

An Investigation on Racecar Starting Positions in the Student Formula Competition Acceleration Event

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ABSTRACT

This article aims to quantitatively investigate the advantages gained when racecars are deliberately positioned far from the starting line in the Acceleration Event of the TSAE Student Formula competition. A racecar acceleration model, verified with an actual race data, is used to predict the race time when the car is initially staged at different positions with respect to the starting line. The results show that the race time can be significantly reduced which can have a considerable impact on the eventual race outcome.

INTRODUCTION

The Society of Automotive Engineers Thailand (TSAE) has been organising the AutoChallenge Student Formula for many years to encourage university students and those in other higher education institutes to showcase their automotive engineering skills in racecar design and manufacturing processes. The Mechanical Engineering Department of King Mongkut's University of Technology Thonburi (KMUTT) has also been an ever present member of the competition since its inaugural edition. The competition requires the teams to design and build a racecar which obeys the Formula SAE regulations [1]. There are two parts to the competition where the racecar is scored: Static Events and Dynamic Events.

This article focuses specifically on the Acceleration Event of the Dynamic part. In this event, the racecar is scored according to the elapsed time it has recorded. Elapsed time is measured from the time the car crosses the starting line until it crosses the finish line 75 meters away. Article D5.2.1 of the regulations [1] states that

Staging – The foremost part of the car will be staged at 0.30 m (11.8 inches) behind the starting line. Cars will accelerate from a standing start.

However, it was observed at several race sessions that some racecars were deliberately staged by their team members behind the starting line at a *distance significantly greater than 0.30 m*. A longer distance behind the starting line enables the racecar to accelerate to achieve a higher speed the instance it crosses the starting line, hence recording a shorter race time and higher scores in the Acceleration event.

It should be clearly stated that the authors have no intention to raise an issue of the failure to follow the rules by any particular competitor. The only objective of this article is to conduct a technical investigation and quantitative analysis into the advantage gained in the Acceleration Event elapsed race time should the investigated racecar intentionally fail to stage the racecar at a recommended distance at the start. An attempt to model the race time with a variation in starting distances will be presented. The ensued analysis discusses how significant this race time reduction advantage can impact the race results and the subsequent standings.

MAIN SECTION

This section will include the following subsections (1) Racecar acceleration model (2) Race time calculations and (3) Effects on race outcome.

RACECAR ACCELERATION MODEL

A racecar acceleration model must be established in order to perform calculations to predict the race time when the racecar starts to accelerate from different positions relative to the starting line. The use of an acceleration model is essential because the actual race data can only reveal the car's speed and displacement accurately up to the finishing line because the driver will step on the brakes and the car's acceleration suddenly stops. The acceleration model will be used to extrapolate the car's speed should the car be allowed to

accelerate one or two seconds longer. It is worth noting that practice race data does not reveal the car straight line acceleration characteristics beyond 75 m. because the team has not been able to run a full test on a long straight road similar to that used in the actual competition.

The actual KMUTT team race data from the TSAE AutoChallenge 2011-2012 will be used for acceleration model verification. The PerformanceBox GPS data acquisition tool was used during the race to record the car's motion. The set of car longitudinal acceleration and speed data will form the basis of the acceleration model formulation. The device is capable of recording the car's acceleration data at 10Hz with 0.01G resolution. Its full specification is given in Reference 2.

The actual race data during the Acceleration Event retrieved from the racecar data logger is



Figure 1a. A photograph of the actual PerformanceBox GPS data logger

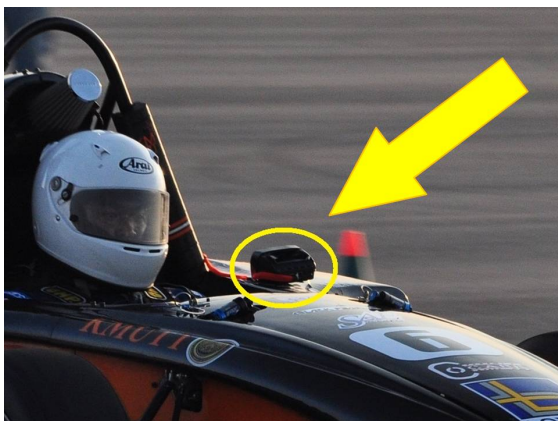


Figure 1b. The GPS data logger is attached on the racecar body to the left of the driver. It is securely fastened to the body using metal brackets.

shown in Figure 2. Both acceleration and speed of the car are plotted in the time domain where $t = 0 \text{ sec.}$ indicates the moment the car starts to accelerate from rest. The car's acceleration data shows that the car is accelerating forward between $0 \leq t \leq 5$ with several 'jerks' representing the gear changes. The driver then begins to brake just before $t = 6 \text{ sec.}$, indicated by the sharp drop in the acceleration curve into the negative value region. This coincides with the car speed data which continues to increase from zero at the beginning to peak at just before $t = 6 \text{ sec.}$ and starts to decrease thereafter. This set of data is recorded at 0.1 sec. time intervals.

The acceleration shows a pattern of a sharp increase in the early stages (low gears) before a steady decrease after several gear shifts into higher gears. Hence, the following acceleration model is proposed to replicate the racecar acceleration during the Acceleration Event

$$a(t) = A(1 - e^{-Bt})(1 - Ct) \quad (\text{Eqn.1})$$

where A, B and C are model parameters which must be optimised.

The car velocity and distance travelled can be calculated from the acceleration function using simple Calculus [3]. The optimisation process is performed by determining the values of all three parameters A, B and C which give the lowest error where the error function is defined as the root-mean-square differences of the car velocities between $1.0 \leq t \leq 5.5$. This time interval is chosen because it represents the period where the car is traveling at its maximum acceleration without inaccuracies from the possible skidding and braking.

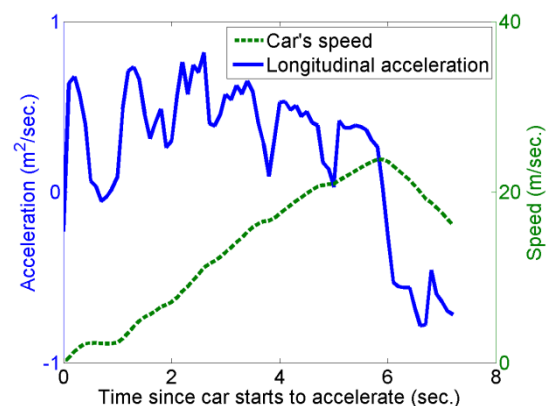


Figure 2. Actual KMUTT team racecar acceleration and speed data recorded during the Acceleration Event at TSAE AutoChallenge 2011-2012

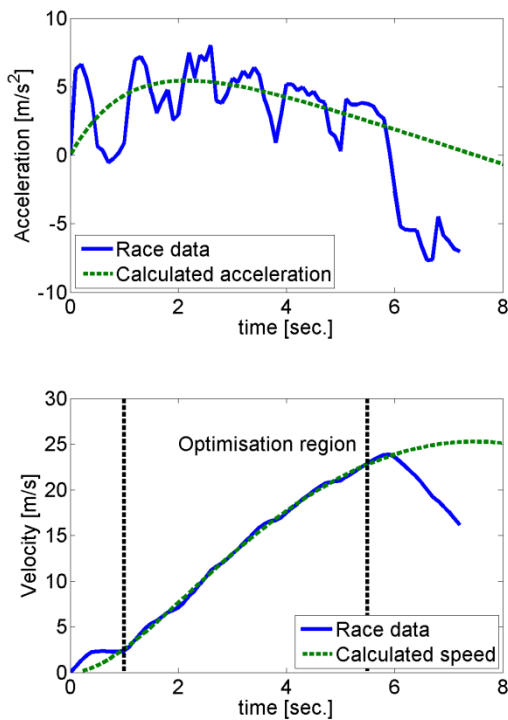


Figure 3. Optimised acceleration model parameters $a(t) = 9.534(1 - e^{-0.750t})(1 - 0.133t)$ are used to generate a velocity curve which shows a good correlation with the actual racecar velocity data.

The optimisation process is completed using MATLAB's solution finding routine which is based on the Newton-Raphson algorithm. Its solution is displayed in Figure 3. The values of the optimised acceleration model parameters are $A = 9.534$, $B = 0.750$ and $C = 0.133$. The root-mean-square error obtained from these parameters is 2.078. Although there is no systematic error tolerance acceptance to verify the model accuracy, the velocity curves in Figure 3 show a good correlation with the actual race data and should be an acceptable evidence for the verification procedure.

RACE TIME CALCULATIONS

A racecar acceleration model has been established so it is now possible to make Acceleration Event race time predictions should the same racecar be staged at different distances behind the starting line using simple calculus [3].

The racecar displacement-time curves of four different starting positions between 0m to 9m are shown in Figure 4. Note that the maximum distance of 9m is arbitrarily chosen to

demonstrate the effects of the advantage and does not reflect what happened in the actual TSAE Student Formula competition. The horizontal dotted lines indicate starting and finishing lines at 0m and 75m, respectively. The race time is the time taken for the car to travel between the starting and finishing line, ie. the time taken between the two intersections between the displacement curves and the horizontal dotted lines.

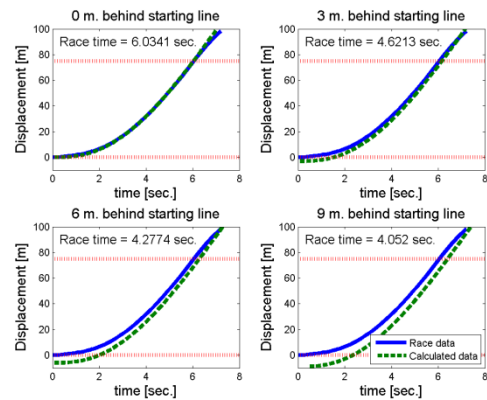


Figure 4. Displacement-time graphs of the racecar at four different starting positions between 0m up to 9m are plotted in comparison with the actual race data.

EFFECTS ON RACE OUTCOME

A more comprehensive calculated data is presented in Figure 5 where the race time is plotted against the starting distances. It shows a significantly shorter race time when the car begins to accelerate further away from the starting line. The race time can be reduced up to almost 2 seconds or approximately 30% of that recorded by the car starting at the line.

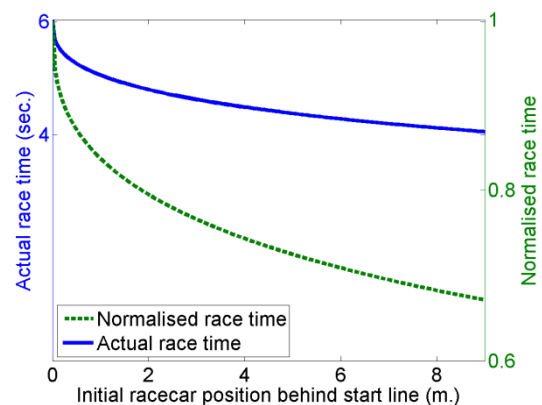


Figure 5. A racecar staged at an exaggerated distance of 9 m. away from the starting line could record a significantly lower race time of up to 2 seconds or 30% than the car staged at the starting line.

This advantage can significantly affect the race outcome, as the winning margin in the Acceleration Event is usually very small, ie. tenths or hundredths of a second. In the TSAE AutoChallenge competition, the winner of the Acceleration Event would be awarded the maximum score of 75 points and the rest of the field would be scored relative to the winner. In the 2011-2012 competition, the race time of the fastest car was under 4 seconds and the margins between the fastest 10 cars are likely to be under 1 second. Hence, the findings presented in Figure 5 show that the amount of time that can be reduced by staging the car further behind the starting line can have a very significant impact on the event results.

It is worth pointing out that the race time reduction is very sensitive to the car initial position especially when the distance behind the start line is small, ie. lower than 2 m. An advantage of nearly one full second is gained when the car is staged one meter behind the starting line. Therefore, it brings into question the time keeping technology. For example, the race stewards at the Japan Society of Automotive Engineering (JSAE) Student Formula would measure the race time using sensors that detect the transponder attached to the driver's left arm. Given that the *nose* of all race cars are staged at the same distance from the start line, the racers position in the cockpit will still differ from car to car, possibly up to 0.30 m., thus resulting in different effective starting positions. Such an effect will be explored and presented in another research article.

CONCLUSION

This article has successfully demonstrated the importance of staging the race cars at the same distance from the starting line because it can produce unfair results by using a verified racecar acceleration model. Further investigations into smaller details such as the advantage gained with respect to the cockpit design will be reserved in future work.

ACKNOWLEDGMENTS

The authors acknowledge the contribution of KMUTT Racing Team: Blackpearl III in providing the race data which is essential to the model verification used in this work.

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Chawin Chanthararasenawong received M.Eng (2003) and PhD (2007) in Aeronautics from Imperial College London. He currently holds an Assistant Professor position at Mechanical Engineering Department, KMUTT. His research interests are wind energy technology, aeroelasticity and dynamical system analysis. He is also an advisor to KMUTT Student Formula team.