Emergency braking distance

document prepared by Jan Hakenberg, 2018-02-17

Background

• in the session on 2017-12-13, the gokart was manually operated by joystick
• at **initial speeds** of **4-6[m/s]** the driver applied the brake until the gokart came to a **full stop**
• the gokart was driven in the Dubendorf handar on asphalt floor (high traction)
• the total weight of the vehicle, i.e. gokart, equipment, driver is estimated at 281[kg]

Purpose of Document

• determine deceleration rate of gokart when wheels are locked with driver inside
• tabulate initial-speed to braking distance, for instance **at a speed of 6[m/s] the gokart stops in 4.6[m]**
• visualize the response time of the brake
• understand how the brake causes the locking of the wheels

Observations

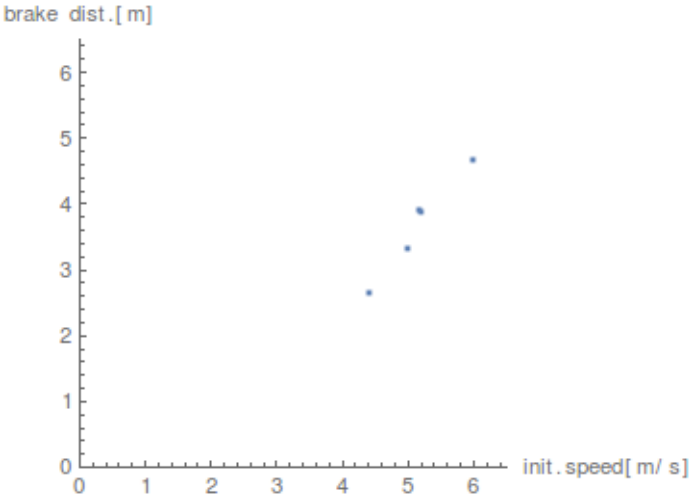
• the braking - as it was carried out - consists of 3 phases:
1) the brake piston moves to max position, typically within 0.05[s]
2) the wheel rate is reduced until the wheels lock
3) deceleration with tires skidding until the gokart comes to a complete stop
• at an **initial speed of 6[m/s]** the duration of phase 2 was observed to be **0.1[s]**
• an estimate for the deceleration constant during phase 3 when the wheels are locked is **-4.5[m/s^2]**

Conclusion

• the document gives an estimate for the braking distance
• the bound should be considered to **initiate emergency stop depending on current speed**
• more experiments can be conducted to understand phase 2, and to improve estimates of constants
• **consider the possibility to emergency brake the gokart without permanent wheel locking**

Summary: Initial speed vs. braking distance

```
res = {
    {4.432, 2.628, 2.1371718},
    {5.005, 3.3156, 2.369406},
    {5.188, 3.88, 2.2849},
    {5.218, 3.874, 3.0098},
    {5.993, 4.647, 2.2843}};
Rasterize@ListPlot[res[[All, {1, 2}]], PlotRange → {{0, 6.5}, {0, 6.5}},
  AxesLabel → {"init.speed[m/s]", "brake dist.[m]"}, AspectRatio → 1]
-2 Median[res[[All, 3]]]
```




```
-4.5698
```

Helper functions

```
shw[A_, v_] := Transpose[{A[[All, 1]], v}]
distance[A_] := Norm[# - A[[-1, {2, 3}]]] & /@ A[[All, {2, 3}]];
fit[B_] := Module[{func = Fit[shw[B, distance[B]], {1, t, t^2}, t]},
  Print[func]; Show[{
    ListPlot[{B[[All, {1, 9}]], shw[B, distance[B]], shw[B, -100 B[[All, 5]]]},
     PlotLegends → {"odometry [m/s]", "dist. from pEnd [m]", "brake pos. [cm]"}],
    Plot[func, {t, B[[1, 1]], B[[-1, 1]]}, ColorFunction → Function[{x}, Red]]
   }, AxesLabel → {"[s]"}, ImageSize → Large]]
tab[A_, start_] := Module[{speed = A[[start - 1, 9]], dist = distance[A][[start]]},
  Print["init. speed = " <> ToString[speed] <> "[m/s]"];
  Print["brake dist. = " <> ToString[dist] <> "[m]";]
seg[{px_, py_, θ_}] := Line[{{px, py}, {px + Cos[θ], py + Sin[θ]}}]
```

BRAKE4 from 4.4[m/s]

```
A = Import["brake4.csv"];
Dimensions@A
```

```
{567, 9}
```

Summary

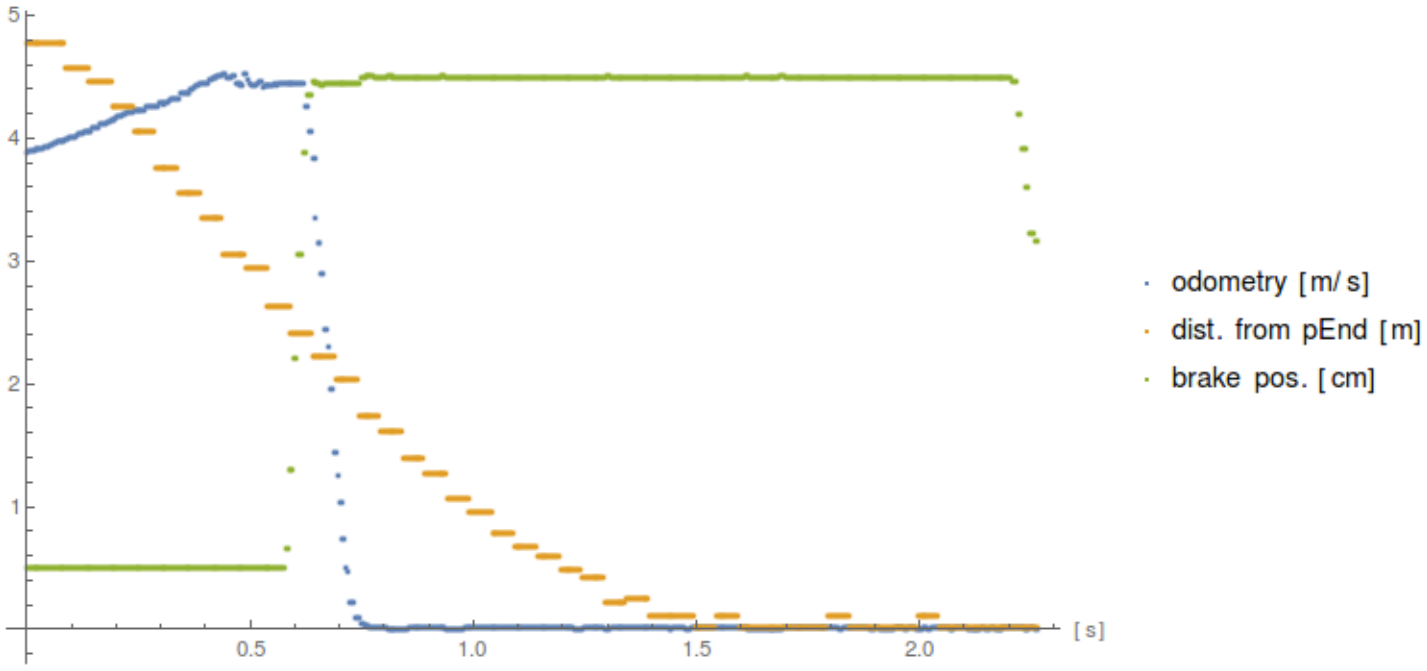
```
start = FirstPosition[0.001 < (Abs[A[[1, 5]] - #]) & /@ A[[All, 5]], True][[1]];
tab[A, start]
```

```
init. speed = 4.432[m/s]
```

```
brake dist. = 2.62806[m]
```

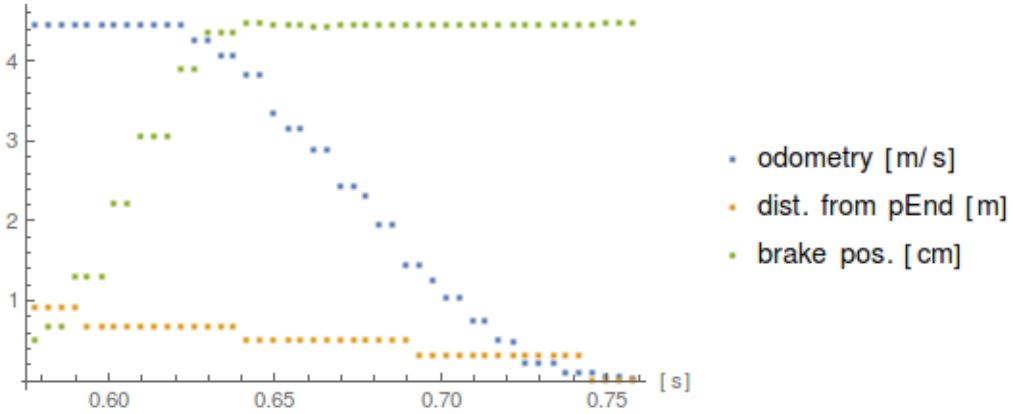
Brake action

```
Rasterize@ListPlot[{A[[All, {1, 9}]], shw[A, distance[A]], shw[A, -100 A[[All, 5]]]}, AxesLabel → {"[s]"},
  ImageSize → Large, PlotLegends → {"odometry [m/s]", "dist. from pEnd [m]", "brake pos. [cm]"}]
```



Until wheel lock

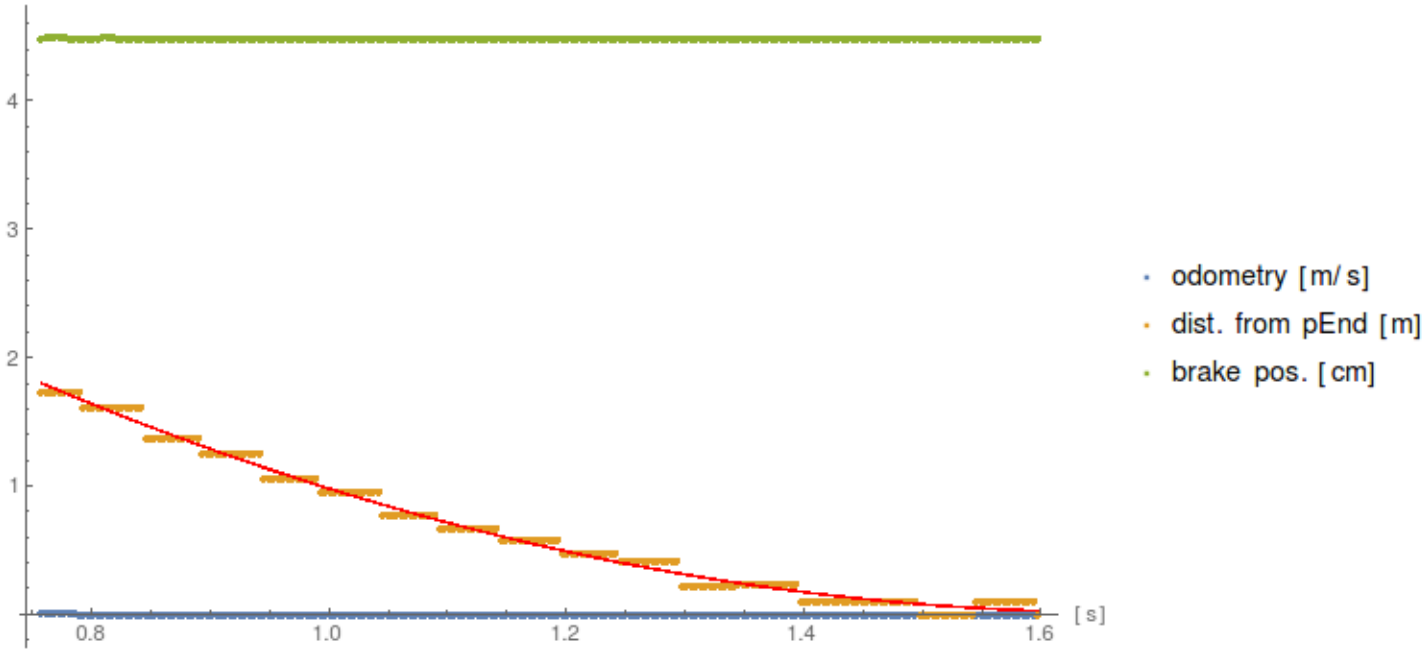
```
B = A[[Range[145, 190]]];
Rasterize@ListPlot[{B[[All, {1, 9}]], shw[B, distance[B]], shw[B, -100 B[[All, 5]]]},
  PlotLegends → {"odometry [m/s]", "dist. from pEnd [m]", "brake pos. [cm]"}, AxesLabel → {"[s]"}]
```



Wheel lock - Quadratic fit

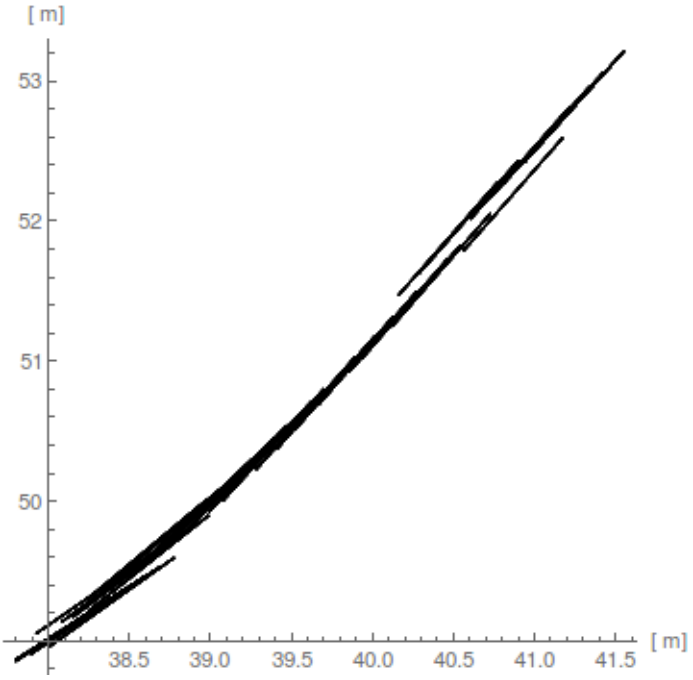
```
Rasterize@fit[A[[Range[190, 400]]]]
```

$5.99497 - 7.1478\ t + 2.13717\ t^2$



Trajectory

```
Rasterize@Graphics[seg /@ A[[All, {2, 3, 4}]], AspectRatio → 1, AxesLabel → {"[m]", "[m]"}, Axes → True]
```



BRAKE2 from 5[m/s]

```
A = Import["brake2.csv"];
Dimensions@A
```

```
{820, 9}
```

Summary

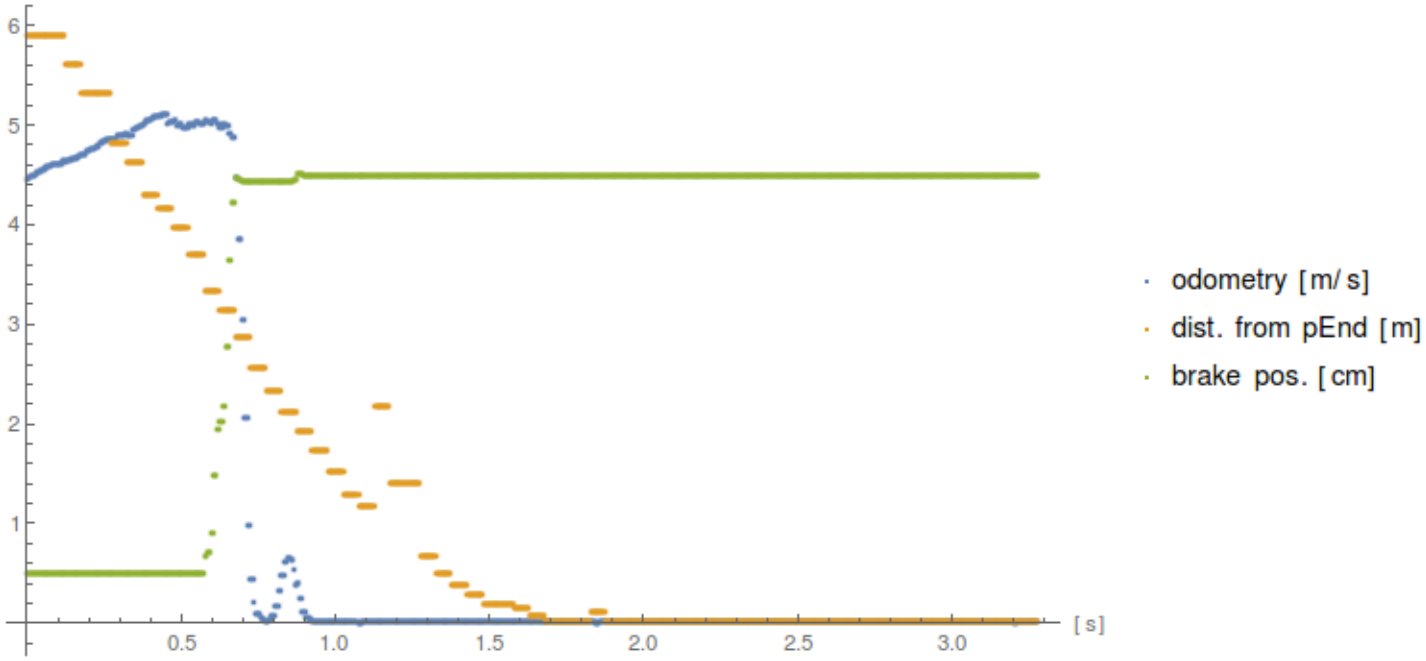
```
start = FirstPosition[0.001 < (Abs[A[[1, 5]] - #]) & /@ A[[All, 5]], True][[1]];
tab[A, start]
```

```
init. speed = 5.005[m/s]
```

```
brake dist. = 3.31561[m]
```

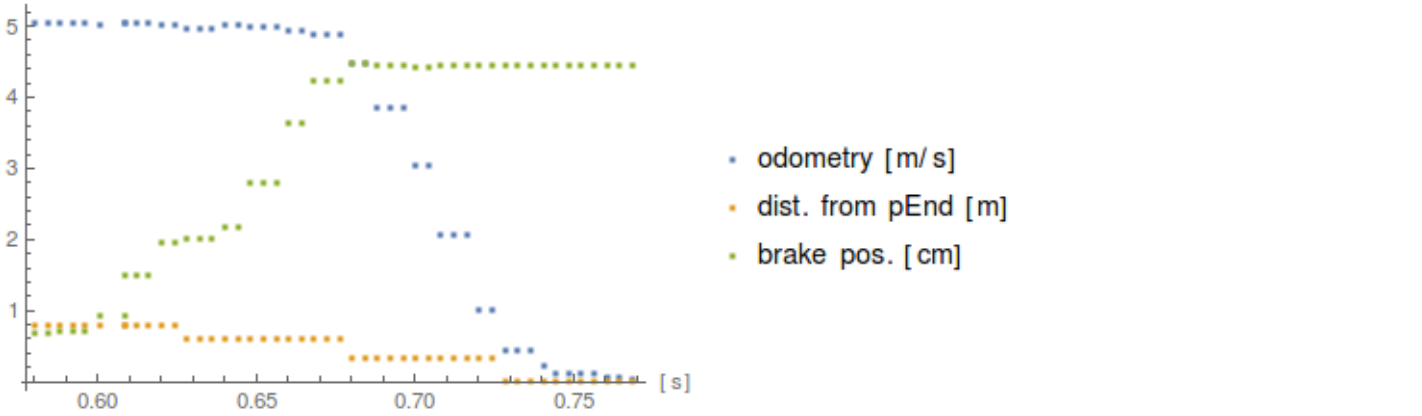
Brake action

```
Rasterize@ListPlot[{A[[All, {1, 9}]], shw[A, distance[A]], shw[A, -100 A[[All, 5]]]}, AxesLabel → {"[s]"},
  ImageSize → Large, PlotLegends → {"odometry [m/s]", "dist. from pEnd [m]", "brake pos. [cm]"}]
```



Until wheel lock

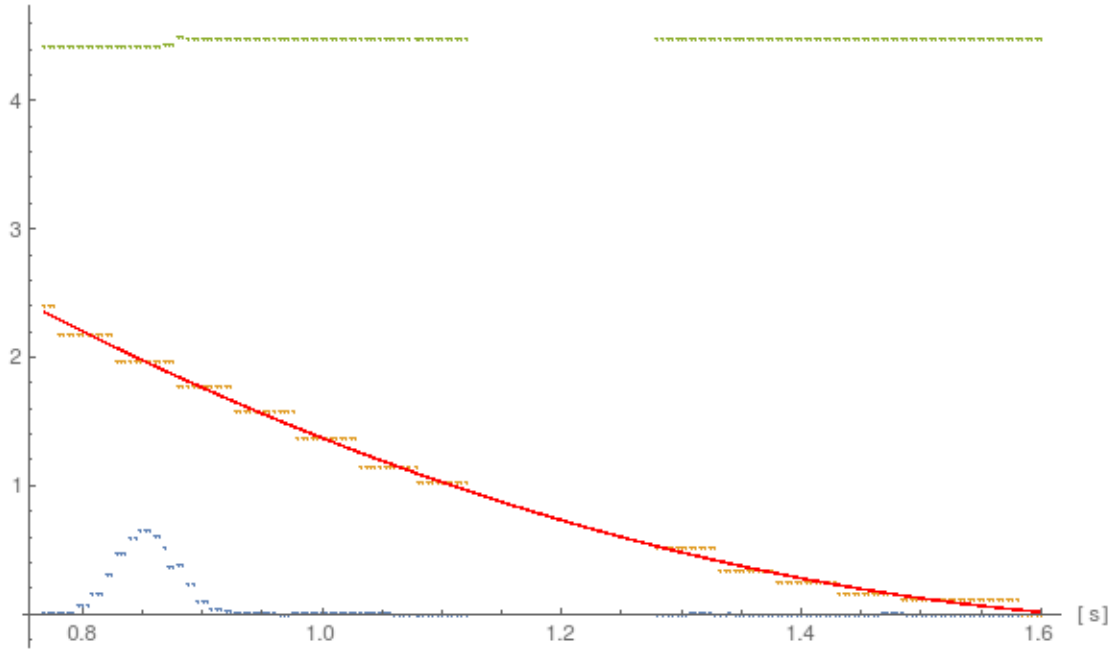
```
B = A[[Range[145, 192]]];
Rasterize@ListPlot[{B[[All, {1, 9}]], shw[B, distance[B]], shw[B, -100 B[[All, 5]]]},
  PlotLegends → {"odometry [m/s]", "dist. from pEnd [m]", "brake pos. [cm]"}, AxesLabel → {"[s]"}]
```



Wheel lock - Quadratic fit

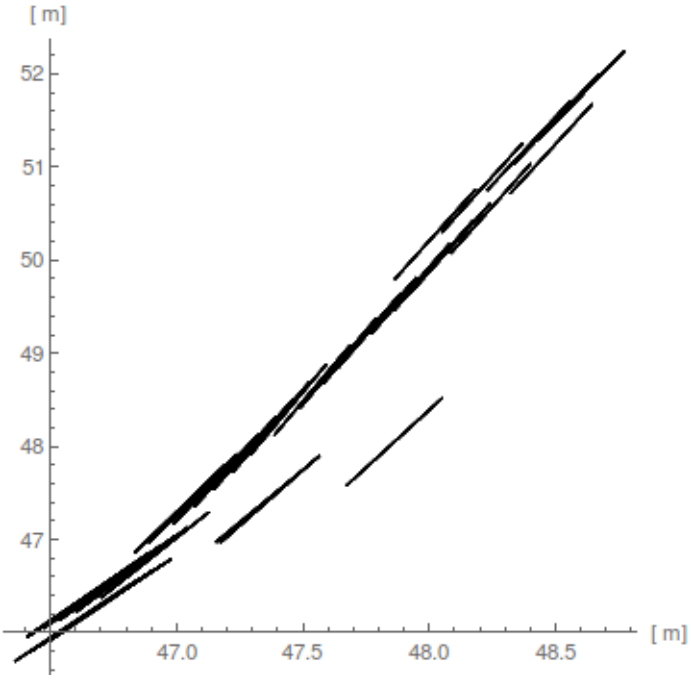
```
Rasterize@fit[A[[Range[192, 280]~Join~Range[320, 400]]]]
```

$7.43114 - 8.42379\ t + 2.36941\ t^2$



Trajectory

```
Rasterize@Graphics[seg /@ A[[All, {2, 3, 4}]], AspectRatio → 1, AxesLabel → {"[m]", "[m]"}, Axes → True]
```



BRAKE5 from 5.2[m/s]

```
A = Import["brake5.csv"][[Range[160, 600]]];
Dimensions@A
```

```
{441, 9}
```

Summary

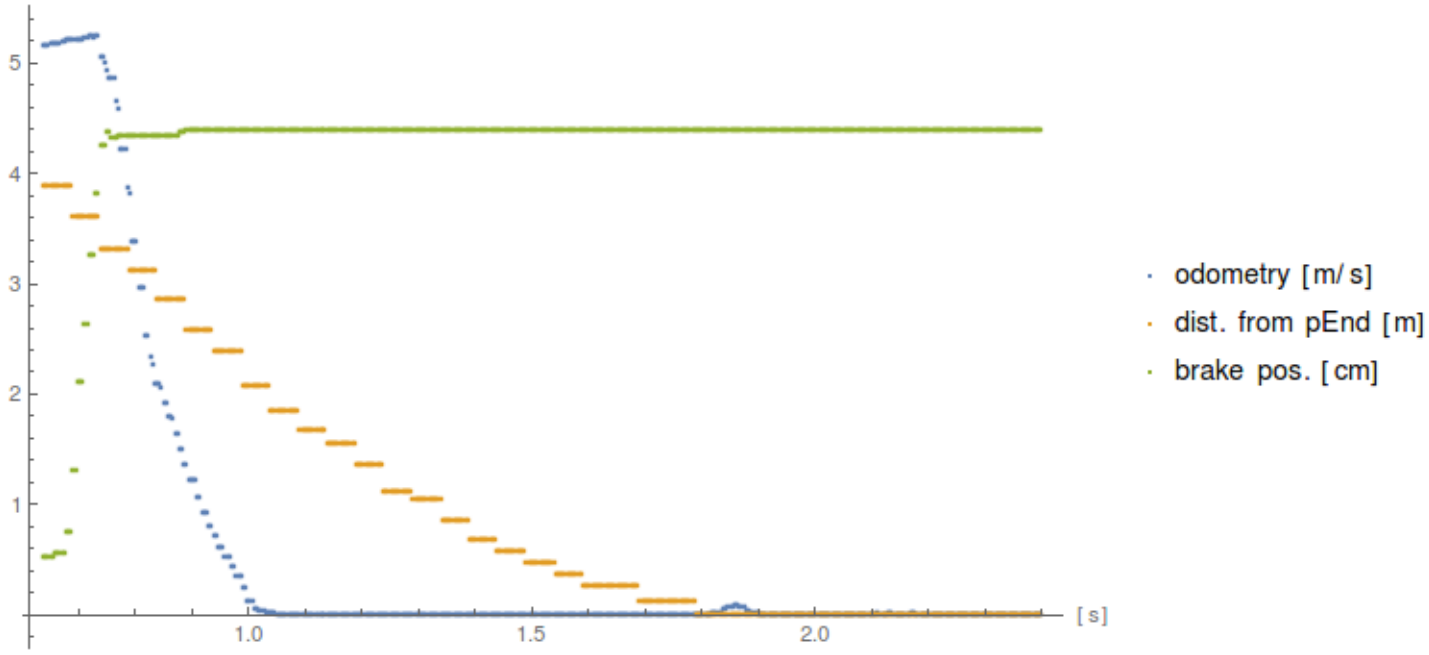
```
start = FirstPosition[0.001 < (Abs[A[[1, 5]] - #]) & /@ A[[All, 5]], True][[1]];
tab[A, start]
```

```
init. speed = 5.188[m/s]
```

```
brake dist. = 3.88025[m]
```

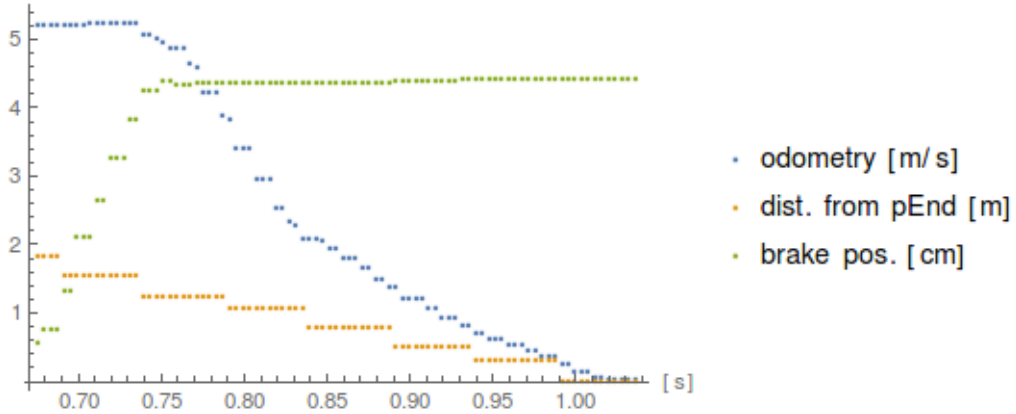
Brake action

```
Rasterize@ListPlot[{A[[All, {1, 9}]], shw[A, distance[A]], shw[A, -100 A[[All, 5]]]}, AxesLabel → {"[s]"},
  ImageSize → Large, PlotLegends → {"odometry [m/s]", "dist. from pEnd [m]", "brake pos. [cm]"}]
```



Until wheel lock

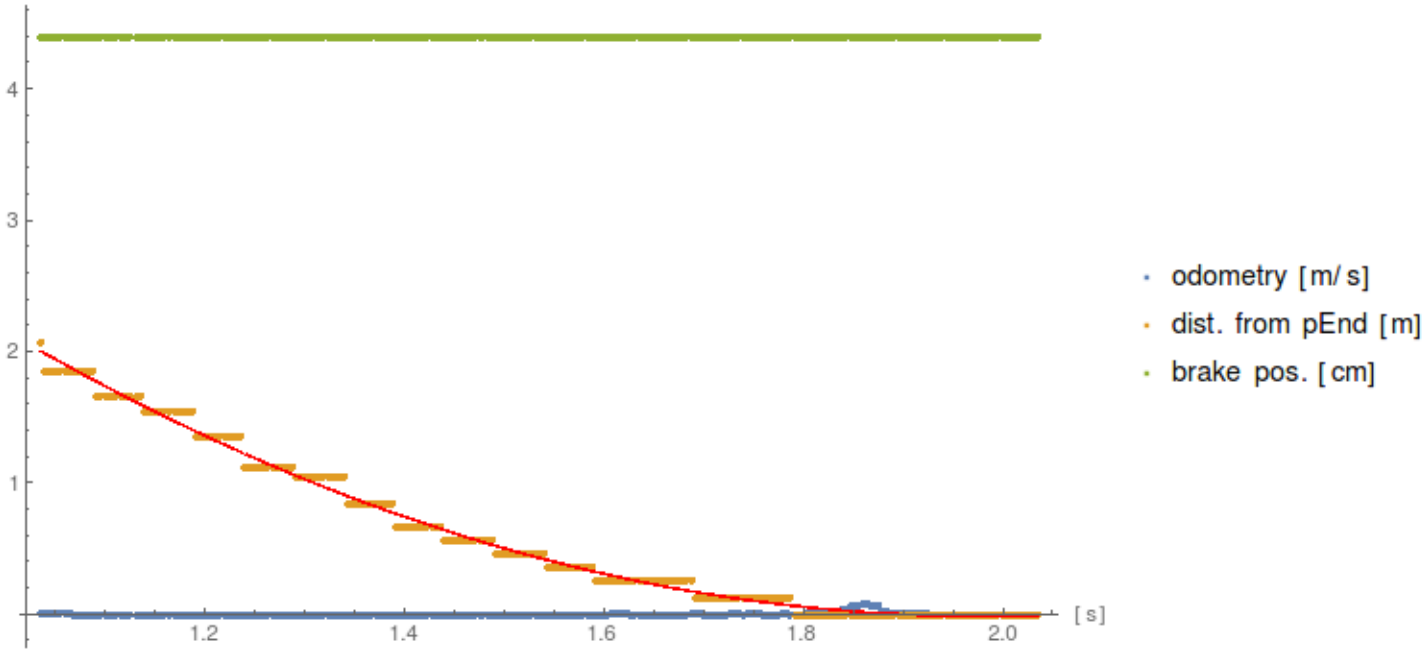
```
B = A[[Range[10, 100]]];
Rasterize@ListPlot[{B[[All, {1, 9}]], shw[B, distance[B]], shw[B, -100 B[[All, 5]]]},
  PlotLegends → {"odometry [m/s]", "dist. from pEnd [m]", "brake pos. [cm]"}, AxesLabel → {"[s]"}]
```



Wheel lock - Quadratic fit

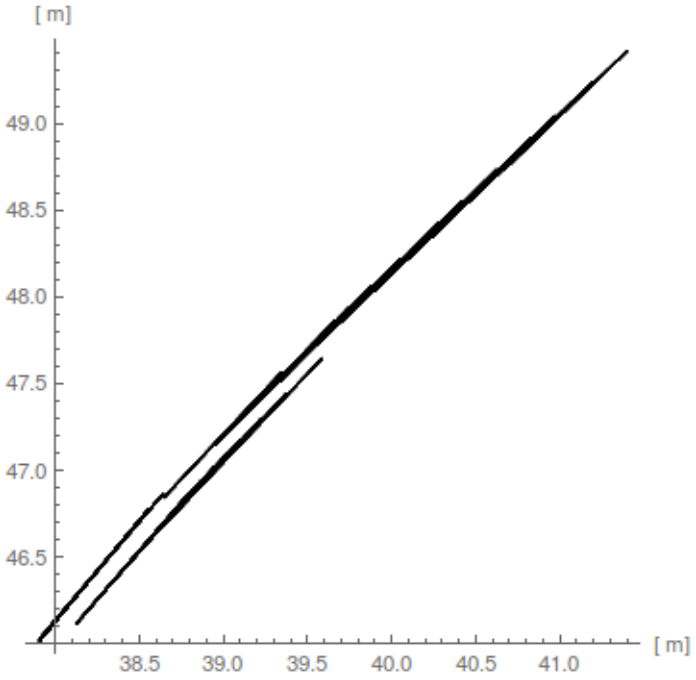
```
Rasterize@fit[A[[Range[100, 350]]]]
```

$8.90563 - 9.02913\,t + 2.28492\,t^2$



Trajectory

```
Rasterize@Graphics[seg /@ A[[All, {2, 3, 4}]], AspectRatio → 1, AxesLabel → {"[m]", "[m]"}, Axes → True]
```



BRAKE1 from 5.2[m/s]

```
A = Import["brake1.csv"];
Dimensions@A
```

```
{580, 9}
```

Summary

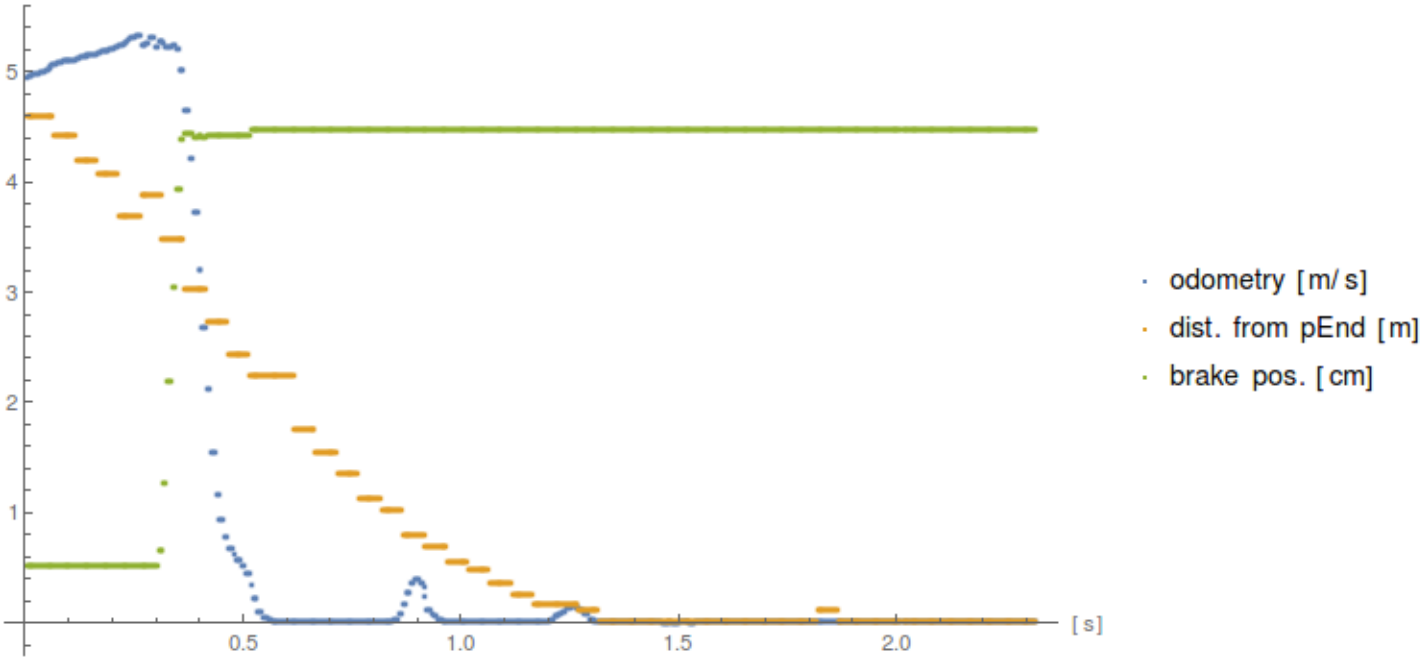
```
start = FirstPosition[0.001 < (Abs[A[[1, 5]] - #]) & /@ A[[All, 5]], True][[1]];
tab[A, start]
```

```
init. speed = 5.218[m/s]
```

```
brake dist. = 3.87411[m]
```

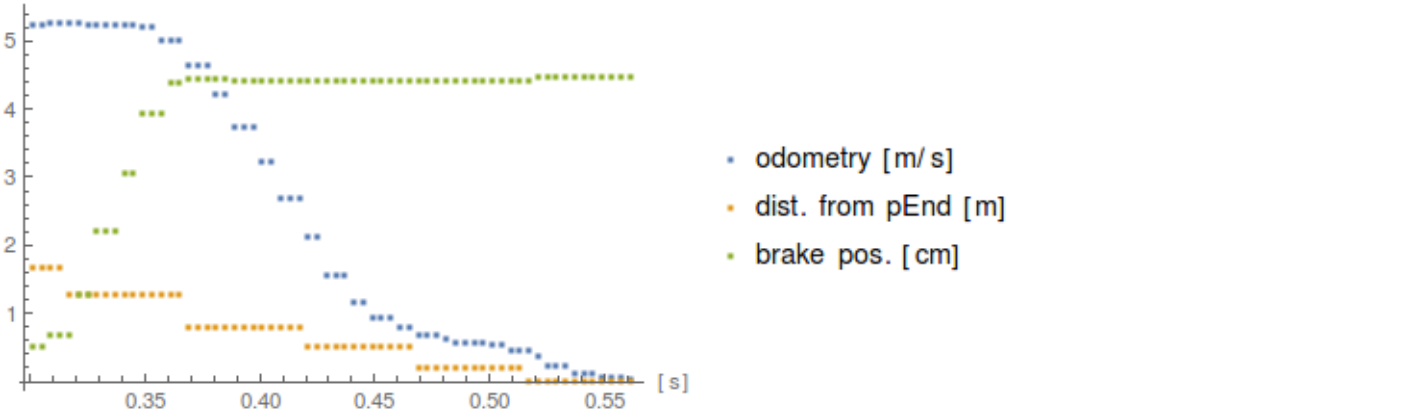
Brake action

```
Rasterize@ListPlot[{A[[All, {1, 9}]], shw[A, distance[A]], shw[A, -100 A[[All, 5]]]}, AxesLabel → {"[s]"},
  ImageSize → Large, PlotLegends → {"odometry [m/s]", "dist. from pEnd [m]", "brake pos. [cm]"}]
```



Until wheel lock

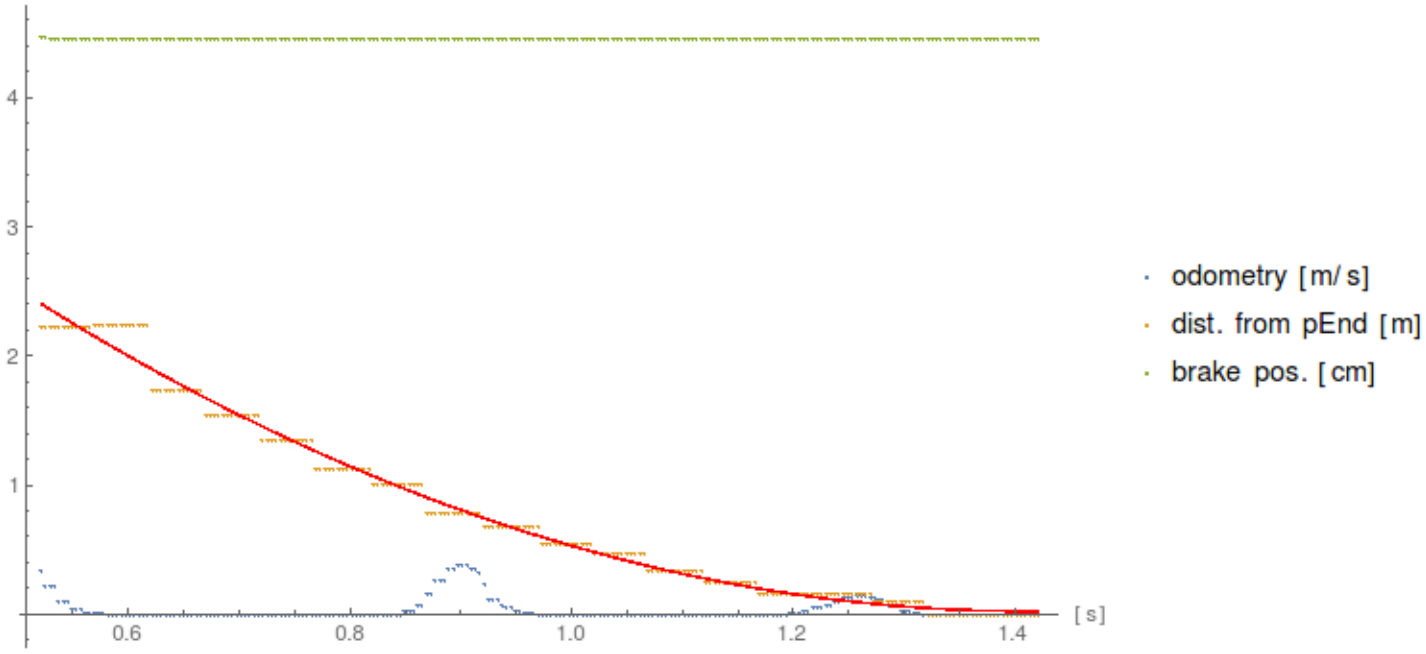
```
B = A[[Range[75, 140]]];
Rasterize@ListPlot[{B[[All, {1, 9}]], shw[B, distance[B]], shw[B, -100 B[[All, 5]]]},
  PlotLegends → {"odometry [m/s]", "dist. from pEnd [m]", "brake pos. [cm]"}, AxesLabel → {"[s]"}]
```



Wheel lock - Quadratic fit

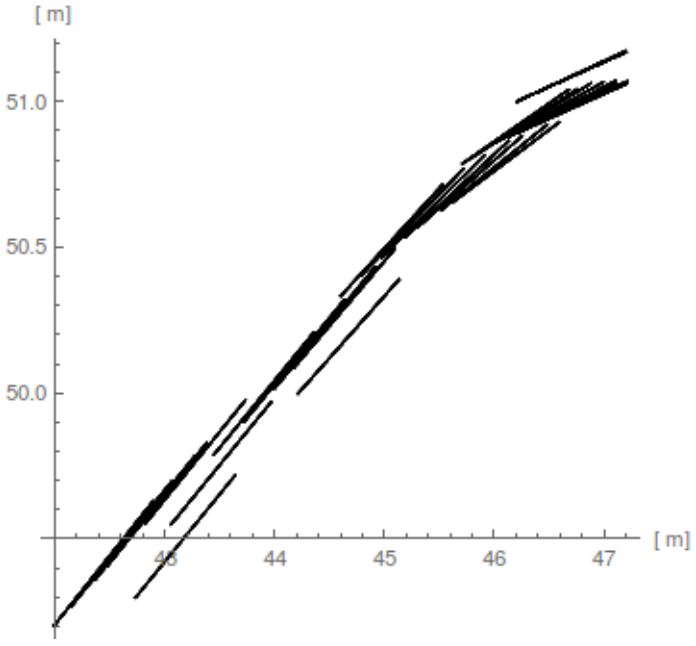
```
Rasterize@fit[A[[Range[130, 355]]]]
```

$6.01753 - 8.49241\ t + 3.00983\ t^2$



Trajectory

```
Rasterize@Graphics[seg /@ A[[All, {2, 3, 4}]], AspectRatio → 1, AxesLabel → {"[m]", "[m]"}, Axes → True]
```



BRAKE6 from 6[m/s]

```
A = Import["brake6.csv"][[Range[600]]];
Dimensions@A
```

```
{600, 9}
```

Summary

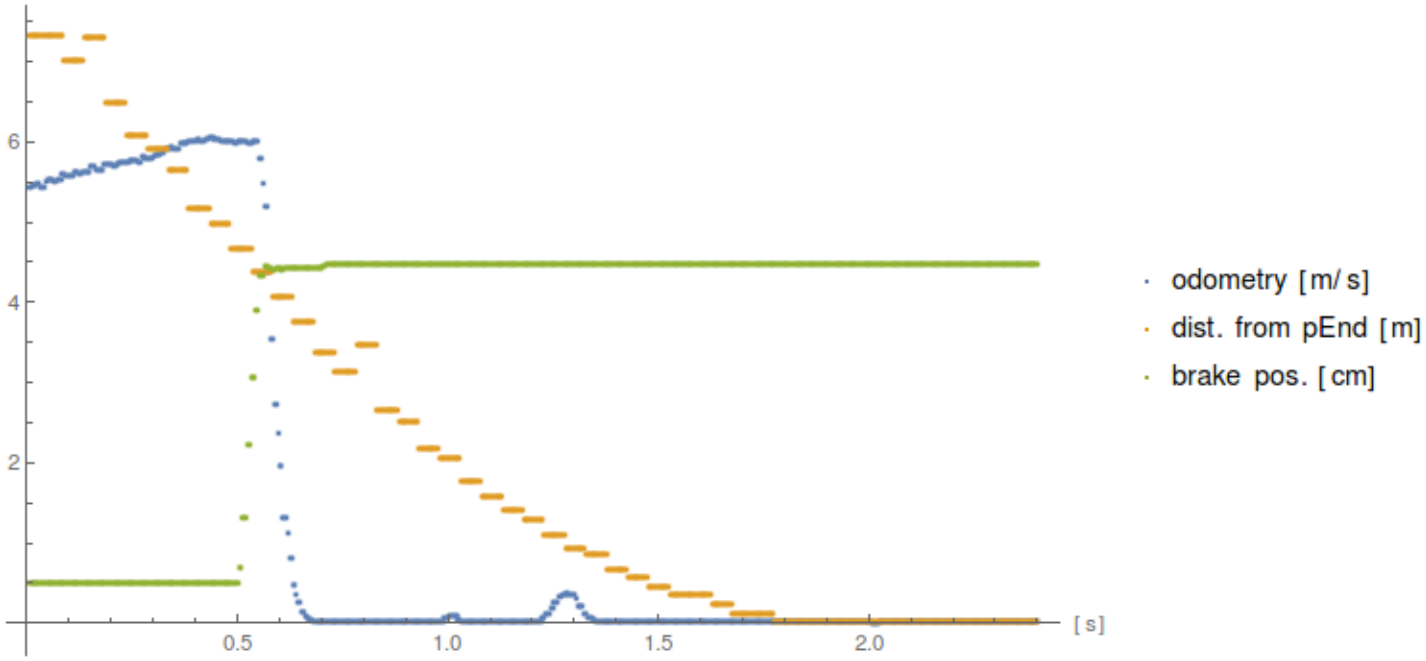
```
start = FirstPosition[0.001 < (Abs[A[[1, 5]] - #]) & /@ A[[All, 5]], True][[1]];
tab[A, start]
```

```
init. speed = 5.993[m/s]
```

```
brake dist. = 4.64708[m]
```

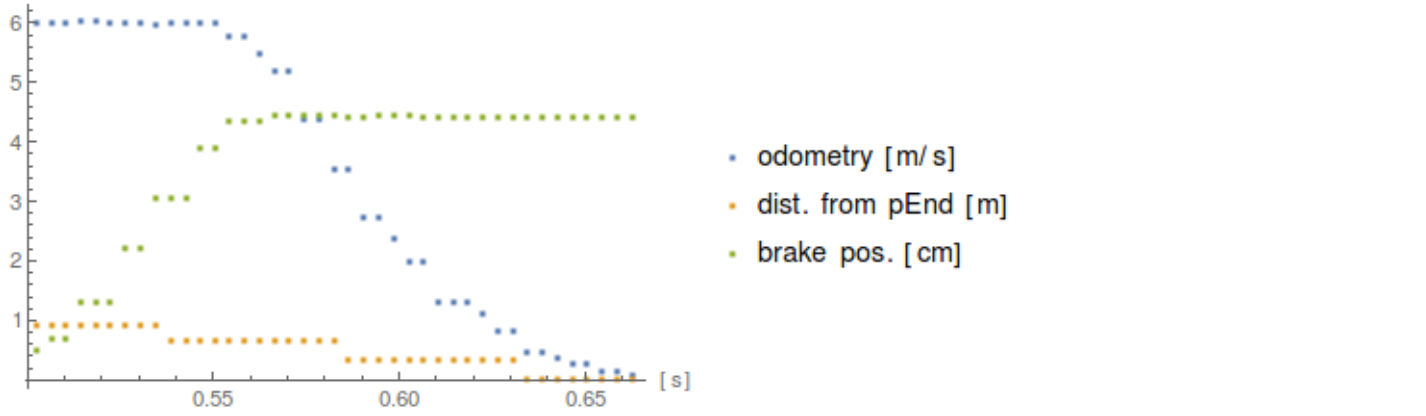
Brake action

```
Rasterize@ListPlot[{A[[All, {1, 9}]], shw[A, distance[A]], shw[A, -100 A[[All, 5]]]}, AxesLabel → {"[s]"},
  ImageSize → Large, PlotLegends → {"odometry [m/s]", "dist. from pEnd [m]", "brake pos. [cm]"}]
```



Until wheel lock

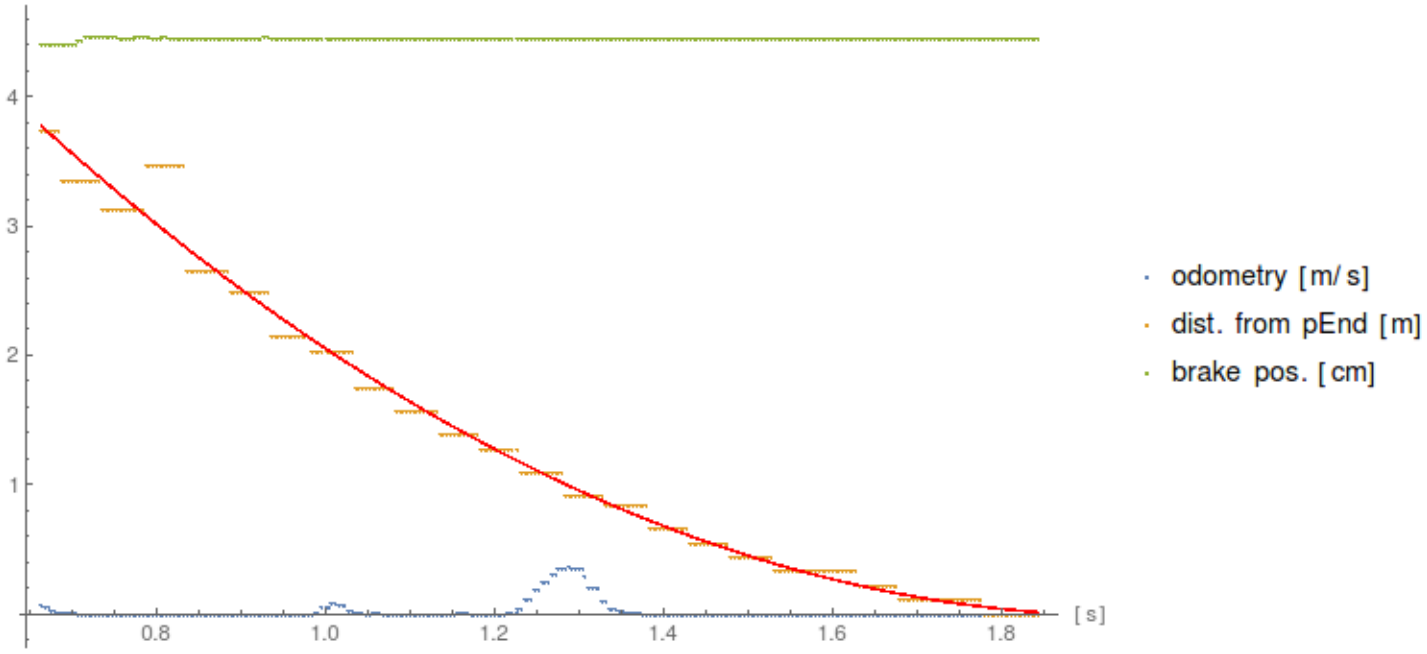
```
B = A[[Range[125, 165]]];
Rasterize@ListPlot[{B[[All, {1, 9}]], shw[B, distance[B]], shw[B, -100 B[[All, 5]]]},
  PlotLegends → {"odometry [m/s]", "dist. from pEnd [m]", "brake pos. [cm]"}, AxesLabel → {"[s]"}]
```



Wheel lock - Quadratic fit

```
Rasterize@fit[A[[Range[165, 460]]]]
```

$8.67788 - 8.90916\,t + 2.28434\,t^2$



Trajectory

```
Rasterize@Graphics[seg /@ A[[All, {2, 3, 4}]], AspectRatio → 1, AxesLabel → {"[m]", "[m]"}, Axes → True]
```