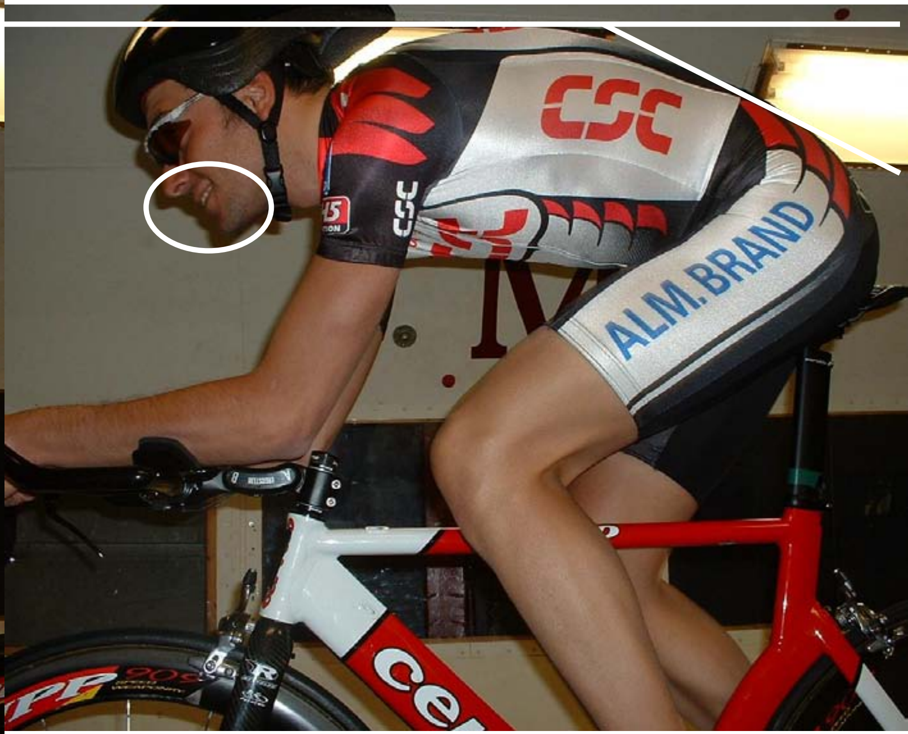
## Position changes

- 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.

# Ivan Basso

## 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

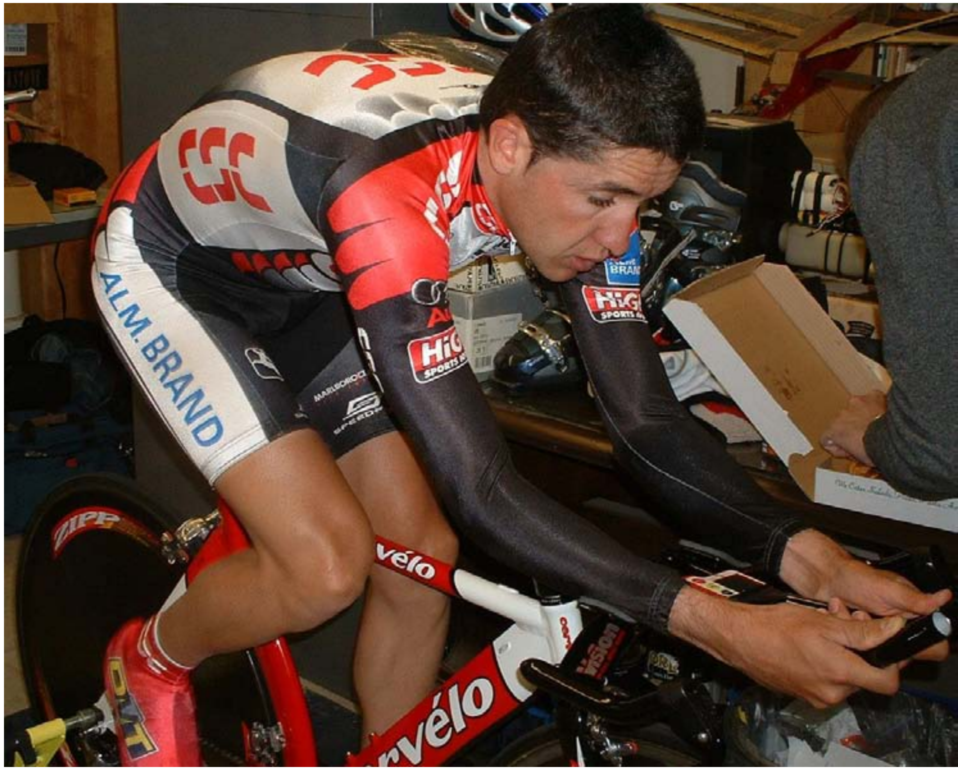
- 3 hours

## 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


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

# 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

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Kim B. Blair PhD
Vice President

# 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

ES.010 Chemistry of Sports
Spring 2013