Technological Development of Speedway: A Review and Analysis

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ABSTRACT

From the available literature it is clear that very little experimental testing has been conducted on Speedway frames to date, yet investigations into the physical parameters are fundamental if the sport is to continue to progress technically. The literature suggests that additional investigations into Speedway could provide a beneficial outcome to the sport and produce an increase in the performance of the bike whilst keeping costs low.

A technology road map of Speedway was created to assess the technical development of the sport since its establishment and determined the trend in the mainstream popularity of the sport. Torsional and virtual testing was carried out on the Speedway frame, determining key performance parameters and behaviour characteristics of the frame and resulted in a validated FEA model of the Speedway frame being developed.

The work reported here facilitates the potential for further development to be undertaken on areas relating to Speedway and in particular the frame. Whilst a validated FEA model was created, the design of the frame could be further optimised to provide a beneficial performance outcome for Speedway.

To everyone that got me through this.

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Chapter 1- Introduction

1.1- INTRODUCTION

This chapter provides an overview of the sport of Speedway and outlines the work undertaken in this research. The justification for completing this research is presented as well as a small review of experimental studies into Speedway motorcycles that have already been completed.

1.2- AN OVERVIEW OF SPEEDWAY

Speedway originated in the southern hemisphere countries of New Zealand and Australia in the early 1920's and is one of the oldest forms of motorsport. The style of Speedway riding and dirt track technology developed in America yet it was in Australia that the first incarnation of modern short track motorcycle racing, eventually known as Speedway took place (Belton, 2002). Current Speedway bikes run a single cylinder 500cc engine mounted horizontally in the frame and can achieve 0-60mph in 2.5 seconds despite only having a single gear ratio (Speedway Great Britain, 2012).

Shortly after its establishment in Australia, Speedway was demonstrated in Britain for the first time in 1928 at High Beech. Williams (1999) illustrates the curiosity that Speedway provoked within people in its early years by sharing the reaction that writer and Oxford University MP A.P. Herbert had when he witnessed Speedway for the first time in 1928:

> *"Heavens, the noise! It is like ten million mechanical drills performing in unison. It swells and falls as the riders take the corners; it echoes about the cavernous concrete halls, drowning the feeble acclamations of the crowd; it dies slowly as the riders stop, and the end of a race seems like the end of a battle. It is titanic and terrible and monstrous; and yet in that enormous place, made by those monsters, it seems appropriate and right. And I do believe I rather liked it" (Williams, 1999).*

After the first meeting at High Beech, the popularity of Speedway within the UK immediately soared with teams forming in many locations around the country, resulting in both domestic and international leagues being established. Although Speedway originated in the southern hemisphere, Williams (1999) indicates that there is no evidence to suggest that Speedway was at any point criticised for being imported into Britain and the significant rise in its popularity within the UK certainly validates this suggestion.

In contrast to Football players, Speedway riders compete in multiple leagues both internationally and domestically but are unable to compete for two teams within the same league. As an example, in 2014, 2013 Speedway World Champion Tai Woffinden competed in the British Elite League for Wolverhampton Wolves as well as in the Polish and Swedish leagues for different teams. In addition to competing in multiple leagues, riders also compete individually in the Speedway World Championship that runs 12 rounds in stadiums around the World, with riders hoping to become Speedway World Champion.

The governance of domestic Speedway is divided between several organisations and companies. Whilst International Management Group (IMG) hold the commercial rights to Speedway which involve the sponsorship and TV deals associated with the sport, the technical regulations are determined by the Fédération Internationale de Motocyclisme (FIM), with the overall administration of Speedway being run by the British Speedway Promoters Association (BSPA).

1.3- JUSTIFICATION FOR RESEARCH

Belton (2002) suggests that the limited nature of the Speedway market deterred many manufacturers from building new Speedway bikes. The hope throughout the majority of the history of Speedway is that either Japan or the USA would invent something that would spike an upward turn in the prosperity of Speedway (Williams, 1999). This perception of Speedway racing has also influenced the amount of research that has been completed on the sport to date. Technical papers on Speedway racing are few with the majority of knowledge about Speedway being held by people who have been involved in the sport since a young age.

One such research into Speedway bikes was conducted by Nick Goozee between 2005 and 2008 and presented by Wagstaff (2011). Goozee and a small group of employees from Penske cars worked with former Speedway World Champion Tony Rickardsson to design and manufacture an improved frame design. They determined that current Speedway frames are particularly weak in the rear sub frame and around the headstock. Tony Rickardsson confirmed that Speedway bikes tend to ‘shimmy’ with a series of vibrations when they hit a rut on the track, which is particularly noticeable on the start/finish line and into the first corner (Wagstaff, 2011). The outcome of the research was a specially designed frame that was rigid enough not to ‘shimmy’ but still flexible enough to give the rider a sense of feel. Although the frame produced a significant increase in the performance of the bike, the final manufactured frame was approximately 4 times more expensive than current frames and as a result never entered into serial production (Wagstaff, 2011). Nick Goozee summarises in the article the reason behind this as that “Speedway does everything for cost” and whilst the final design had the potential to revolutionise the sport, the cost would have been too extreme for the sport to sustain financially (Wagstaff, 2011).

Whilst this design never entered put into production, the nature of the research suggests that additional investigations into Speedway technologies could provide a beneficial outcome to the sport and that the technology currently in operation has the potential to be improved to produce an increase in the performance of the bike, whilst keeping costs low.

1.4- AIMS AND OBJECTIVES

Overall Aim

The overall aim of the project is to document the evolution and development of Speedway technology and with the use of physical testing and simulation develop a validated CAD and FEA model of a Speedway motorcycle frame.

Objectives

- Conduct a comprehensive review of relevant literature related to Speedway
- Produce a technology roadmap that documents the evolution of Speedway
- Determine trends in the popularity of Speedway and suggest possible future advancements
- Design a test rig and experiment that can be used to determine the physical properties of a Speedway frame
- Conduct physical testing on a Speedway frame to determine its physical parameters
- Produce a CAD model to determine the relevant properties of the current Speedway frame to validate the FEA model
- Develop a validated FEA model of the Speedway bike using results obtained from physical testing

1.5- THESIS STRUCTURE

The remainder of this research thesis will follow the subsequent structure. Chapter 2 documents the technical and business evolutions of Speedway and a technology road map is presented, which project the future possible pathways for the sport. The literature reviewed in Chapter 2 does not provide insight into the technical characteristics of Speedway motorcycles hence an extensive literature review on areas relating to Speedway such as motorcycle dynamics is presented in Chapter 3. The methodology used during physical testing and the development of the CAD and FE models is given in Chapter 4 with the results presented in Chapter 5 and compared and discussed in Chapter 6.

1.6- SUMMARY

Speedway is one of the oldest forms of motorsport in the world yet extent of the research into the motorcycles performance and underlying dynamics is minimal. Previous research suggests that there is a requirement for further work to be undertaken to progress the sport forwards and to prevent it from stagnating. The aim of this research project is to document the evolution and development of Speedway technology and with the use of physical testing and simulation develop a validated FEA model. The experimental methodology for physical testing and simulation is outlined in Chapter 4 with the results and discussion presented in Chapters 5 and 6 respectively.

Chapter 2- Technology Road Map

2.1- INTRODUCTION

In this Chapter, a documentation of the technical and business evolution of Speedway is provided and an assessment on their effect on the mainstream popularity of the sport to date. In addition to this, a technology road map of Speedway is presented that shows the potential future pathways for the sport.

2.2- BRIEF LITERATURE REVIEW

Technology road mapping is a planning process that simultaneously considers markets, products, technologies as well as research and development. The popularity of road mapping within industry is rapidly increasing as it helps to predict a markets future technologies based on product trends and consumer needs (Technology Commercialisation, 2015). Brindle (2013) explains that road maps define technology pathways showing how incremental innovations happening in parallel add up to new technologies and products in the future. Roadmaps heavily focus on the future pathways for the product and assess how different potential pathways are likely to affect the success of a market or product.

The success of future products and technologies is explained by the Diffusion of Innovation Theory which explains at what rate new ideas and technologies spread through a specific population and why. The theory does not take into account the social support to adopt the new idea and Rogers (2003) explains that failed diffusion does not necessarily mean that the technology or product was not adopted by anyone but rather that full diffusion was not achieved due to either competition from other products or a lack of awareness of the product.

2.3- <u>SPEEDWAY BIKE</u>

Speedway racing, commonly described as “hectic, dangerous and exciting” (Speedway GP, 2014) consists of 4-6 riders competing over four laps around an oval track (Figure 1)

Figure 1- Speedway track layout at British round of the Speedway GP held at Millennium Stadium, Cardiff

Speedway bikes (Figure 2) run a single cylinder 500cc engine mounted horizontally in the frame to lower the centre of gravity height and can achieve 0-60mph in 2.5 seconds despite only having a single gear ratio (Speedway Great Britain, 2012). The main frame is a lightweight tubular construction of steel with two distinct styles of rear sub frame, either a curved sub frame around where the wheel is mounted or a diamond shape sub frame (Cycle Chaos, 2010).

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Figure 2 - Annotated diagram of standard Speedway motorcycle (Speedway GP, 2015)

As a safety precaution Speedway bikes feature no brakes to prevent the type of incident that could happen if four riders charge into a bend at high speeds and the leading man decelerates too quickly (Belton, 2002). Leading link front suspension is currently used with rubber bands fitted between the main fork and the cantilever link providing the suspension (Figure 3).

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Figure 3- Leading Link Suspension System (Speedway GB, 2005)

The art of broadsiding (Figure 4) was established as the quickest way of cornering on a dirt track by American rider Maldwyn Jones in 1922 and is specific to Speedway racing (Belton 2002).

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Figure 4- A Speedway rider showing the art of broadsiding (The Riders Digest, 2013)

At high speeds, a rider will slip the rear wheel of the bike producing a gyroscopic action. This opposes the natural behaviour of the bike as a result of the centripetal forces produced. Speedway riders use the throttle to control the slide and increase or decrease the rate at which the rear wheel spins (Hodgdon, 1934).

2.4- SPEEDWAY ORIGINS

Speedway first came to the UK in 1928, amidst depression and poor economic conditions. There was mass unemployment and by 1933 unemployment figures were as high as 22.8% (Lambert, n.d). According to Belton (2002), Speedway became a cheap distraction from the “grim austerity of life”, significantly aiding its rise in popularity in the early years. Williams (1999) explains that of the new sports launched in the 1920s and 30’s, only Speedway and greyhound racing attracted sufficient following to become accepted as a major British sport. Unlike football, Speedway featured no betting and spectators openly interacted with each other. Belton (2002) explains that this environment became fundamental to Speedway’s initial success and its early domestic expansion.

After the first Speedway meeting at High Beech in 1928, the sport rapidly expanded with clubs emerging throughout the UK. Jacobs (2001) explains an agreement between the International Speedways Ltd and Greyhound Racing Association (GRA) for the use of their principal tracks in London and North England. This proved to be crucial to the continued success of Speedway in the UK because in Australia, several greyhound racing operations had become insolvent due to the competition from Speedway.

Williams (1999) highlights another distinctive feature of Speedway, one that it shares with greyhound racing, is that it was almost completely commercialised. The growth of Speedway was so extensive within the UK in the early 1930's that top riders were among the highest paid sportsmen in Britain. The demand for experienced riders often exceeded supply and top riders no longer raced only for cash prizes but were paid appearance money. By the late 1930's, the Speedway Control Board (SCB) were forced to implement a maximum payment fee for riders, yet this still resulted in average riders in the First Division being paid more than their equivalents in other sports (Williams, 1999).

Although spectator numbers were high at the time and provided an insight into the popularity of Speedway, the sport collapsed in many places that it was tried. Gate receipts were sufficient to maintain Speedway as a professional sport but it could not be sustained in many locations (Williams, 1999; Belton, 2002; Jacobs, 2001). Williams (1999) explains that the failure of Speedway in so many tracks in the North during the early 1930's and then the subsequent partial revival in the number of league tracks in the late 1930's may suggest that the level of unemployment at the time influenced spectator numbers. Williams (1999) discusses this further to suggest that promoters saw Speedway as an opportunity for profit. When A.P Hunting, a leading promoter at the time, came to Britain in 1928 he described his intention for Speedway as "purely and simply the commercialisation of a wonderful sport". Early promoters of Speedway opened tracks for "mushroom growth" that paid no one but themselves and never intended to do so. Whilst this indicates that promoters hindered the progress and expansion of Speedway, they may have underestimated the cost of Speedway promotion (Williams, 1999).

At the time of domestic expansion within the UK, there was also a surge in the technical development of Speedway bikes. Initially there was no specifically designed Speedway bikes, with riders instead competing on stripped down road bikes that were tuned for racing on loose dirt. The Douglas (Figure 5) and Rudge (Figure 6) were the most popular bikes yet varied significantly in design and favoured different riding styles.

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Figure 5- 1929 Douglas DT5 (Black Country Biker, 2010)

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Figure 6- 1928 Rudge Speedway Bike (Paternoster, 2009)

The power output of the Douglas was characteristically steady and consistent due to the bikes lower centre of gravity, resulting in it being easier to steer and broadside (Dropbears, 1997). The Douglas (Figure 5) had a noticeably longer wheelbase base than the Rudge (Figure 6) as a result of the flat twin cylinder engine that was horizontally mounted within the frame. Early flat twin engines were arranged with the cylinders on opposite sides of the crankshaft, i.e. in line with the frame, which later became known was the boxer twin crank configuration. This caused uneven cooling of the cylinders and required the motorcycle to have a longer wheelbase to provide sufficient cooling. In this configuration, the primary force generated by one piston counteracts that generated by the other at all times, resulting in excellent primary engine balance in a 4 stroke cycle regardless of the number of cylinders (Hanlon, 2007). The Douglas was described by many as being able to “look fast even when standing still” and was possibly the first specifically designed Speedway machine (Dropbears, 1997).

In contrast to the Douglas, the Rudge (Figure 6) featured a 4-valve single cylinder engine mounted vertically upright within the frame. It had a considerably shorter wheelbase compared to the Douglas, making it faster over a single lap and easier to maintain (Newcastle Speedway, 2005). The Rudge is noticeably taller than the Douglas as the frame needs to be high enough above the engine to allow the cylinder heads to have sufficient banking clearance. This also raises the centre of mass position of the bike, affecting the handling characteristics of the bike. Although both the Rudge and Douglas were competitive, the variations in design resulted in them being suited to different riding styles. The long wheelbase of the Douglas was the choice of bike for the leg-trailing riders whilst the shorter Rudge wheelbase suited the foot forward riding style (Figure 7).

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Figure 7- Trailing Leg and Foot Forward Riding Styles (Defunct Speedway, 2005)

By the start of the 1930's, Rudge and Douglas became increasingly uncompetitive in Speedway and eventually both stopped competing a few years later. The reasons behind them leaving the sport remain unclear although research suggests that the companies were unable to expand at the same rate as the Speedway industry at the time and decided to leave the sport.

Whilst Rudge and Douglas were gradually becoming uncompetitive, a new manufacturer, John Alfred Prestwich (JAP) entered into Speedway and immediately became competitive. Like Rudge, JAP adopted the same layout with the 2-valve engine being vertically mounted within the frame. The JAP's power came from the high torque values it developed and its significantly longer stroke compared to the Rudge and Douglas (Newcastle Speedway, 2005). In contrast to Rudge, the JAP engine filled the majority of the frame making the bike extremely compact but more difficult to maintain. JAP became so successful within Speedway that their design became the standard for Speedway bikes in subsequent years, yet the importance of the Rudge and Douglas should not be overlooked as the engine and frame design heavily influenced later designs. Newcastle Speedway (2005) explain that the extent of the JAP's standardisation of the Speedway bike by the late 1930's was so significant that the make of machine was no longer listed in the event programme or even discussed during the race meetings.

As the JAP bike continued to develop and dominate Speedway, several modifications were implemented to improve the reliability of the machine and to aid the riders in the transportation between events. Belton (2002) suggests that the changes made to the bikes were subtle, taking place over many years and were usually adaptions of the original model to accommodate changing tracks and technology. As Speedway bikes continued to evolve in the mid 1930's, the gearbox was maintained but intermediate gear pinions used previously by Douglas were removed, resulting in the option of a single gear. The gear ratio was altered using the sprocket on the countershaft yet most riders changed either the rear wheel sprocket or the engine sprocket (Belton, 2002).

Further modifications were brought in to aid riders' performance at a wider variety of tracks and to further accommodate individual riding styles. The rear spindle slots were lengthened to enable the wheelbase to be changed to suit a specific circuit, an arrangement that is still used today (Newcastle Speedway, 2005). Frames were manufactured with the headstock set round because they twisted during riding and riders find that the bike handled better when they were bent (Newcastle Speedway, 2005).

In spite of the developments to the bikes technology, the most significant technical advancement during this time was the establishment of the first engine test procedure created by JAP in 1931 (Speedway Forum, 2005). At this time, standardised engine testing was not done in any other form of motorsport, demonstrating that at this moment in time, Speedway was at the forefront of technology and would have set the standard for engine testing in other forms of motorsport.

Speedway bikes became significantly quicker throughout the 1930's, causing a significant rise in the number of false starts at race meetings. To prevent Speedway attendances declining, electric starting gates were demonstrated for the first time in a competitive Speedway race in 1933 as a replacement for the rolling start. The trial was so successful that the Speedway Control Board made the use of an electric start gate compulsory for all tracks in 1934 (Jacobs, 2001). Belton (2002) suggests that the introduction of a starting gate, which is still in operation today, prevented spectators becoming disengaged with the sport, with many of them becoming irritated at the high number of false starts.

The technology advancements made by JAP during the 1930's allowed Speedway to continue to expand domestically as it encouraged an increased involvement in the sport. Such was the domestic success of Speedway it soon expanded internationally and became fully established in many countries by the mid 1930's. By 1936, many European countries such as Poland, Sweden and Denmark were hosting events yet league racing was not established in Poland and Sweden until 1948 and as late as 1970 in Denmark.

2.5- THE 'GOLDEN AGE' OF SPEEDWAY RACING

By the late 1930's, Speedway was thriving within the UK as teams continued to emerge. Speedway stopped hosting race meetings in 1939, as both riders and promoters became involved in the war effort. In contrast to football, which continued to operate as normal during the war, Speedway largely disappeared, yet when it returned it became arguably the most popular sport at the time (Dalling, 2011).

Fully competitive Speedway returned to Britain on 22nd April 1946 and with attendance figures at race meetings comparable to that of football matches, Speedway gained a "position of honour" within British sporting life at the time (Dalling, 2011). Recordings of capacity attendances became regular and crowd restrictions were required at several London clubs in order to ensure the safety of spectators, riders and support staff (Belton, 2002).

Several leading social commentators at the time acknowledged Speedway's importance in post war society with Richard Hoggart (1957) describing Speedway riders as on par with footballers and boxers as the "true working class heroes" of the era. Dalling (2011) describes Speedway's brief period of glory in the years immediately following the Second World War as a phenomenon. The reasons behind the sports unprecedented popularity in the late 1940's lie in the defining factors behind Speedway as a sport. In contrast to football and rugby, Speedway fostered a real sense of community and togetherness, which people needed after the war (Dalling, 2011).

When competitive Speedway returned to the UK, it felt like nothing had changed and there was a real sense of continuity within the sport. The six years of war had left young men with little time for Speedway so the majority of the 1946 teams consisted of pre-war veterans. Transport issues meant that the American and Australian riders that had dominated British Speedway in the late 1930's were unable to return to Speedway (Dalling, 2011). The riders competing at this time were much older having returned from war, but a new generation of riders would take time to emerge (Dalling, 2011).

In addition to the cultural continuity there was also a degree of technical continuity within Speedway. Before the war, JAP emerged as the leading Speedway manufacturer and when the sport restarted in 1946, riders quickly started riding their pre-war JAP's and the manufacturer continued to dominate Speedway throughout the 1940's and 1950's.

After the war, JAP could not afford to invest in technical development of their Speedway engines, needing time to recover financially. As a result, post war Speedway bikes were largely the same as those used before (Figures 8 and 9), resulting in the sport stagnating technically.

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Figure 8- 1939 JAP Engine Speedway bike with a Martin Cornerford Chassis (Newcastle Speedway, 2005)

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Figure 9- 1949 JAP Speedway Bike (Vintage Motorcycles, 2013)

By the mid to late 1940’s, despite taxation and government threats to close down clubs, Speedway reached the peak of its popularity within the UK. Domestically, the sport had returned to its previous success with 40 clubs competing over three leagues but this was not the case in America. Belton (2002) suggests that within a few years of the Second World War ending, the influence of American riders in UK Speedway was non-existent. The UK government viewed Speedway as a threat to the industrial productivity and economic recovery and the sport was used to aid in the economic recovery of the UK (Dalling, 2011). In 1947, the government introduced an entertainment tax, which took 48% of the cash flow through the turnstiles of every Speedway club in the country. Jacobs (2001) explains that the tax discouraged investment into the sport and clubs’ facilities, preventing the sport from expanding domestically. At the time, live sports were partially exempt from the tax, yet the government did not view Speedway as a sport, instead branding it a “trial of speed” and therefore concluding that clubs were not exempt from the tax (Jacobs, 2001), resulting in several clubs such as Wembley closing due to financial reasons yet domestic Speedway remained largely popular.

The post war popularity of Speedway within the UK gave encouragement for other series of racing including Formula 1 and MotoGP to establish. Whilst they did not rival Speedway in terms of popularity and attendances at the time, it shows that the success of Speedway and the atmosphere it produced inspired other forms of motorsport to be created. Far from being a 'second rate' motorsport, Speedway was leading the way.

By 1950, Speedway was still in its golden era. 93,000 people witnessed the World Championship final and with more than 50 clubs in operation across the country, the future of Speedway looked secure.

2.6- THE DECLINE OF SPEEDWAY RACING

Speedway continued to be popular domestically in the early 1950's, but by 1955, clubs reported a huge slump in the number of people attending races, with crowds in the north were often considerably lower than in the south (Dalling, 2011). During the 'Golden Era' clubs such as West Ham, Wembley and Wimbledon formed the backbone of Speedway within the UK but were unable to avoid the decline in attendance figures. Belton (2002) suggests multiple reasons behind Speedway's domestic decline, such as the rapid expansion of the sport after the war as well as the introduction of TV viewing.

In 1960, domestic Speedway was restructured to revitalise the popularity of the sport. A group of Speedway enthusiasts and former riders came together to form the Provincial League. Several old tracks that closed due to taxation were revived and new clubs were introduced into the league. As a result, the number of operational tracks within the UK more than doubled (Belton, 2002).

Although this was a successful restructure at the time, it was only a temporary solution and within a few years of its introduction, domestic Speedway was again declining. By 1963, there were two divisions of Speedway in the UK but only six teams competing in the top tier. This was not the case internationally and although Australian interest in Speedway declined, the scene in Europe was continuing to grow after the 'Golden Era' (Belton, 2002). The international expansion of Speedway was so substantial that in 1960, the World Team Cup was introduced and in 1961, the Speedway World Championship Final was held outside of Wembley for the first time in Speedway history in Malmo, Sweden (Belton, 2002).

To avoid further domestic crisis, the National League was created by a group of Speedway promoters. The league operated until 1965, where it merged with the Provincial League to form the British League (Belton, 2002). In 1965, promoters of the sport also established the British Speedway Promoters Association (BSPA) and gained more influence into Speedway administration. This established an effective and efficient structure, progressing Speedway and increasing its popularity within the UK. This resulted in domestic expansion in the years following the merger and by 1968, 10 new Speedway teams had been established (Belton, 2002). The restructure and rebuilding of Speedway during the 1960's led to a new era of popularity in the late 1960's to early 1970's.

In contrast to the technical continuity that occurred in the years following the end of the Second World War, a considerable amount of technical developments were made between the 1950's and 1970's which assisted in the renewed popularity of Speedway at the start of the 1970's

JAP had been the dominant manufacturer within Speedway and had remained relatively unchallenged. In 1952, Czech motorcycle company ESO emerged as competition to JAP. Although ESO eventually competed with a specially designed Speedway engine, during their first competitive season they raced using a JAP engine whilst design plans and manufacturing of their engine was finalised. ESO bikes became immediately competitive against the previously dominant JAP bikes. They were fundamentally cheaper to run, more reliable and easier to maintain than the JAP bike although not necessarily quicker over a single lap (Newcastle Speedway, 2005).

Whilst JAP was still competitive, ESO brought in a series of developments to their custom built Speedway engines. Although ESO had specifically designed their engine for classic Speedway (300-400m tracks), the crankshaft assembly was modified so that the engine could be used on the larger tracks whilst also increasing the reliability of the bike for shorter distances. The main bearing of the crankpin on the drive side was enlarged so that one set of rollers were shifted closer to the engine sprocket. The rigidity of the crankshaft assembly was also further increased by reinforcing the connecting rod pin by introducing a ring of special material (Cyber

Motorcycle, 2004). ESO paid much attention to the connecting rod, which they completely redesigned, into a new shape. The optimised design featured enlarged pins, which go around both the small and big end to ensure the rigidity of the connecting rod when maximum loads are applied.

The most significant design that ESO introduced originated from track design and went on to revolutionise Speedway technology. A new design of telescopic front fork suspension was trialled on a Speedway bike for the first time, significantly increasing the handling capabilities. The frame was also re-designed to make the saddle sit as low as possible in order to lower the centre of mass to further assist the handling capabilities of the bike (Cyber Motorcycle, 2004).

Cossalter (2006) explains that by lowering the centre of mass, the rear end of the bike tends to slip during acceleration as a result of the rear slip angle being significantly greater than that of the front. This allows the rider to slide the rear end and broadside much easier, resulting in the rider being substantially quicker over a single lap. Due to the increased handling capabilities, the engine and gearbox were shifted rearwards slightly, allowing the drive chain to be much shorter, reducing the risk of it becoming detached (Cyber Motorcycle, 2006).

The speed of the ESO bike combined with its reliability gained attention from many riders competing on a JAP and as a result of their inability to adapt and bring in new development, JAP stopped competing in Speedway in the early 1960’s. ESO later merged with Czechoslovakian motorcycle company JAWA, who became the leading manufacturer within Speedway in the mid to late 1960’s (Newcastle Speedway, 2005).

Like ESO, JAWA continued the development process of the bikes, focusing specifically on the engine. Until now, the Speedway engines that had been used by Douglas, JAP and ESO had been two valve single cylinder engines but JAWA saw potential to increase performance. In 1966, JAWA modified their Speedway engines by increasing the number of valves from two to four (Figure 10) favouring riders who wanted extra power.

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Figure 10- Cutaway drawing of JAWA's new 85 x 87mm 4 valve Speedway engine (Motorcycle Weekly, 1982)

In a four valve engine, each cylinder has two inlet valves and two exhaust valves, increasing the air intake of the engine and hence the volumetric efficiency. In addition, it also allows the engine to operate at a higher rpm compared to a two valve system, as the exhaust valves are much smaller, increasing the maximum power output of the engine. In a 4-valve configuration, the engine produces a steadier power delivery at low speeds and better acceleration. It also allows the spark plug to be positioned in the centre of the combustion chamber to create a more efficient flame spread and combustion process. This configuration was so successful and popular amongst riders that it continued to dominate Speedway throughout the 1970’s (Cyber Motorcycle, 2004).

2.7- The Resurgence of Speedway Racing

Speedway entered into its second boom of popularity at the start of the 1970’s as a result of the business and technological developments introduced during the 1950’s and 60’s. As a result of the establishment of the BSPA and new league structure, Speedway now had a stable and effective foundation, which continued until the late 1970’s.

After becoming the leading Speedway manufacturer, JAWA continued the technical development of their bike. In 1976 JAWA designed their first bespoke Speedway engine, the ‘894’ (Figure 11), underlining their intention to be competitive in Speedway for many years.

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Figure 11- JAWA 894 and 895 engine designs (Motorcycle on paper, 2012)

The 894 focused on the ‘simplicity of strength’ (Cyber Motorcycle, 2004) which was incorporated into the engine design. The crankshaft was split vertically, with each individual half consisting of thick wall castings. The additional strength was necessary in order to cope with the large forces generated by the crank, which in combination with the flywheel, con rod and large pistons amount to a considerable mass. In order to maximise the torque output of the engine when operating at low speeds the flywheels required were made extremely large and heavy. Additionally, the crank runs on cylindrical rolling bearings and to handle the additional stresses, two sets of rollers were used on the drive side of the engine as opposed to the single set on the timing side (Cyber Motorcycle, 2004). When the engine was tested in race conditions, JAWA noted that there was a large amount of vertical movement in the connecting rod and after further investigation concluded that the movement was necessary for the engine to rev freely. The JAWA 894 engine was widely used by Speedway riders throughout the 1970's and 80's but in 1986 JAWA introduced the '895' Speedway engine as an alternative for riders (Figure 11). The 895 engine proved to be the final developments introduced to the JAWA Speedway series and was the last JAWA engine to be vertically mounted within the frame before the orientation change in the 1994 (Cyber Motorcycle, 2004).

In the late 1970's, Weslake emerged as a competitor to JAWA but were only involved in Speedway until 1983. During this time, they won two Speedway World Championships and were popular with many top riders. In contrast to JAP bikes where the engine filled the frame and featured a long stroke cylinder, the Weslake was very compact and had a much shorter stroke with its power coming from its high revving capabilities (Newcastle Speedway, 2005).

Whilst Weslake was starting to deteriorate in Speedway in the early 1980's, Italian engine manufacturer Guiseppe Marzotto (GM) emerged. Their first version of a complete Speedway machine was produced in 1979 and they obtained their first major success in 1983 (Newcastle Speedway, n.d). When Weslake ceased competing, GM and JAWA became the only two manufacturers in Speedway, which still remains today.

In contrast to Speedway, where the majority of modifications to the bike are subtle adaptations of the original model, other forms of Motorsport such as MotoGP were introducing technical developments that were far more sophisticated and advanced than what was being used in Speedway despite being a much younger form of motorsport. MotoGP teams were continuously introducing modifications to their bikes, assisted by changes in regulations. This reflected the need for technical progression and innovation within the sport whilst keeping with the development of production bikes (MotoGP, 2001). As a result of the limited applicability of

Speedway technology outside of the sport, it has minimal external influences to push the technology forward, causing Speedway to fail to strive for continuous technical development to maintain the sports progression.

2.8- CONTEMPORARY SPEEDWAY

By the mid 1980's, Speedway entered into another period of decline, a trend which has continued into the modern era of the sport. Although there had been a series of technical developments introduced, the lack of competition between manufacturers resulted in a certain amount of excitement being lost from the sport causing Speedway's domestic popularity to decline. The foundation of Speedway remained secure since its restructure during the 1960's, no additional adaptations to the structure had been made since then, causing the sport to stagnate. In an attempt to solve the situation, Speedway was restructured for both domestic and international competitions. This solution had worked previously to revitalise the sport and regain its popularity and there was much hope that it would have the same effect again. In 1995, the British League was replaced by the Premier League. This was only a temporary setup as 2 years later the format was modified into three tiers to create the British Elite League, which is still in operation today. The top tier was renamed the Elite League with the second and third tiers called the Premier and National Leagues respectively (Belton, 2002). Currently, there are 30 teams competing over all 3 leagues yet there is growing concern that some of them will not remain open for much longer, with several teams reporting up to 6 figure losses for last season. This causes potential issues for the Sky Sports contract for Elite League Speedway broadcasting as at least eight teams need to compete to fulfil the contractual terms (Keep Turning Left, 2010).

To aid in the restoration of domestic popularity, a series of technical advancements were introduced were also introduced. In 1992, leading link suspension was introduced into Speedway as a replacement for the previously used telescopic fork suspension with several people involved in the sport considering it as the most significant technical development introduced into Speedway to date.

Leading link suspension comprises of a tubular connecting the steering column to the link pivots, which incorporates anchorages for the suspension struts (Foale, 2006). The system has the advantage that when the bike is cornering they do not twist like telescopic suspension, preventing alteration to the steering geometry. In contrast to telescopic forks which require a lot of maintenance and have reduced damping and absorption capabilities, leading link suspension systems are much stronger. They also have a greater rigidity and feature a damper that absorbs the impact of the bump, providing smoother handling and improving stability. Although technical development of the front suspension system had been introduced, it is necessary that the rear sub-frame of the Speedway bike remains rigid as the riders slide the bikes around a corner resulting in rear suspension not being possible (Foale, 2006).

In 1994, the configuration of Speedway bikes was further modified when the majority of riders opted to change the orientation of the engine mounting from being vertically mounted within the frame to being laydown along the base of the frame (Figure 13). Although this modification was not adopted by mainstream Speedway until 1994, there is evidence that laydown engines were tested in Speedway from as early as 1948 when engineer and rider Wal Phillips experimented with the concept (Figure 12). After conducting multiple tests, it was determined that due to the deep dirt track surface that was being used at the time, the bike was too difficult to ride (Speedway Forum, 2009).

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Figure 12- Wall Phillips Laydown Bike (Speedway Forum, 2009)

In comparison to the laydown designs currently used in Speedway, Wall Phillips' design is heavier and as a result adds considerable weight to the bike, affecting its handling performance and power output. This is potentially why the design did not get adopted by the majority of riders at the time and it wasn't until 1994 when a lighter and more sophisticated design was introduced that it was finally adopted as the standard Speedway setup. Current laydown engines build the revs up quicker and higher yet the frame has a tendancy to flex if the track is bumpy and if the rear wheel is forced to raise up off the ground, the bike can spin around and in a snap which is common (Speedway Forum, 2011). In competive races today, it is common to see the front wheel twist to the right at the top and to the left at the bottom, as a result of scrubbing on entering the corner as the bike twists and flexes. This tendency is more common with laydown engines because when the engine is mounted vertically, the frame and bike is much more rigid and stable preventing it from flexing and twisting as much (Speedway Forum, 2011).

In the modern era of Speedway racing it is also now compulsory for all Speedway bikes to run with a dirt deflector (Figure 13) yet many people feel that they ruin the image of Speedway and need to be integrated more fully into the overall aesthetics of the bike.

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Figure 13- Current Speedway bike showing the use of a dirt deflector (Monster Energy SWC, 2014)

An early adaptation of the dirt deflector was first seen in 1983, yet the design was more of long rear mudguard and had a tendency to fall off. A later version of the dirt deflector, which closely resembles what is used today was trialled in 1994 but it was only temporary, as a short way into the season Speedway decided not to proceed with the design. This was later reversed in 1997 and deflectors are still used on all competing Speedway bikes.

In 2011, in an attempt to please local residents and safeguard clubs close to residential areas by reducing the motorcycle's noise, Speedway's governing body the FIM introduced new homologated silencers. The new silencer designs are restricted to 96 decibels yet riders have reported that the bike's power disappears through the exhaust and a significant amount of torque is removed from the engine, causing it to stall (Speedway Forum, 2011). This increases the risk of the riders crashing as the rear wheel tends to rise of the ground as a result of the engine stalling. Mechanics are now having to service engines after 15 races instead of the previous 30 as the new silencer design features plates which block the exhaust gases from leaving quickly, resulting in a build-up of back pressure within the exhaust pipe and engine, causing the silencer and the exhaust pipes to get hot which damages the engine (BBC Sport, 2011). In addition to the backpressure build up, the new design is also substantially heavier than the silencers previously used and the additional weight produced a change in the handling characteristics of the bike which was not beneficial to riders.

In an attempt to keep up with new and developing technologies being introduced into other forms of motorsport, the first electric Speedway bike was produced in 2012 (Figure 14) with a new electric league being established (Eliseo Hummer, 2012).

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Figure 14- Electric Speedway Bike (Eliseo Hummer, 2012)

Whilst electric racing has been integrated into other forms of motorsport, the concept of an electric Speedway bike is revolutionary, yet has come under harsh criticism from fans who believe that it does not incorporate the essence of Speedway racing. The Eliseo Hummer Speedway bike features a synchronous electric motor with a peak power of 22kW and a top speed of 121 km/h. Although this concept requires several years more development, it could provide a solution to some of the fundamental issues behind the continued decline of Speedway.

2.9- FUTURE PATHWAYS FOR SPEEDWAY RACING

Technology roadmaps are used within industries to define technical pathways that show how parallel incremental innovations, result in new technologies and products (Brindle, 2013). In essence, they highlight factors most likely to drive the continued development of a product and assess the potential benefit of the development to the product. The technology road map of Speedway racing is presented in Figure 15 and shows the technical development of the sport in last 25 years, giving an assessment of its current technology whilst also providing the pathways for future development in a vision timeline. The following subsections go into further detail about each of the pathways and outline their potential effect on Speedway.

2.8.1- MATERIALS

Figure 15 shows four possible future pathways for Speedway that would enable to the sport to continue to progress technically and aid in its popularity expansion within the UK, whilst also increasing the safety of riders and reducing injury. The first potential future pathway is the use of alternative materials such as aluminium, titanium and carbon fibre in the frame designs of Speedway motorcycles. Steel has been used as the core material for frames since the sports establishment yet the use of alternative materials could provide a safety and performance gain to riders. Whilst carbon fibre is very light it does not provide as much benefit compared to the other two materials due to its characteristics and properties. Although carbon fibre is strong, with a high strength-to-weight ratio, it is also rigid and with the little damping capabilities of both the frame and the bike, it will most likely cause an adverse effect on motorcycle dynamic performance and increase rider injury. An additional design limitation of carbon fibre is the occurrence of galvanic corrosion of parts that are interfaced to aluminium parts, which is a likely occurrence within Speedway. The most promising material pathway in terms of performance, safety and cost is the use of aluminium and titanium in the frame design. Both materials are stiff and light, providing increased performance of the bike whilst also reducing the risk of rider injury. The use of these materials would result in the bike being considerably lighter overall and with a minimum weight of 77kg being imposed in Speedway, the lighter frame weight would enable additional weight to be put elsewhere on the bike resulting in a better weight distribution of the bike. The bike would also have less momentum due to the reduced weight resulting in a reduction in rider injury caused at high speeds. The use of titanium on the frame is currently prohibited under the current regulations, so the future pathway is to initially use aluminium as an alternative to steel frames by 2018, then a regulation change to be introduced in 2020, allowing the first titanium Speedway frame to be used in a competitive race by 2022.

2.8.2. TYRE-TRACK INTERACTION

In recent years, the amount of riders being injured in race meetings or the race meet getting cancelled all together has increased due to the limited understanding of the tyre-track interaction of loose shale. The specification of the loose surfaces varies from track to track, as the organisers of the individual event are responsible for the specification of the track surfaces, with many different variations and compositions used. Figure 15 shows the future pathway for studies into the tyre-track interaction and specifically an assessment of the coefficient of friction to be initiated in 2018 leading to a better understanding of the variations in grip levels of the motorcycles. If a better understanding of this concept was gained, the performance of riders in the races would increase, aiding in the viewing spectacle and the occurrence of rider injury would be reduced, both leading to a positive drive in the popularity of the sport whilst also driving technical development. Furthermore to the grip level studies, a number of race meets are currently cancelled due to rain, as the track surface becomes largely un-rideable when wet. A beneficial future pathway to Speedway is the introduction of a water- resistant track surface by 2025, enabling race meets to always take place and giving satisfaction to spectators attending meets, as the chances of cancellation would be void.

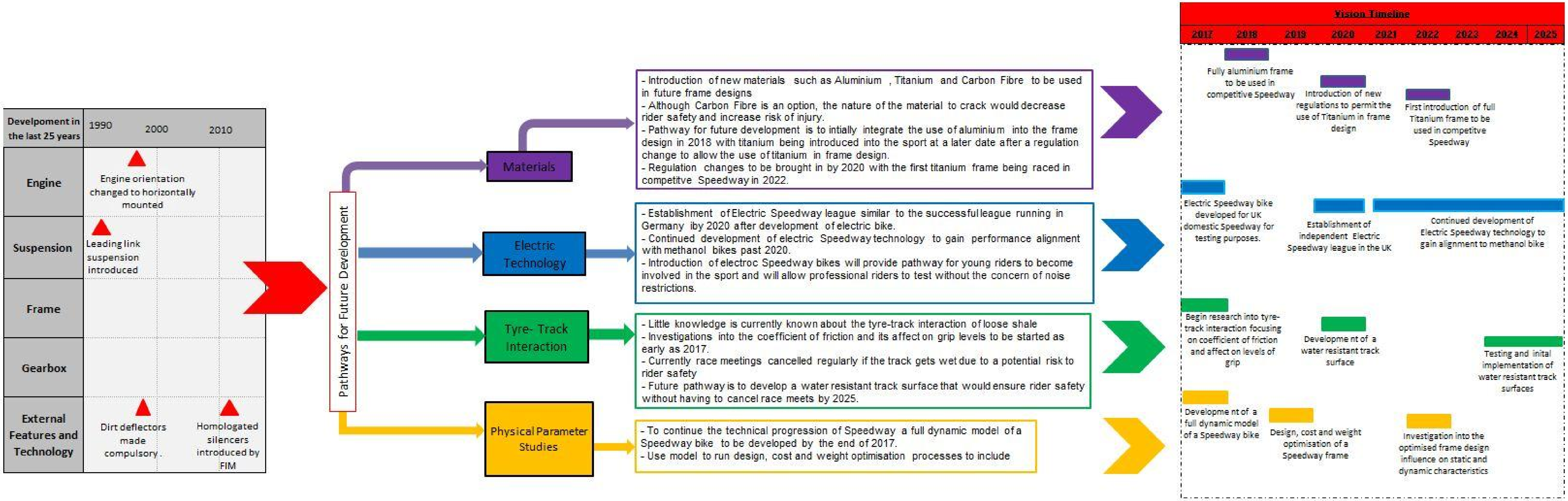
2.8.3. PHYSICAL PARAMETERS

As a result of the limited applicability of Speedway technology, little research has been conducted into the physical parameters and characteristics of both the complete bike and individual assemblies. To assist in the continued technical progression of Speedway aiding gains in performance, a full dynamic model of a Speedway bike should aim to be developed by 2017/2018. This technology would allow the static and dynamic performances of the bike to be monitored with changing parameters such as the use of alternative materials and varying coefficient of friction values. In addition to the model of the motorcycle itself, a track input that simulates a loose track surface can be used in the analysis, to obtain a more accurate analysis of the variation in performance with changing parameters. Both of these technologies would enable optimisation processes to be undertaken to involve the other future pathways proposed for Speedway in the Figure 15. The optimisation process would enable Speedway to progress technically whilst also maintaining as low cost as possible and increasing manufacturing efficiency. In turn, this will increase the performance of the bike, enabling the races to be closer fought and increasing the popularity of the sport.

2.8.4- ELECTRIC TECHNOLOGY

Methanol bikes have been used in Speedway since its establishment, yet very little work has been completed focusing on alternative technologies. One such technology that could be used in conjunction with current bikes is electric technology. A successful electric league is already established in Germany (Electric-Speedway,2015) with the bikes being 95% cheaper to run than current Speedway bikes and able to run 24 hours a day. Speedway riders are largely unable to test using current bikes as a result of the continuous noise complaints from close residential areas resulting in a 96 decibel noise restriction. The development of electric Speedway would allow riders to test all year round and also provide a pathway for young riders to become involved in the sport in a controlled and safe environment. Although electric Speedway would provide a beneficial pathway for Speedway in certain areas, the majority of the spectator support is an ageing demographic that have grown accustomed to the methanol bikes and are reluctant to divert. In order to maintain and increase the mainstream popularity of the sport, electric Speedway technology must initially be introduced in conjunction with modern Speedway, in a parallel league to Elite league but with an overlapping structure. Electric Speedway technology remains in its early development so the future pathway for this technology is to develop an electric Speedway bike with performance more aligned to current bikes by 2018 with the establishment of the electric

Speedway league to run in parallel with the Elite league to start in 2020. Although this technology does not directly influence the performance of the bikes, it does provide a pathway for Speedway to reinvent itself with modern technology and allow a new age of riders to come through.



Develpoment in the last 25 years	1990	2000	2010
Engine	Engine orientation changed to horizontally mounted		
Suspension	Leading link suspension introduced		
Frame			
Gearbox			
External Features and Technology	Dirt deflectors made compulsory.		Homologated silencers introduced by FIM

- Introduction of new materials such as Aluminium , Titanium and Carbon Fibre to be used in future frame designs
- Although Carbon Fibre is an option, the nature of the material to crack would decrease rider safety and increase risk of injury.
- Pathway for future development is to intially integrate the use of aluminium into the frame design in 2018 with titanium being introduced into the sport at a later date after a regulation change to allow the use of titanium in frame design.
- Regulation changes to be brought in by 2020 with the first titanium frame being raced in competitve Speedway in 2022.

- Establishment of Electric Speedway league similar to the successful league running in Germany iby 2020 after development of electric bike.
- Continued development of electric Speedway technology to gain performance alignment with methanol bikes past 2020.
- Introduction of electroc Speedway bikes will provide pathway for young riders to become involved in the sport and will allow professional riders to test without the concern of noise restrictions.

- Little knowledge is currently known about the tyre-track interaction of loose shale
- Investigations into the coefficient of friction and its affect on grip levels to be started as early as 2017.
- Currently race meetings cancelled regularly if the track gets wet due to a potential risk to rider safety
- Future pathway is to develop a water resistant track surface that would ensure rider safety without having to cancel race meets by 2025.

- To continue the technical progression of Speedway a full dynamic model of a Speedway bike to be developed by the end of 2017.
- Use model to run design, cost and weight optimisation processes to include

Figure 15- Technology roadmap of Speedway showing the potential future pathways

2.10- DISCUSSION

Speedway has experienced multiple periods of success throughout its history yet these have been unsustained. Speedway became the first established form of motorsport within the UK in the 1930's and as the mainstream popularity of the sport increased, clubs emerged throughout the country. This popularity continued throughout the 1940's and well into the 1950's. As a result of the six-year war absence, Speedway failed to develop throughout this period and although the continuity of the sport was what fans needed, it was detrimental to the sport in the long term. The lack of development into Speedway resulted in the sport stagnating and Speedways appeal started to decline by the mid 1950's. This lack of development is rare in any other form of motorsport but at the time Speedways' administration did not act on the situation.

As a result of the decline in mainstream popularity in the late 1950's, a restructure was implemented to revitalise the sport. The new structure of Speedway introduced an administration which had never been seen in Speedway before and the operation and foundation of the sport became effective and efficient. This in conjunction with a series of technical developments introduced throughout the 1960's not only revitalised the sport but entered it into a second boom of popularity in the late 1960's.

This second surge in popularity could not be sustained and by the early 1980's, Speedway began another general decline. The reasons behind the decline are not fully defined but research suggests that the lack of competition between manufacturers caused spectators to become disengaged with the sport. Whilst there was technical development during this time, the administration of Speedway remained effective and as a result they implemented no developments to the administration of Speedway to aid in its domestic expansion. The general decline of mainstream popularity of Speedway initiated in the1980's and has continued into the modern era of Speedway, affecting attendance figures and the money invested in the sport. When considering the rise and fall in popularity of the sport, a trend emerges which repeats periodically throughout the history of the sport (Figure 16).

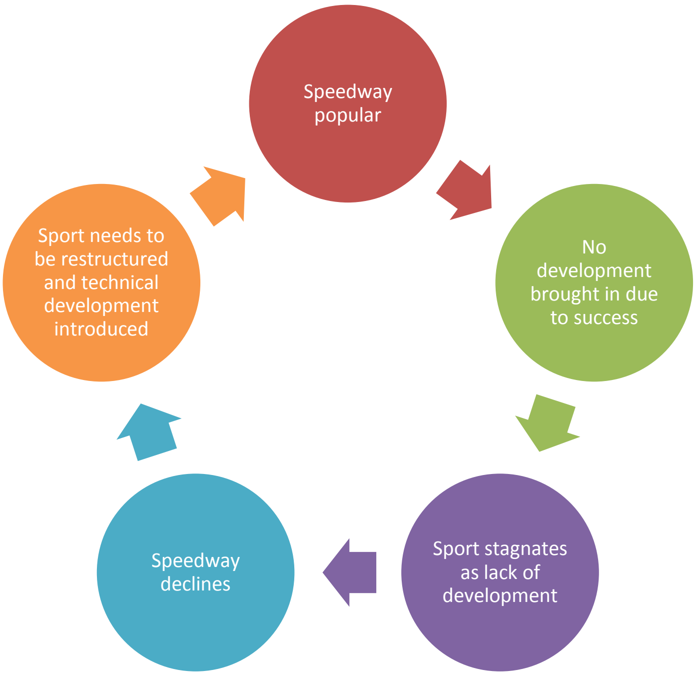


Figure 16- Flow Chart highlighting a trend within Speedway

The above cycle (Figure 16) was deduced by considering the timeline of Speedway history. This cycle is an example of diffusion innovation theory, where the rate at which an idea spreads through a specific population is monitored. An example of this cycle is in the 1930's, when at this time Speedway was at one of the highest points in its popularity, yet over the next 30 years very little technical or business developments were introduced, causing a stagnation of the sport. As a result of Speedway stagnating, there was a drop in the popularity of the sport and Speedway started to decline. In an attempt to restore popularity, the structure and format of Speedway was modified and a series of technical developments introduced, a combination of which helped restore the popularity of Speedway. This cycle was repeated later in the 1970's and most recently in the 1990's, yet this time the popularity of the sport has not returned and even with restructure, the sport has continued a general decline domestically.

After the most recent restructure of Speedway in 1997, the sport has been unable to restore its mainstream domestic popularity suggesting that an alternative approach needs to be taken, yet the reason behind the decline is not yet fully defined. Technical developments that have been introduced have more often than not been subtle adaptations to the original model. The last revolutionary technology introduced into Speedway was in 1992, when leading link suspension as first trialled. When considering the ‘feel’ of Speedway throughout its history, there is a sense that the sport has lost sight of its original goal and purpose. Speedway started as a group of people racing around an oval track and when people became interested in the sport and started going to watch the race, the focus shifted to entertaining the spectators. When Speedway started to prosper, this focus died away and more effort was spent on making money as promoters became more heavily involved in the sport. With the current situation of Speedway, focus is starting to shift back to making it more of a spectator sport, so that domestic Speedway can remain financially sustainable. At times when Speedway prospered financially, promoters of the sport established several new clubs within a very small area and as a result the Speedway fan base was spread too thin. In addition, Speedway also became nationalised and as a result lost the ‘community feeling’ that made it so popular before and after the war. Speedway declined because spectators no longer felt the same connection or loyalty to a specific club and instead became passive observers.

The trend in mainstream popularity of Speedway since its establishment is demonstrated in Figure 17, which is a qualitative representation of the popularity trend. Although there is no published evidence to support the data, the trend is developed from the literature and research presented in the technology road map. There are a number of limitations to the graph as the relationship is based on the authors’ interpretation of the popularity at the time as a result of the technical and business developments introduced at the time and the trend is unable to be quantified.

When Speedway established itself in the UK after the first official meet at High Beech in 1928, the sport quickly expanded as shown by the sharp trend gradient of the first peak (Figure 17) and as a result of the rapid expansion throughout the 1930’s, both team and league racing were established. Speedway experienced a six-year absence from 1939 due to World War 2, yet continued to expand in popularity upon returning. The summation of this post war popularity came in 1950, where Speedway reached its highest point of mainstream popularity, with 93,000 people witnessing the 1950 World Championship Final, yet shortly after, Speedway experienced a severe drop in mainstream appeal (Figure 17). A potential reason behind such a significant rise and fall of the first peak is the lack of structure that was in place within Speedway at the time and although a league structure was in place, the administration was not effective. When Speedway became regularised and a more effective structure was established in 1965, due to the creation of the BSPA, the mainstream popularity of the sport began to increase again. This suggests that the business development and structure of the sport is a driving factor behind the popularity of Speedway. As a result of a more effective structure being introduced in 1965, the subsequent declines in the sport after this date are not as substantial as the first.

An anomaly arises in the trend curve (Figure 17) between 1982 and 1987, where there is a significant bump in the trend line. During this time, JAWA introduced a series of modifications to their engine, yet more importantly, GM emerged as a fellow leading manufacturer. The competition that developed between the manufacturers became a spectacle and the sport increased in popularity. This period of prosperity was short lived and Speedway initiated another steady decline.

The general decline of Speedway continued until 1995 when Speedway underwent its most extensive restructure to date. The recovery pattern in the 90’s was repeated in the same fashion during the 1970’s although it did not work immediately as seen by the long duration of the trough in Figure 17. The structure change implemented in 1995 had to be further modified in 1997 for the mainstream popularity of Speedway to start increasing again. This suggests that whilst technical development is important, it is the business structure that is current driving force behind Speedway. The strong structure in place after 1997 is also evident by the duration of the peaks as whilst the first two peaks are relatively comparable in size and duration the length of the final peak is almost double, indicating that the most effective structure is in place by this point. The significant drop in the height of the final peak in comparison to the first two could be a result of a lack of technical development. Whilst there is a good structure in place, the technical structure of Speedway is being left behind in terms of technical advancements and development in comparison to other forms of motorsport. As a result of experiencing a technical stagnation, it is possible that many supporters have lost interest in the sport, become disengaged and have taken their audience elsewhere.

In addition to demonstrating the popularity trend of Speedway since 1928, Figure 17 shows that there are potential future pathways for the sport (Figure 15), resulting in an upward surge in the popularity of the sport. Figure 18 suggests that a simple restructure of the sport is insufficient, hence the focus of the future pathways is on increasing the technical development of Speedway.

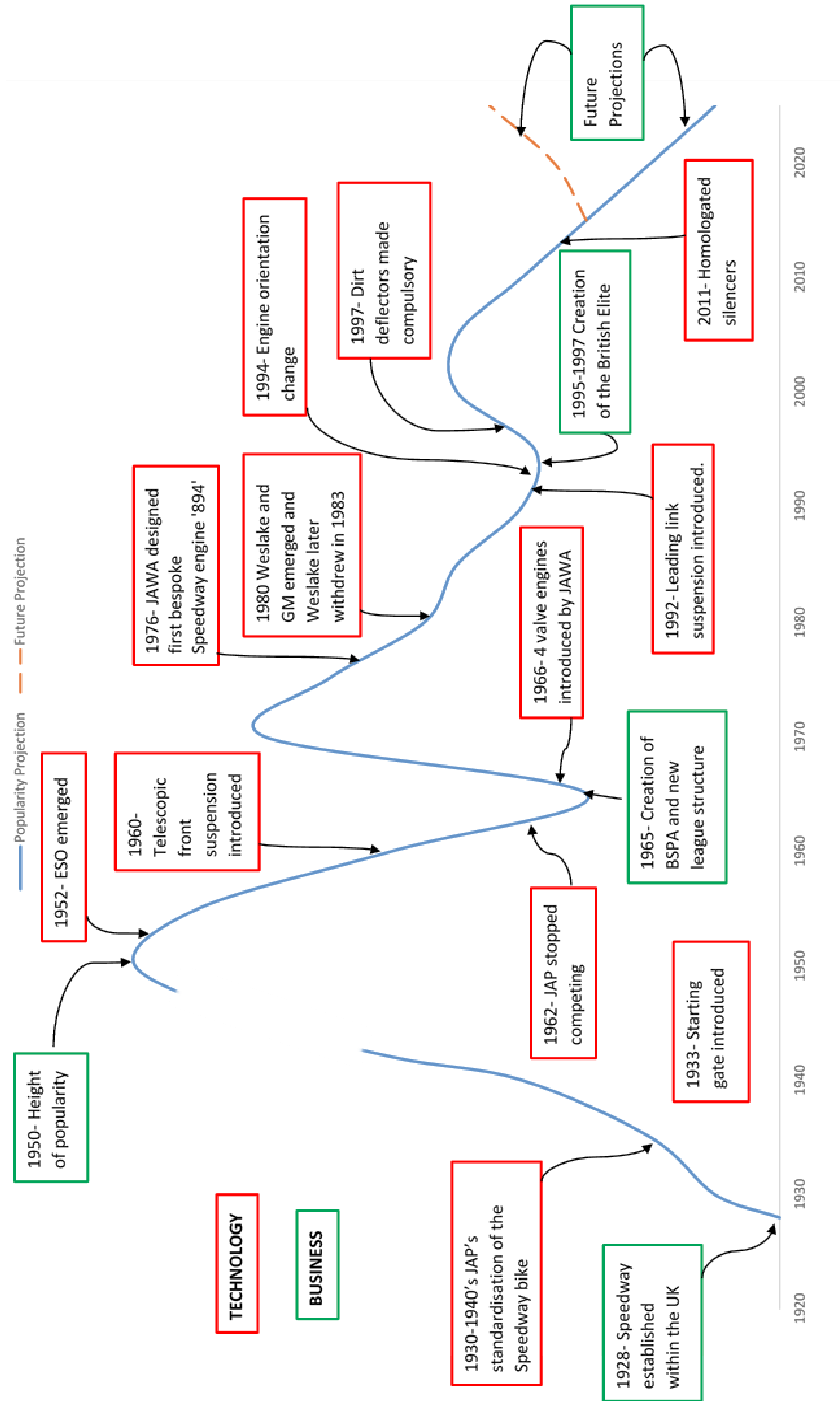


Figure 17- Popularity trend of Speedway since its establishment in 1928

In conclusion, the business structure in place has been the driving force behind the mainstream popularity of Speedway to date, as only when business developments are introduced has there been an increase in the popularity of Speedway after a general decline.

Although technical developments are important, they have only been a catalyst to popularity and have been unable to independently influence popularity to date. An interesting concept to consider is the potential effect of introducing revolutionary technical development into Speedway and whether that would then become a parallel driving factor. The potential future technical pathways are presented in the roadmap and if introduced would increase performance and rider safety whilst also providing an avenue for young riders to become involved in the sport. In turn, all of these pathways will lead to the continued development of the sport and increase its popularity, preventing the sport from stagnating and eventually dying out.

2.11- SUMMARY

The technology road map presents the trends in the business and technical developments since the sports establishment in 1928. It shows that although there has been considerable technical development of the motorcycles, it has been more adaptations rather than original advancements. The technology road map suggests that the frame is the least developed area of the bike despite its significant influence on the safety of riders and their long term health as outlined in the literature review. Previous experimental research carried out by Goozee (Wagstaff, 2011) shows the potential for frame development and gives some insight into the performance benefit providing the cost can be kept low to sustain the sports financial impact. The aim in undertaking this project is that the work achieved within this thesis can be used to build the foundation for future work into frame development to take place.

Chapter 3- Literature Review

3.1- INTRODUCTION

In this Chapter a review of the published literature on areas relating to Speedway such as motorcycle dynamics is presented. The literature available on Speedway is relatively sparse and generally based on the experience of riders and people involved in the sport. The majority of books that have been published, inform readers of the history of a specific team or an era of racing, such as the books published by Belton (2002) and Dalling (2011), but often do not contain information regarding the technology involved in Speedway.

3.2- MOTORCYCLE DYNAMICS

Whilst there are no apparent technical papers on Speedway technology, a number of papers have looked at other areas related to the sport, specifically motorcycle dynamics and the injuries of Speedway riders. One such paper by Skyrme *et al.* (2003) discusses the previously unreported condition of traction osteophyte. They claim that "traction osteophyte formation at the base of the fifth metatarsal is directly related to the activity of Speedway riding and the condition only presents itself in the right foot of riders". This long-term injury could perhaps be mitigated by having riders ride alternatively clockwise and counter-clockwise but the sport has historically run counter-clockwise.

As Speedway is a repetitive sport compared to other forms of motorcycle racing, it has been used in a number of investigations for handlebar vibration, which could result in "white finger" (Matsumoto *et al.*, 1986; Mirbod *et al*., 1997; Yokomori *et al*., 1986). Yokomori *et al*. (1986) explains that the vibrational sources in motorcycles that cause "white finger" are transmitted along three paths in the motorcycle; handlebars, saddle and the footrest. As all three vibrational paths are connected through the main frame of the motorcycle, it suggests the importance of the frame in rider safety as well as the instrumental impact of the frame characteristics on rider injury.

Cossalter *et al*. (2015) discusses the important role that the flexibility of frames has on the motorcycle's dynamics and their effect on the stability characteristics of the motorcycle. It is explained that the optimal flexibility of a motorcycle remains an open research topic and an established method for frame flexibility measurement has yet to be defined, with different manufacturers currently using a range of measurement approaches. Raines and Thorpe (1986) conducted static tests, focusing on the torsional stiffness of the frame using a framework of tubes similar to some motorcycle chassis' and defined the twist axis along which no lateral displacement takes place when a torque is applied about it. Further investigations into structural flexibility have since been conducted by Bocciolone *et al*. (2005) and Cossalter *et al*. (2002) amongst others with the latter paper using a method of modal analysis to study the vibrations of the whole motorcycle, showing the presence of various out of plane modes of vibration in a frequency range below 50Hz. Kalsule *et al*. (1999) explains that modal analysis is an established technique that provides definition of the dynamic properties of a structure which are related to the stiffness, mass and damping properties of the structure. In his later work on the subject Cossalter *et al*. (2015) outlined the importance of considering that the static compliance is a combination of the modal compliances of various modes of vibration.

In a similar manner to Cossalter, Bocciolone *et al*. (2005) used numerical and experimental studies to investigate the static and dynamic properties of motorcycles frames by determining the static stiffness, natural frequencies and vibrational modes with the aid of a specifically designed test rig that loaded the chassis in torsional and flexural configurations. The investigation was developed from previous work by Wilson-Jones (1951), Cossalter (1999) and Dohring (1956) who all determined the presence of three instabilities that occur during vehicle running. The characteristics of the vehicle instabilities has been extensively researched throughout the years to gain a better understanding of their identity and overall effect on the performance and stability of motorcycles. Later papers by Sharp (1978) and Roe and Thorpe (1989) discuss how motorcycles are prone to two basic oscillatory steering instabilities, a low speed high frequency flapping of the handlebars, known as "wobble" or "shimmy" and a `high speed low frequency snaking of the whole machine, known as "weave". The third instability, "capsize" is non-oscillatory and is the tendency of a motorcycle to fall down when moving at low speeds.

Of the two oscillatory modes, weave is the first one that a rider will experience, occurring at a frequency band between 2-4Hz and involves the steer, roll and yaw motions of the motorcycle. Wobble occurs at a slightly higher frequency range of between 6-8Hz and involves mainly steering oscillations (Cossalter, 2006). Roe and Thorpe (1989) concluded in their investigation into the influence of frame structure on the dynamics of motorcycle stability that to obtain wobble stability, the frame must have a high stiffness both in torsion and laterally but in particular torsional. They went on further to suggest that variations in the frame stiffness do not influence weave instability in the same way that it affects wobble and suggested that the stiffness of the front forks is the dominant parameter on weave stability. For high speeds normally experienced by Speedway bikes, this is not necessarily the case. With the frames traditionally having a high torsional stiffness to reduce the wobble instabilities common to the sport, the handling can often become twitchy, resulting in the bikes “chopping” sideways when cornering at high speeds on a bumpy track (Roe and Thorpe, 1989).

3.3- MODELLING AND SIMULATION

In their study on closed loop simulation, Beghi and Frezza (2007) highlight that the motorcycle industry lags behind the automotive industry in the use of simulation technology but suggests that the motorcycle development process is innovative and the use of virtual prototyping is rapidly increasing. Sharp *et al*. (2004) explains that the increased use of automated multibody dynamics software has further opened up the topic of motorcycle dynamics in recent years. A paper by Beghi *et al*. (2007) on modelling using virtual prototyping agreed with this and further explains that the increased use of virtual prototyping tools in the motorcycle industry focuses on reducing the development time of new models and increasing the speed of performance optimisation.

Although the topic has opened up in recent years, modelling of single track vehicles has been investigated for many years with the first seminal technical papers on the subject being published by R.S Sharp in 1971 (Rajput *et al*., 2007)on the stability of motorcycles in a straight line. In the study the vehicles were treated as two rigid frames joined together by a revolute joint, with freedom of the front frame to steer relative to the rear frame. The model featured a 4 degree of freedom (DOF) model corresponding to the lateral, yaw, roll and steer motions. The author assumed that the bike only experienced small perturbations, allowing the model to become linearised and the rider was modelled as being rigidly attached to the main frame and was restrained from body lean movements. The tyre forces were modelled as a linear function of the sideslip and wheel camber angles (Sharp, 1971). After his seminal paper Sharp (1971) developed the model further and published an advanced motorcycle model that featured four rigid bodies connected together to simulate eight DOF (Sharp, 1994). According to Nehaoua *et al*. (2013) the originality of this model lies in the integration of the frame flexibilities and the riding tilting motion.

Beghi *et al*. (2007) suggests in his paper on the modelling of a motorcycle shock absorber for virtual prototyping applications that the conventional linear models that are often used are often inadequate to describe the behaviour of complex non-linear components. Alternative modelling techniques are often required when dealing such components in a suspension system, given that the shock absorber, which is arguably the most important part of the system, exhibits non-linear and time variant behaviour (Beghi *et al.*, 2007).

Sharp *et al*. (2004) and Beghi *et al*. (2007) both highlight that the accuracy of the predicted motorcycle behaviour depends heavily on the choice of model selected as well as the accurate input parameter values. Sharp *et al*. (2004) suggests that during cornering, the interaction between the in-plane and out-of-plane modes makes effective analysis of the vehicle dynamics complicated. The major issues regarding accurate modelling relate to the representation of the frame flexibility, tyre-road contact geometry and the tyre shear forces. Sharp *et al*. (2004) goes on further to suggest that many previous authors findings relate to motorcycle and tyre descriptions which are somewhat dated and use tyre models which have a limited domain of applicability suggesting that significant development in this field could be made.

In one such paper by Breuer and Pruckner (1998), the possibility of using multibody simulation tools such as ADAMS to simulate accurate motorbike vehicle dynamics was discussed and in particular the weave mode characteristics of the bike. The motorbike model constructed for the simulation was simplified to consist of four parts: the main body with the driver fixed on it, the steering system and both wheels with four DOF. This is a significantly simplified model with many other authors such as Sharp (1994) and Cossalter (2002) adopting to use motorcycle models with 8 and 11 DOF (Figure 18) respectively.

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Figure 18- 11 Degree of Freedom Motorcycle Model (Cossalter, 2002)

Breuer and Pruckner (1998) identify in their paper using multibody simulation that weave mode is an eigenvalue vibration, where the damping coefficient of the system decreases with an increasing vehicle speed. They use an eigenvalue analysis to ascertain different complex eigenvalue results and explain that the real term produced by the eigenvalue analysis indicates the damping ratio of the system whilst the imaginary term presents the damped frequency. Figure 19 shows a comparison between the eigenvalues in straight running (grey spots) and during cornering (black spots) for a set lateral acceleration of 5m/s² as determined by Cossalter (2002). The set lateral acceleration corresponds to a roll angle of 30° and the velocity was varied from 3m/s to 60m/s during the simulation.

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Figure 19- Root locus plot in steady state cornering with varying speed (Cossalter, 2002)

If a given system is critically damped then the eigenvalue analysis will provide no imaginary term with the sign of the real term in each eigenvalue indicating the stability of the mode. A negative real term means stable eigenvalues, a real term that is zero results in permanent yet limited oscillatory behaviour and a positive real term relates to unstable system behaviour (Figure 19 and 20) (Breuer and Pruckner, 1998; Cossalter *et al*., 2002; Rajput *et al*., 2007).

Figure 20 highlights the influence of speed on the stability of out-of-plane modes, which involve roll, yaw, steer angles and the frames lateral stiffness.

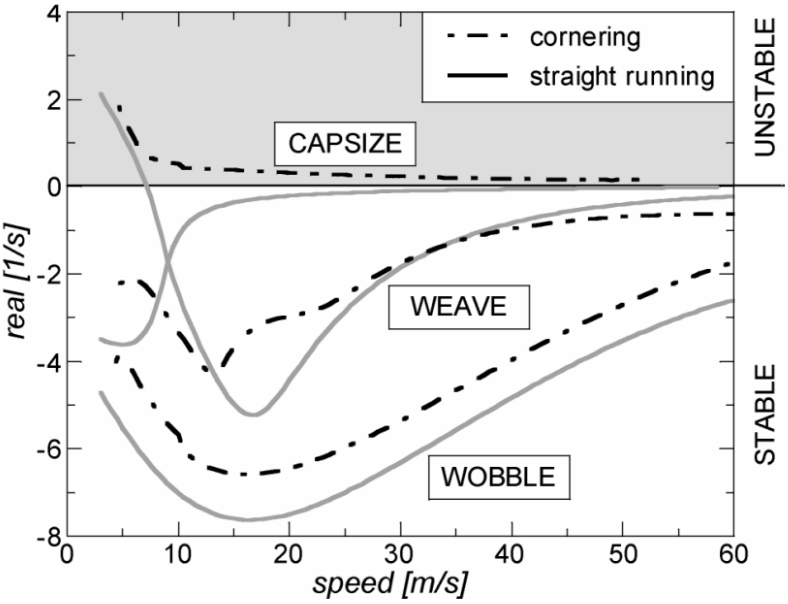


Figure 20- Stability of out of plane mode in straight running and in cornering (Cossalter, 2002)

A combined analysis of both graphs show that the capsize mode is significantly influenced by lateral acceleration (Figure 20): it is stable in straight running for all speeds as shown by the continuous grey line but the dashed line shows that the mode becomes unstable whilst cornering at low speeds. The weave frequency mode is not affected by lateral acceleration (see Figure 19) but at low speeds, it is stable during cornering and unstable in straight running. As the speed increases, the weave mode becomes more damped in straight running as shown by the increased negative value of the real eigenvalue term. As the speed increases further to high speeds then the mode is more damped and stable whilst cornering. Cossalter (2002) explains that the lower damping at medium speeds is associated with the coupling of the weave and bounce modes as shown in Figure 19. The final mode associated with vehicle dynamics is the wobble mode whose stability and frequency decrease as the speed and lateral acceleration increase. The coupling that occurs between the in-plane and out-of-plane modes according to Cossalter (2002) has the most important effect on lateral acceleration of the bike. He explains that during straight running, capsize, weave and wobble modes do not involve in- plane-degrees of freedom. In contrast to this, when cornering, the modes involve both in-plane and out-of-plane modes and Cossalter (2002) observed that speed does not significantly affect the in-plane modes whilst in straight running yet considerably influences these modes during cornering.

Although the development of virtual prototyping using multibody simulation tools has rapidly expanded in recent years' the maximum performance optimisation is achieved when these tools are used in collaboration with physical testing and other virtual testing methods such Finite Element Analysis (FEA). The complete development process is explained by Tuluie and Erickson (2000) in their paper on racing motorcycle design processes using physical and virtual testing methods. They explain that despite using different tools for certain aspects, the same process of initial calculation and modelling, followed by laboratory based experiment to validate the model, followed by subsequent iterations of laboratory tests and design improvements using a selected optimisation process is always used.

In a racing motorcycle chassis, the structural stiffness of the chassis is widely acknowledged to be a compromise between a design that is neither too stiff nor too compliant (Foale, 2006). Tuluie and Erickson (2000) explain the reason for this is that at large lean angles, the suspension is partially unable to absorb the vertical and longitudinal road inputs, which are instead absorbed by the lateral, longitudinal and torsional compliance of the chassis. Too little compliance and the traction and grip may suffer yet too much compliance can produce dynamic instabilities. This is critical for Speedway racing and there has been little research into the technology behind Speedway, resulting in little information regarding the performance and characteristics of the frame being available and known.

3.4- SUMMARY

Although the available literature on Speedway is sparse, the extensive research into related subject areas like motorcycle dynamics has developed a foundation for the underlying dynamics of Speedway bikes and the optimum frame design to be better understood. This in conjunction with further studies including physical testing and simulation investigations could lead to a reduction in the long term injuries of riders as presented in the literature review and aid in the sports technical progression. A documentation of the sports technical progression is given in the technology road map presents in Chapter 3.

Chapter 4- Experimental Testing

4.1- INTRODUCTION

This Chapter presents the methodology used during physical testing and FE simulation. From the literature studied, it is evident that very little experimental testing has been conducted on Speedway frames to date, yet investigations into the physical parameters of Speedway frames are fundamental if the sport is to continue to progress technically. In this chapter, the experimental setup and methodology is presented as well as the input parameters and CAD model used in the development of the FE model.

4.2- PHYSICAL TESTING

The aim of the experimental study was to establish the physical parameters of the frame under torsional loading. The results of the physical testing were then used to validate the CAD and FEA model later developed. The most frequently adopted method of physical testing to determine stiffness properties is to fit a series of strain gauges to the motorcycle, in this case the frame and test under a range of loading conditions.

4.2.1- STRAIN GAUGE PREPARATION AND BONDING

Adhesives are the most common agents for mounting strain gauges onto a test specimen, yet certain types of gauges can be welded onto the surface of the specimen. According to Efunda (2015) the most popular method for adhesive mounting is the tape assisted installation method. In the bonding of the strain gauges to the Speedway frame, this installation method was used and the gauging process from Omega (2003) was followed (Appendix A). Improper installation of the gauges may affect the surface bond between the gauge and the test specimen resulting in degradation in the validity of the test results so considerable care was taken during the installation process. An example of a strain gauge installation is given in Figure 21.

Figure 21- Strain Gauge Bonded to the Test Specimen

4.2.2- Positioning of Strain Gauges

In total there were seven strain gauges bonded to the Speedway bike frame in various positions on the main frame and sub frame assemblies (Figures 22 and 23).

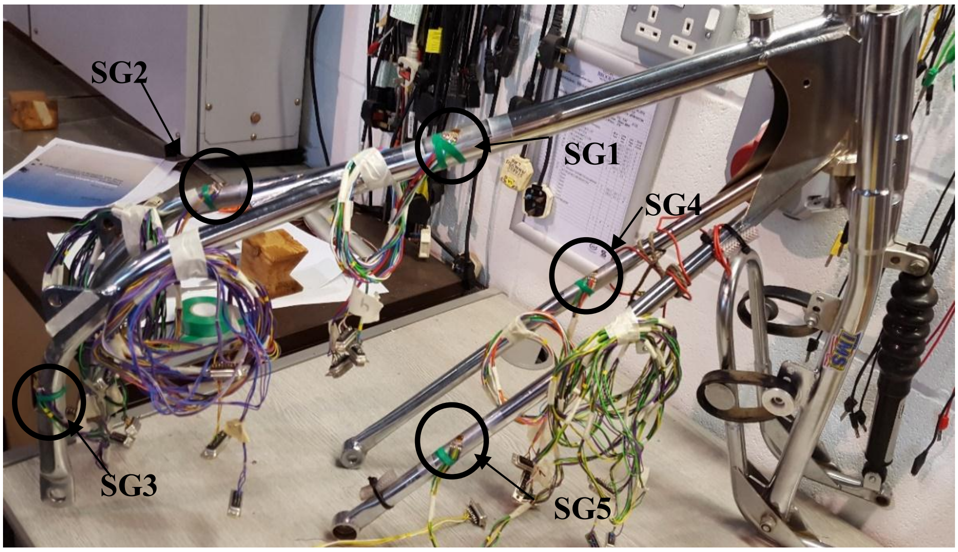


Figure 22- Speedway Main Frame with Strain Gauges

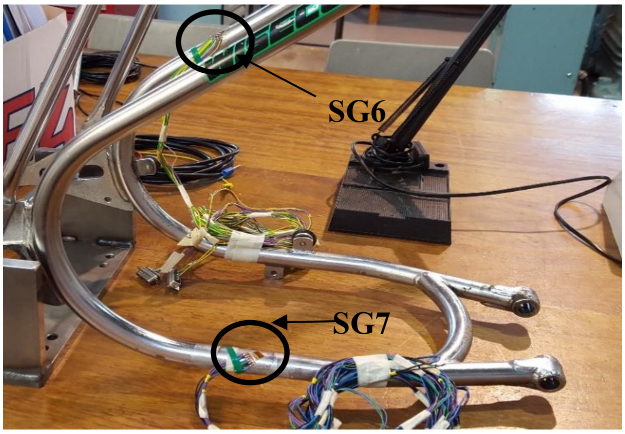


Figure 23- Speedway Sub-Frame with Strain Gauges

The location of each of the strain gauges on both the mainframe and sub frame was influenced by a number of factors. It was reported that the Speedway bike used for this experiment had been previously raced, resulting in several sponsorship stickers and logos being placed on the bike yet it was considered that the previous use of the bike had not affected the material properties of the frame. Attempts were made to remove the stickers, but a thick adhesive residue remained which would have resulted in an unsatisfactory surface bond between the gauge and the test specimen. As a result of this, the gauges were placed in areas that were free from stickers and residue as well as any other contaminants such as oil and grease.

To measure the strain at various locations along the frame assembly, a strain gauge was bonded to every tube in the frame assembly. The exact location of the strain gauge is not too critical as the strain should not vary along a straight cylindrical tube but the strain relationship between two gauges is important as that will determine the strain profile of the frame. The frame and sub-frame assembly shown in Figure 24 is mounted on the test bed prior to testing and Table 1 provides more in-depth information of the location of each individual gauge.

Figure 24- Speedway mainframe and sub-frame assembled on the test bed

The left hand side (LHS) and right hand side (RHS) definition is taken from the rider facing forwards from the bike.

Table 1- Location of Strain Gauges

Gauge Number	***Location of Gauge***	***Additional Information***
SG1	360mm down from the headstock on the main frame	Along axis definition
SG2	40mm from start of main frame bend	LHS upper tube of main frame
SG3	20mm from end of main frame bend	RHS upper tube of main frame
SG4	230mm along lower tube of main frame from headstock	LHS lower tube of main frame
SG5	455mm along lower tube of main frame from headstock	RHS lower tube of main frame
SG6	Start of Rear sub frame bend	LHS tube of sub frame
SG7	End of Rear sub frame bend	RHS tube of sub frame

In addition to the strain gauges, a series of linear variable differential transducers (LVDT's) were also used in the experiment to gather additional data to aid in determining the physical parameters of the Speedway frame.

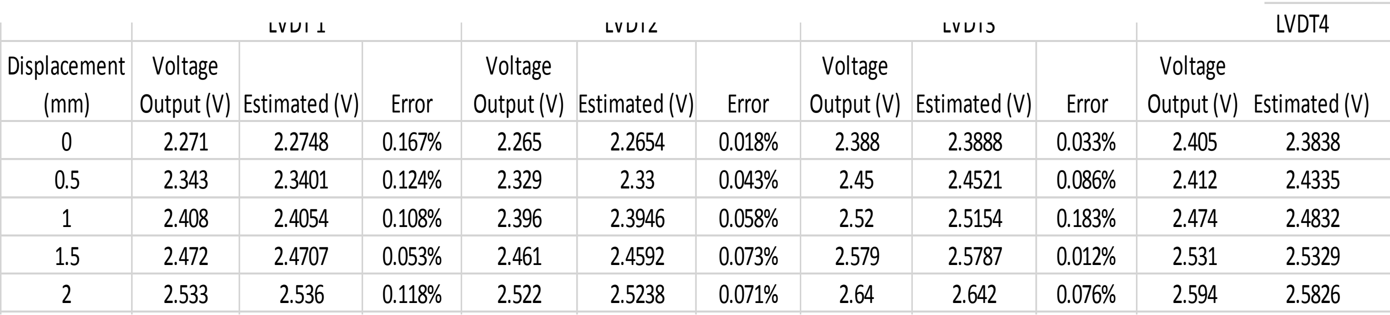
4.2.3- LINEAR VARIABLE DIFFERENTIAL TRANSDUCER SETUP

Linear Variable Differential Transformers (LVDT's) are used to measure the linear displacement of a test specimen under a range of loading conditions. In its simplest form, the design consists of a cylindrical arrangement of primary and secondary windings with a separate cylindrical core, which passes through the centre (LVDT, 2015). A distinct advantage of using an LVDT is that the moving core does not come into contact with any other electrical component in the assembly. This results in a high reliability of results and a long working life of the device. The LVDT design also lends itself to easy modification so that it can be used in a wide range of applications in both research and industry (LVDT, 2015)

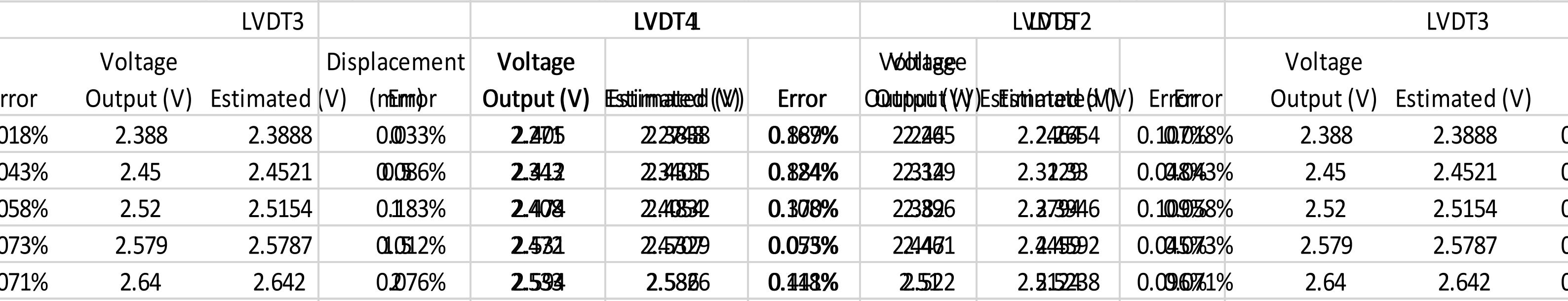
In order to obtain reliable results, the LVDT's first had to be calibrated to the optimum piston compression distance before testing could begin. The operating range of the devices was approximately between -2V to 3V. At –2V the LVDT piston was fully compressed and at 3V the piston was fully extended. Outside of this operating range then the LVDT's do not register an output voltage and a displacement value is unable to be obtained. It is important to calibrate the LVDT's to the midpoint of their operating range to obtain the most accurate results. Figure 25 shows the equipment used for the calibration and the process involved extending the piston by a known displacement by rotating the equipment's micrometre and then measuring the output voltage. Each complete rotation of the calibration equipment corresponded to a displacement of 0.5mm. Table 2 shows the output voltages obtained for each LVDT during the calibration procedure.

Figure 25- Calibration Equipment

Table 2- LVDT Calibration data with expected results and percentage error



	LVDT1			LVDT2			LVDT3			LVDT4	
Displacement (mm)	Voltage Output (V)	Estimated (V)	Error	Voltage Output (V)	Estimated (V)	Error	Voltage Output (V)	Estimated (V)	Error	Voltage Output (V)	Estimated (V)
0	2.271	2.2748	0.167%	2.265	2.2654	0.018%	2.388	2.3888	0.033%	2.405	2.3838
0.5	2.343	2.3401	0.124%	2.329	2.33	0.043%	2.45	2.4521	0.086%	2.412	2.4335
1	2.408	2.4054	0.108%	2.396	2.3946	0.058%	2.52	2.5154	0.183%	2.474	2.4832
1.5	2.472	2.4707	0.053%	2.461	2.4592	0.073%	2.579	2.5787	0.012%	2.531	2.5329
2	2.533	2.536	0.118%	2.522	2.5238	0.071%	2.64	2.642	0.076%	2.594	2.5826



	LVDT3			LVDT4			[illegible]			LVDT3	
rror	Voltage Output (V)	Estimated (V)	[illegible]	Voltage Output (V)	[illegible]	Error	[illegible]	[illegible]	[illegible]	Voltage Output (V)	Estimated (V)
018%	2.388	2.3888	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.388	2.3888
043%	2.45	2.4521	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.45	2.4521
058%	2.52	2.5154	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.52	2.5154
073%	2.579	2.5787	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.579	2.5787
071%	2.64	2.642	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.64	2.642

Table 2 shows that as the displacement was increased the voltage output increased and gradually rose towards the end of the operating range of the LVDT's. As a result, the LVDT's were calibrated to the extension set when the LVDT is secure in the calibration device and there is no additional displacement. This is not the ideal calibration setting for the device as the optimum output voltage is approximately 1V but due to the nature of the calibration device's design, this was unable to be achieved as the LVDT piston could not be compressed more than its standard setup. The table also gives the percentage error values for each of the voltage readings. All of the errors are under 1% with the majority of the values being under 0.2% showing a good level of accuracy between the predicted results and the actual results obtained from the experiment.

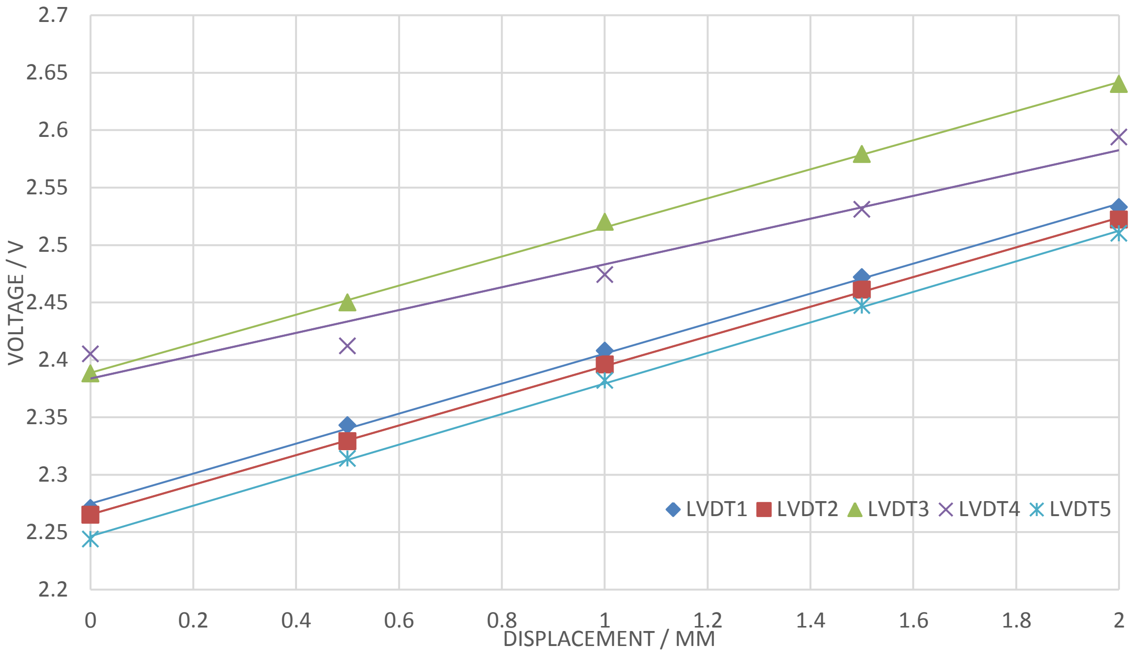


Figure 26- Voltage against Displacement for the LVDT's

Figure 26 shows is a plot of the voltage output of the LVDT’s with changing displacement during the calibration process and shows that whilst the LVDT’s were not calibrated to their optimum compression, they are still within the linear operating range of the device and will provide accurate results during testing.

For the LVDT’s to record data, the bike had to be mounted on the rig at 90° as shown in Figure 24. The LVDT’s were orientated in places close to a strain gauge in order to measure the displacement at locations where strain was measured so that a validated FEA model can later be created. The limitations of putting LVDT’s directly onto the frame is that they have to be mounted on a completely flat surface so at some strain gauge locations, an LVDT could not be applied as the test specimen was either curved or bent. Table 3 shows the locations of the LVDT’s around the Speedway frame test specimen.

Table 3 - Location of LVDT's

LVDT Number	***Location of LVDT***	***Additional Notes***
LVDT 1	In the centre of the headstock plate	
LVDT 2	175mm from top rear sub frame connecting spindle	15mm from Gauge 6 (LHS sub frame)
LVDT 3	140mm from SG4	60% of way down LHS lower main frame tube
LVDT 4	50% of way down LHS main tube frame	Close to SG2
LVDT 5	Engine plate	Towards outer edge of plate

The data obtained from the LVDT's and strain gauges during testing were recorded using a Spider 8 data acquisition system (HBM, 2007.). The system was set up to calculate additional parameters such as the principal strains and principal angle using the data obtained from the gauges in addition to material properties such as the Young's modulus and Poissons ratio.

As a result of the number of gauges bonded to the frame and the number of available ports on the Spider 8, the frame was tested in two stages to allow all of the gauges to be tested. In the first test, gauges 1, 3, 4 and 7 were tested and the second run consisted of the remaining three gauges.

A Radicon- Avery Denison torsion test rig (Figure 27) was used in the experiment and whilst the equipment has no facility for outputting an electrical torque signal, the value can be read from the dial on the rig. The machine works by engaging a clutch and motor system and applying a rotational displacement to the test specimen.

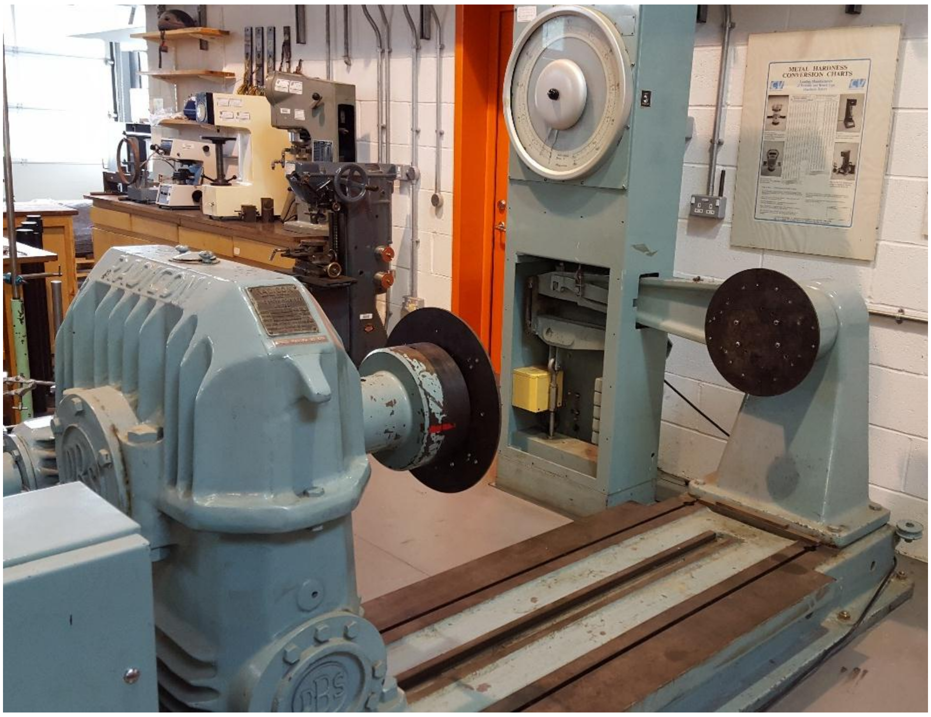


Figure 27- Torsion Test Rig

The experimental investigation was conducted by applying a rotational displacement of 2 degrees per minute to the Speedway frame. When the torque value read 10 Nm, the machine was stopped and a time delay was used to distinguish between different torque values in the subsequent data files. After 5-10 seconds delay the machine was restarted and the frame was further twisted at the same rotational displacement until the next torque value was reached on the rig. Data samples were continuously taken throughout the tests and the machine was stopped every 10 Nm increments from 10Nm to 100Nm. To validate the results obtained in the experiment, the test was repeated by applying the same rotational displacement but in the reverse direction and stopping the machine at the same torque increments from 100Nm to 10Nm. The test was then repeated again following the same procedure to gain four sets of data to improve the accuracy of the overall final results.

For the investigation, it was not necessary to increase the rotational displacement enough to surpass 100Nm of torque as this research only focuses on the linear region of a stress-strain plot and the frame does not need to be taken close to its yield point. The time delay used in the experiment shows a plateau in the strain readings when plotted against time, correlating to a specific torque value. The results obtained from physical testing were used in the development of the FE model undertaken later in this research.

4.3- FINITE ELEMENT ANALYSIS AND SIMULATION

Physical testing of the Speedway frame was conducted to validate the CAD and FEA models developed in this research. The aim is to use both sets of results in collaboration with the technology road map to progress the technical development of Speedway racing.

4.3.1- DEVELOPMENT OF SPEEDWAY BIKE CAD MODEL

Using measurements taken from the Speedway bike on loan to the university, a CAD model of the Speedway bike was developed (Figures 28 and 29) using the input parameters shown in Table 4. Solid models were used to better represent the geometry of the bike and only the parts of the bike that were mounted on the test rig during physical testing were assembled in the CAD model. This resulted in the FEA model being as geometrically similar to the experimental setup as possible.

Table 4- Input parameters for CAD model of Speedway bike

Input Parameters of CAD Model		
No of Solid Parts in Assembly	12	
Dimensions of Frame	Outer ϕ (mm)	Inner ϕ (mm)
Main Frame	22	17
Subframe	22	18
Central Tube of Main Frame	30	26
Headstock	36	30
Constraints		
Pin Connectors	19	

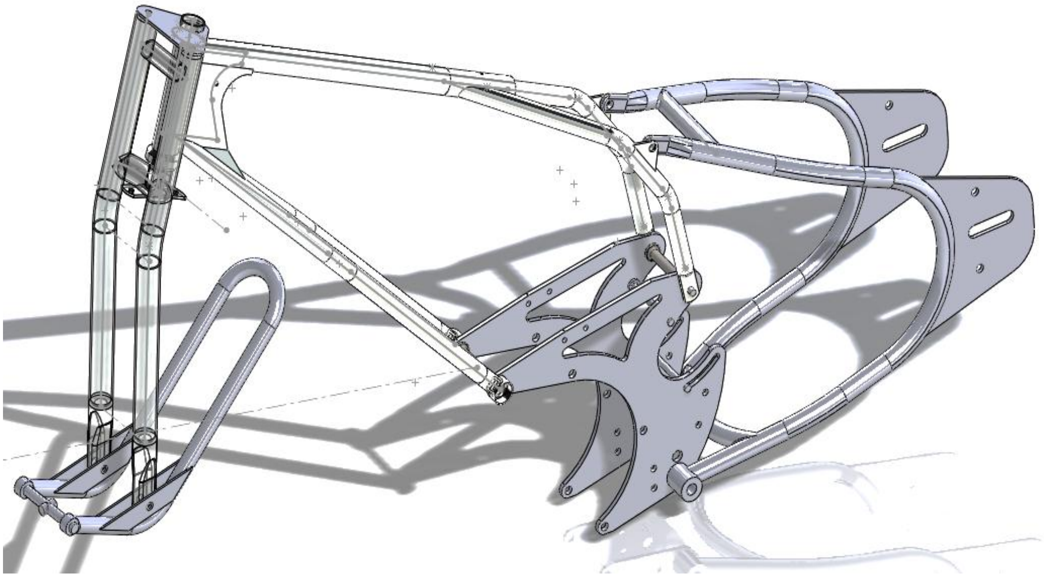


Figure 28- CAD of Speedway Frame

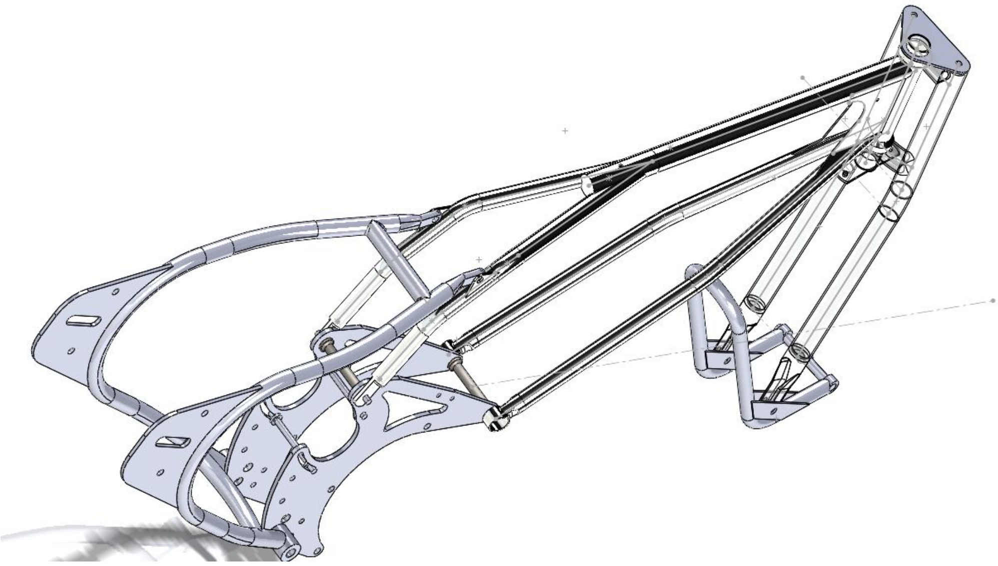


Figure 29- Alternative angle of Speedway bike CAD model

4.3.2- Development of Finite Element Model of Speedway Bike

The CAD model created in Figures 28 and 29 was developed into an FE model with the aim of obtaining a correlation between the experimental and simulated data, resulting in a validated FE model of a Speedway bike being produced.

The FE model was developed using the parameters given in Table 5 and the final FE model is shown in Figures 30 and 31. The model consists of solid elements rather than shell elements as solid elements are naturally more suited to larger complex models such as a frame, whereas shell elements are often used for thin parts. A curvature based study of high order element analysis was used to increase the correlation between both sets of results as it provides a better mapping effect compared to a linear study. With a tetrahedral mesh (Figure 31) a curvature based study allows intermediate points to be determined and in the context of a beam, the study allows the complete circumference of the beam to be mapped.

Table 5- Input parameters for FE model of Speedway bike

Inputs Parameters of FE Model	
Mesh Parameters	
Global Element Size	3mm
Mesh Control	1.75mm
Number of Elements	735,022
Material Properties	
Material Name	AISI 1035 Steel
Elastic Modulus	2.05e11 N/m^2
Poissons Ratio	0.29
Yield Strength	282685049 N/m^2
Tensile Strength	585000002.9 N/m^2

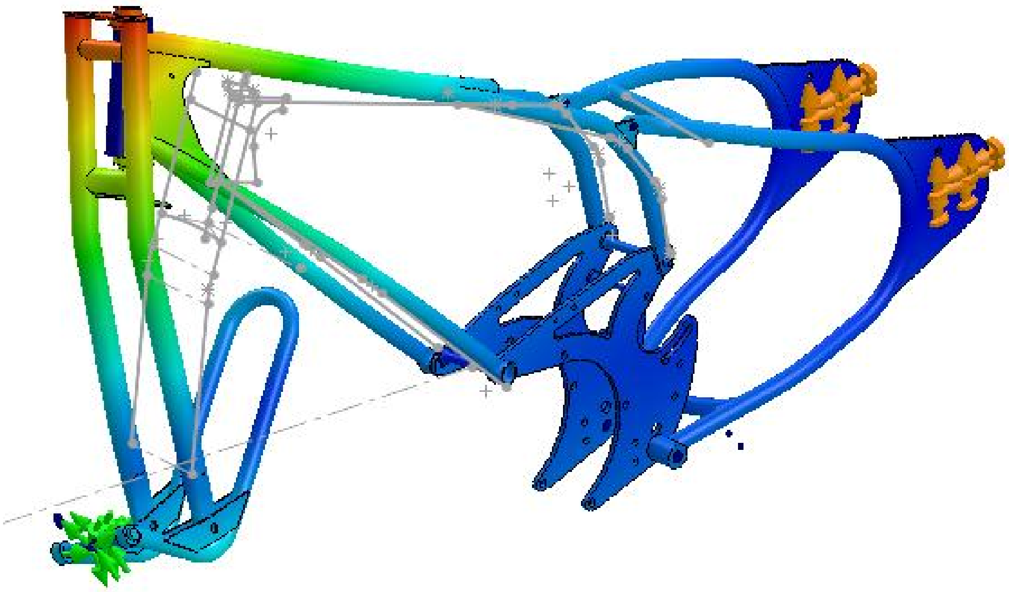


Figure 30- FEA model of Speedway bike

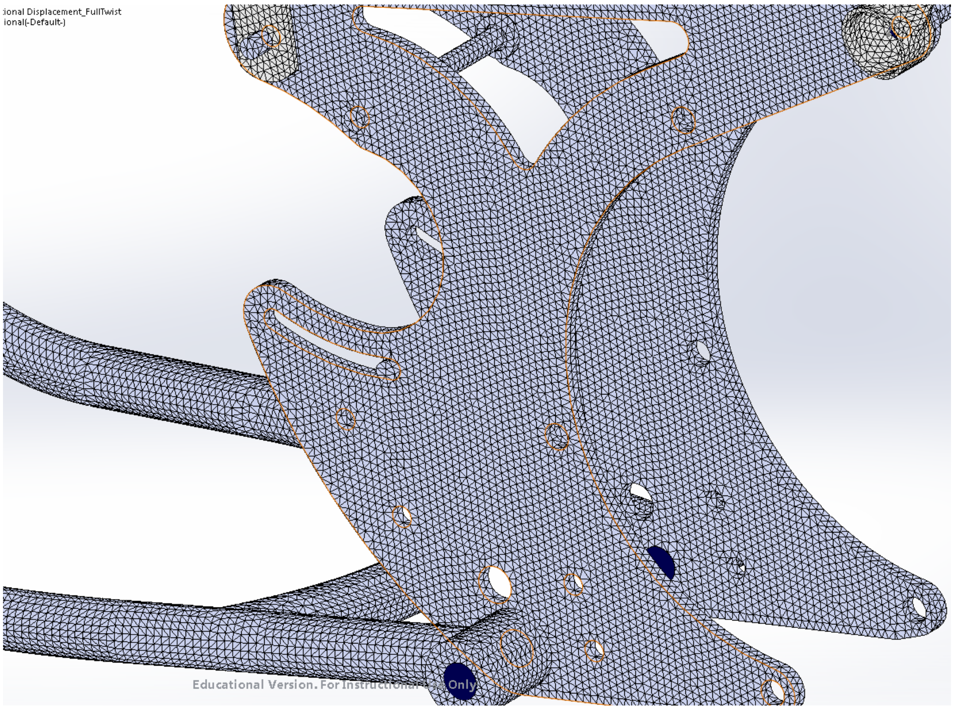


Figure 31- Close up image of meshing of FEA model

Multiple connections and constraints, mainly rigid, pins and radial were added to the model to aid in the representation of the behavioural characteristics of the physical system. A cylindrical extrusion (Figure 32) was added to the spindle linking the front forks to correctly simulate the loading conditions of the bike on the test rig.

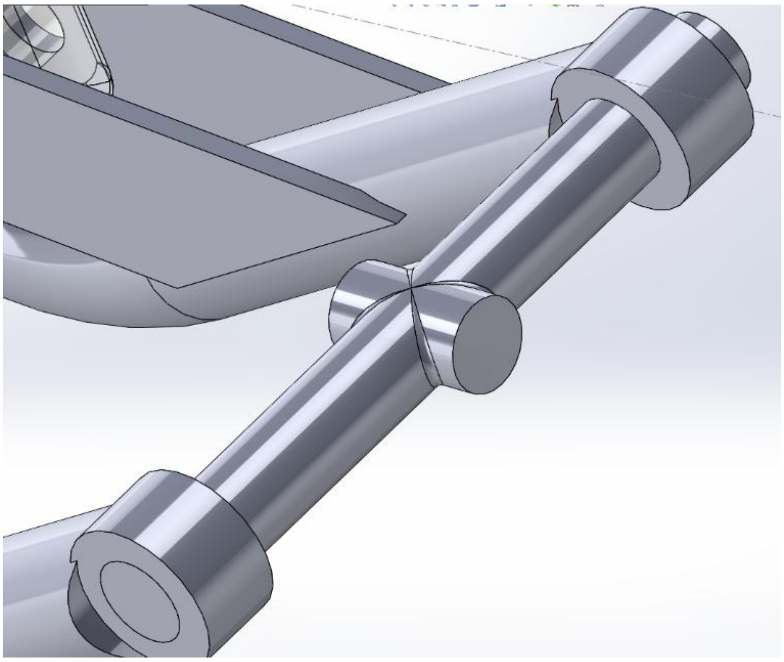


Figure 32- Cylindrical extrusion attached to the front wheel spindle

Pin connections were used throughout the model to connect the relevant bodies together with SolidWorks modelling the pin connectors as solid beam elements which allow rotation and translation between the connected faces. The degree of rotation of the pin depends on the moment that develops within the joint and the specified rotational displacement (SolidWorks, 2009). Pin connectors were chosen instead of rigid connections as in the physical system the individual faces translate and rotate relative to each other and this connection is the most effective way of simulating this behaviour. In contrast to pin connections, rigid connectors make the two selected faces completely rigid with respect to each other and the connected bodies are unable to either translate or rotate in any direction. The connection also applies an idealised setting of infinite stiffness and the connection can significantly affect the behaviour and results of the rest of the system as a result (SolidWorks, 2009).

The rear of the bike model was fixed through the rear wheel spindle slots to accurately simulate the loading conditions of the test rig (Figure 33) and using the data obtained from the experimental results, the applied twist was calculated for each torque value. This was inputted into the FEA model as a rotational displacement applied to the extrusion (Figure 32), resulting in the displacement being applied to the same place in the simulation as in the physical testing. A hinge joint was also added to the extrusion, allowing the bike to deform in the same manner as during physical testing aiding in the validation between results.

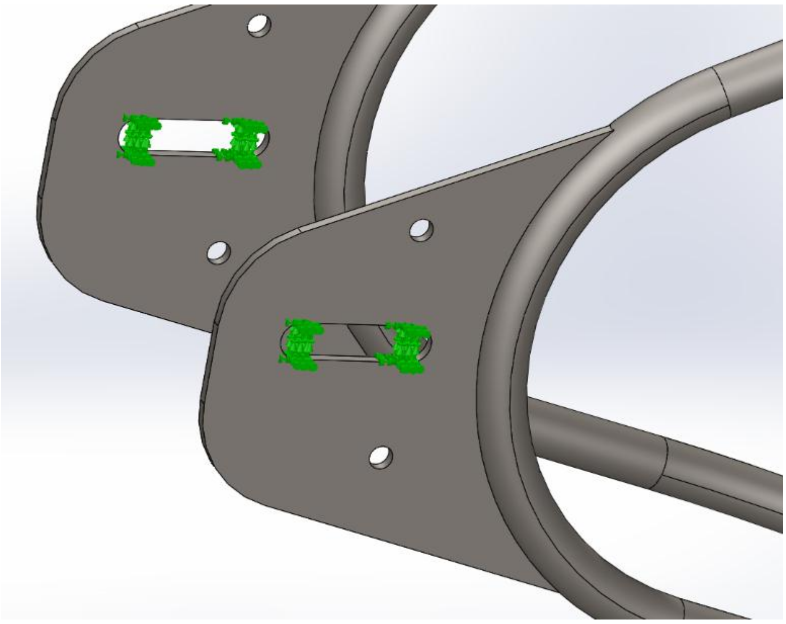


Figure 33- Fixed geometry applied to the rear of the frame

4.4- SUMMARY

A Radicon-Avery torsional test rig with the aid of strain gauges and LVDT's was used to investigate and determine the physical parameters of the Speedway frame. The bike was mounted at 90 degrees to the rig and a rotational displacement applied to the frame enabling the key physical parameters to be determined. In addition to physical testing, using the CAD input constraints defined, an FE model was developed and the key parameter values compared. The results of the physical testing are presented in the next Chapter and discussed in further detail in Chapter 6.

Chapter 5- Results

5.1- INTRODUCTION

Chapter 5 presents the results from torsional testing and simulation studies. The physical parameters of the Speedway frame determined from testing, such as the principal strains, torque and stiffness are provided, alongside the deformation results and stiffness values from the FE simulation and analysis. A more detailed discussion and comparison of the results can be found in Chapter 6.

5.2- TORSIONAL TESTING

The following figures present the data obtained from physical testing where a Speedway frame was tested under torsional loading. Although seven gauges were tested in total, one of the gauges, gauge 7, did not transmit strain readings in one direction during testing so therefore could not been included in the calculation of the principal strains. Accidental damage to the gauge when mounting the bike on the test rig is the most likely reason as to why the gauge failed to transmit a signal.

Figure 34 shows the principal strain values for six gauges and the linear trend is to be expected as the components were well within the elastic region of the material’s deformation characteristics.

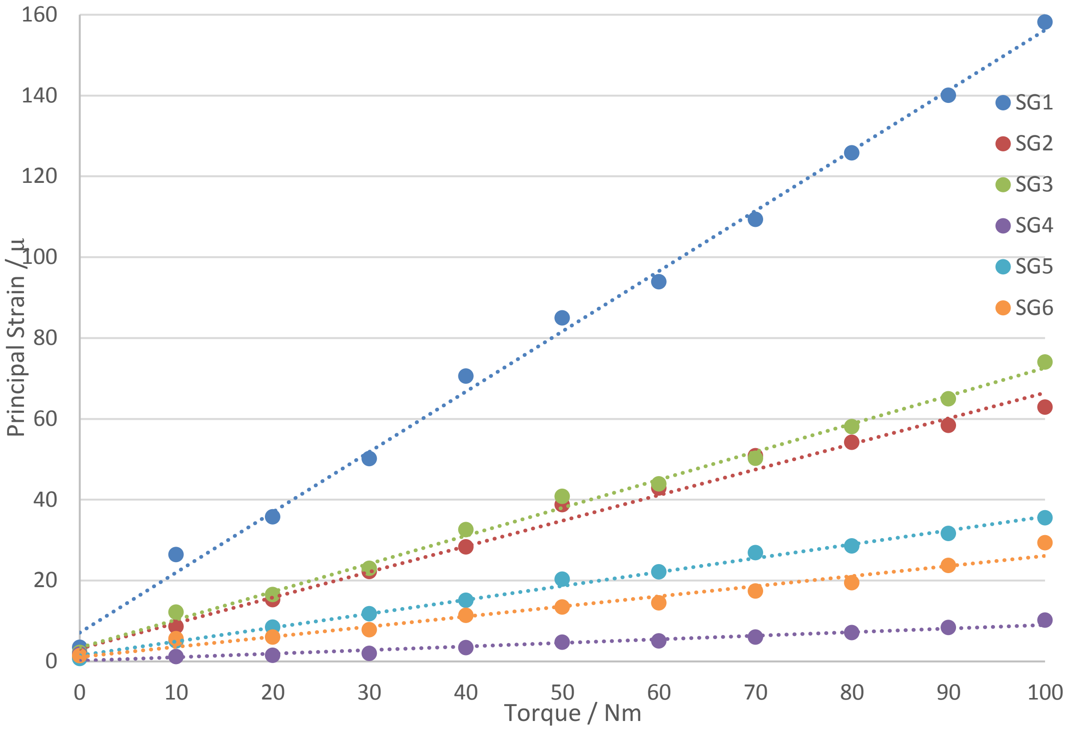


Figure 34- Principal Strain values in line with the strain axis

Figure 35 shows the principal strains at 90 degrees to the strain axis and similarly to Figure 34 follows a linear trend as expected by the stress-strain relationship.

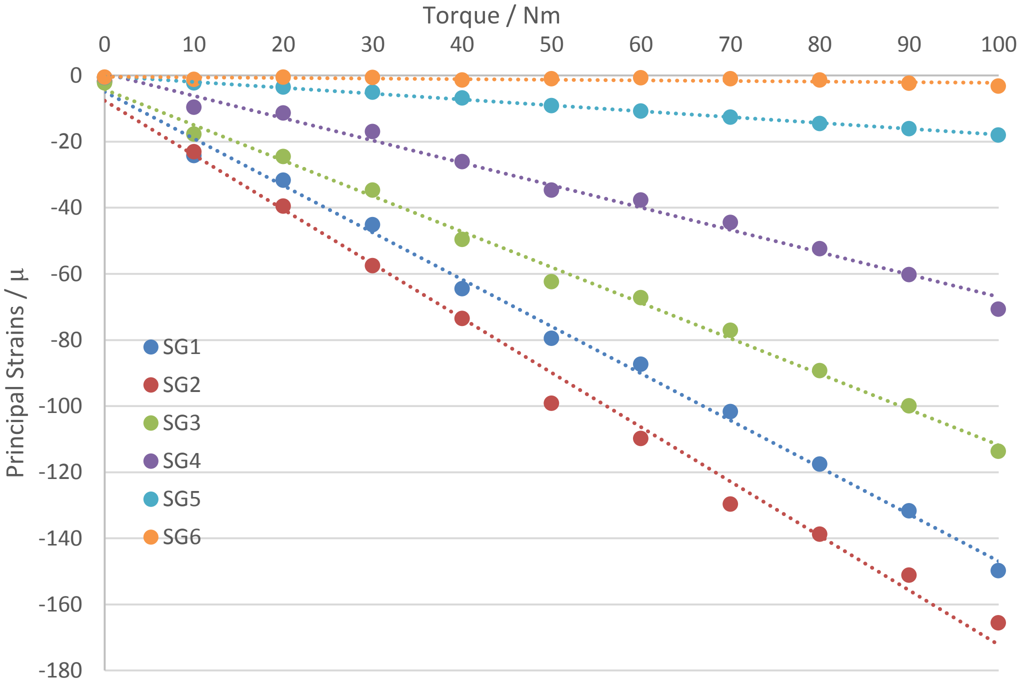


Figure 35- Principal Strains at 90 degrees to the strain axis

Figure 36 shows the LVDT displacement as the rotational displacement applied to the frame, increasing the torque experienced by the frame. The LVDT's which operated within the boundaries of their operating range provided a linear displacement when the frame was twisted as expected.

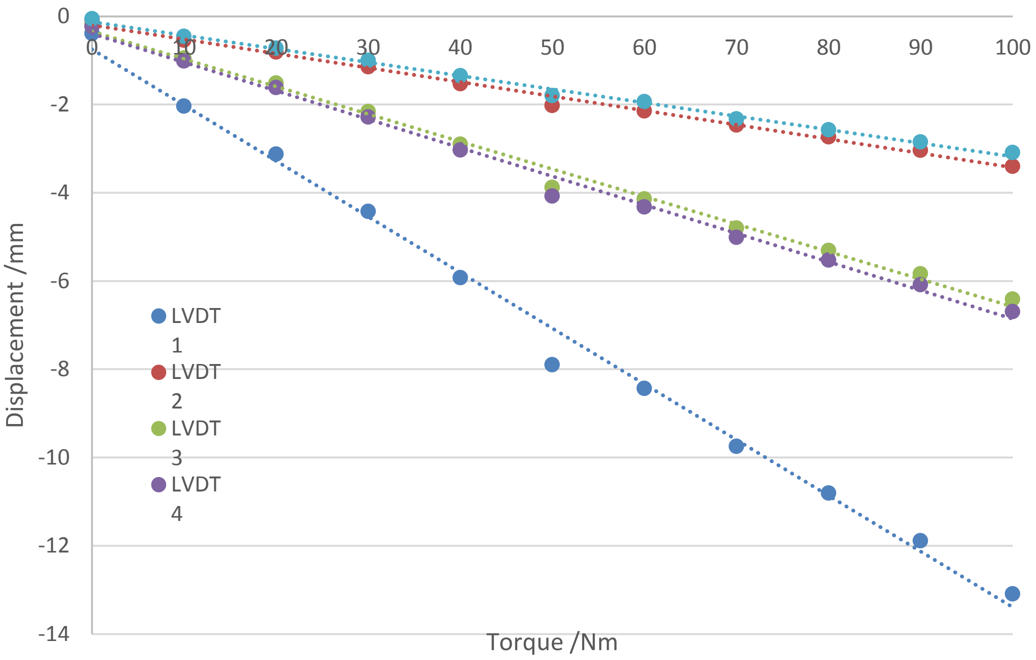


Figure 36- Displacement against Torque for the LVDT's

Using the data sets from the physical testing, the twist was determined for the range of torque values experienced by multiplying the rate of rotational displacement applied to the frame by the time that it was being twisted as shown by the time channel added to the Spider 8 software system. Figure 37 is a graph of torque against twist for the Speedway frame yet the figure shows that there is a torque applied to the frame without any twist being generated from the rig. This shows the significant amount of slack in the machine and as result the data was recalibrated to remove the play from the test rig and the results presented in Figure 36. The gradient of the Torque vs Twist graph (Figure 38) represents the stiffness of the physical frame as shown in Table 6.

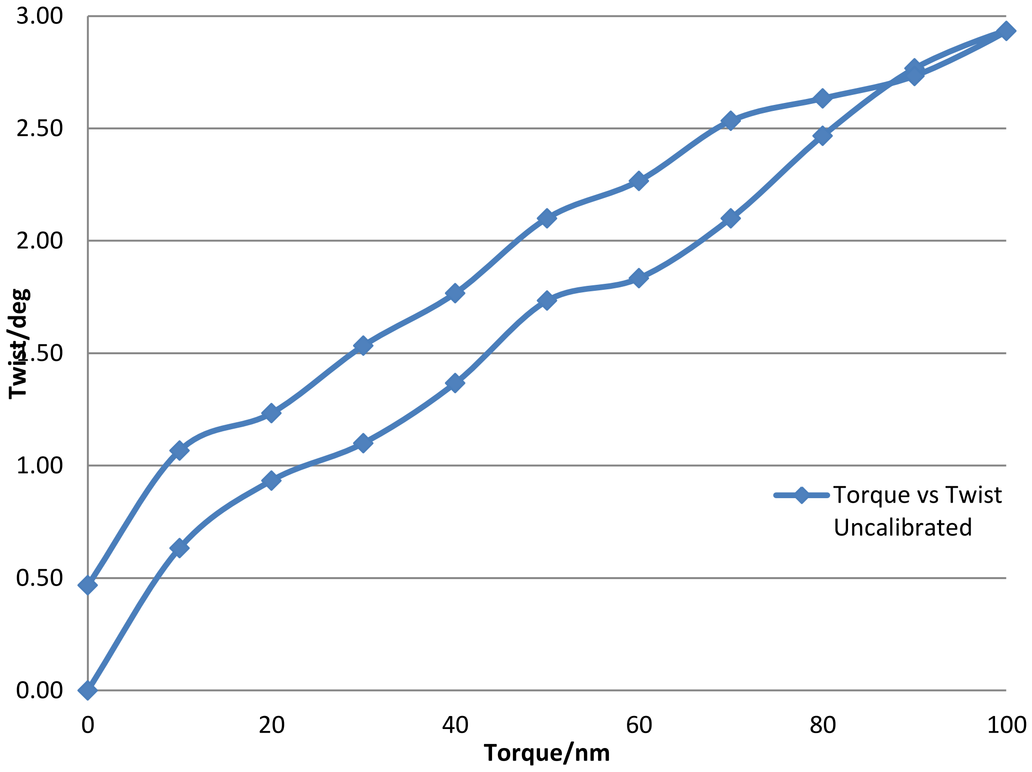


Figure 37- Torque vs Twist Uncalibrated

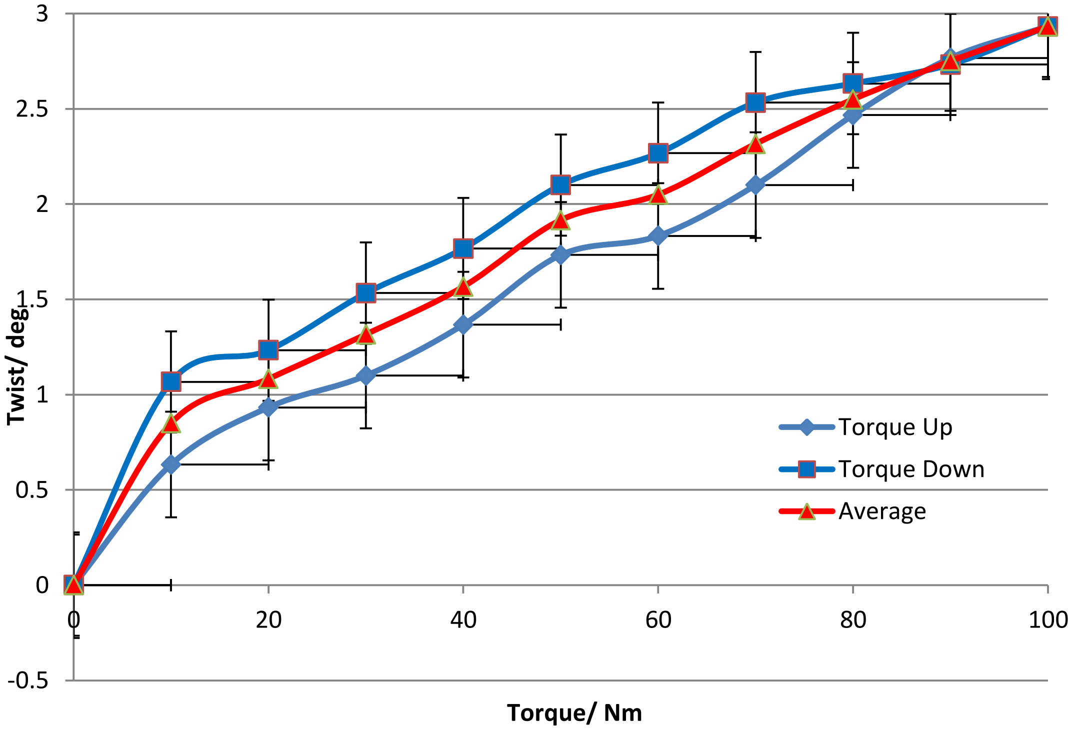


Figure 38- Torque vs Twist Calibrated

Table 6- Frame stiffness results from physical testing

Torque (Nm)	Time (s)	Twist (°)	Stiffness (Nm/deg) Torque/Twist
10	19	0.633	15.789
20	28	0.933	21.429
30	33	1.100	27.273
40	41	1.367	29.268
50	52	1.733	28.846
60	55	1.833	32.727
70	63	2.100	33.333
80	74	2.467	32.432
90	83	2.767	32.530
100	88	2.933	34.091
90	94	2.733	32.927
80	97	2.633	30.380
70	100	2.533	27.632
60	108	2.267	26.471
50	113	2.100	23.810
40	123	1.767	22.642
30	130	1.533	19.565
20	139	1.233	16.216
10	144	1.067	9.375

Figure 38 presents the errors obtained for the torque and twist obtained through physical testing. The majority of the errors experienced are a result of human error as the torque readings were measured and the rig stopped when a human eye determined the next torque mark had been reached and the machine stopped. Whilst experience with the machine allows timing to be predicted to a certain extent, this is impossible to replicate at every torque value and as a result account for the majority of the errors incurred.

5.3- FEA SIMULATION

The following figures present the deformation experienced by the frame during FEA simulations and a comparison between the principal strain values from FEA and physical testing as well as the deflection characteristics of the frame.

Figure 39 shows the displacement of the frame during simulation from the top and side view. The grey centre of the model that can be seen in the figure represent the original position of the frame prior to simulation and present a good concept of the level of deformation that the frame experiences even at such low torque values.

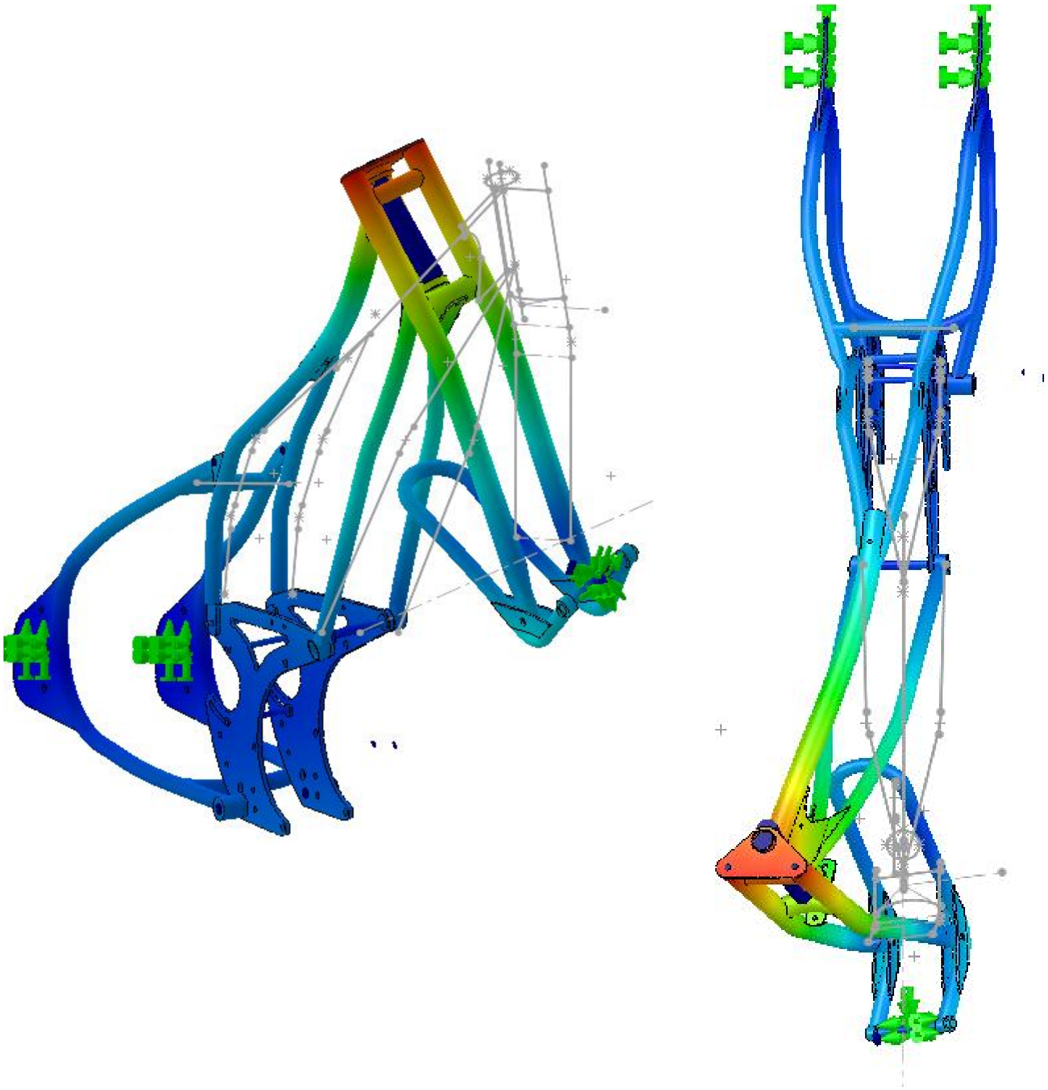


Figure 39- Deformation of the Frame at 100Nm- Top and Side View

Figure 40 presents further angles of the Speedway frame, showing the level of displacement experienced throughout the entire frame and again the grey outlines are shown in the figure and indicate the initial positioning of the frame before a rotational displacement was applied to the frame.

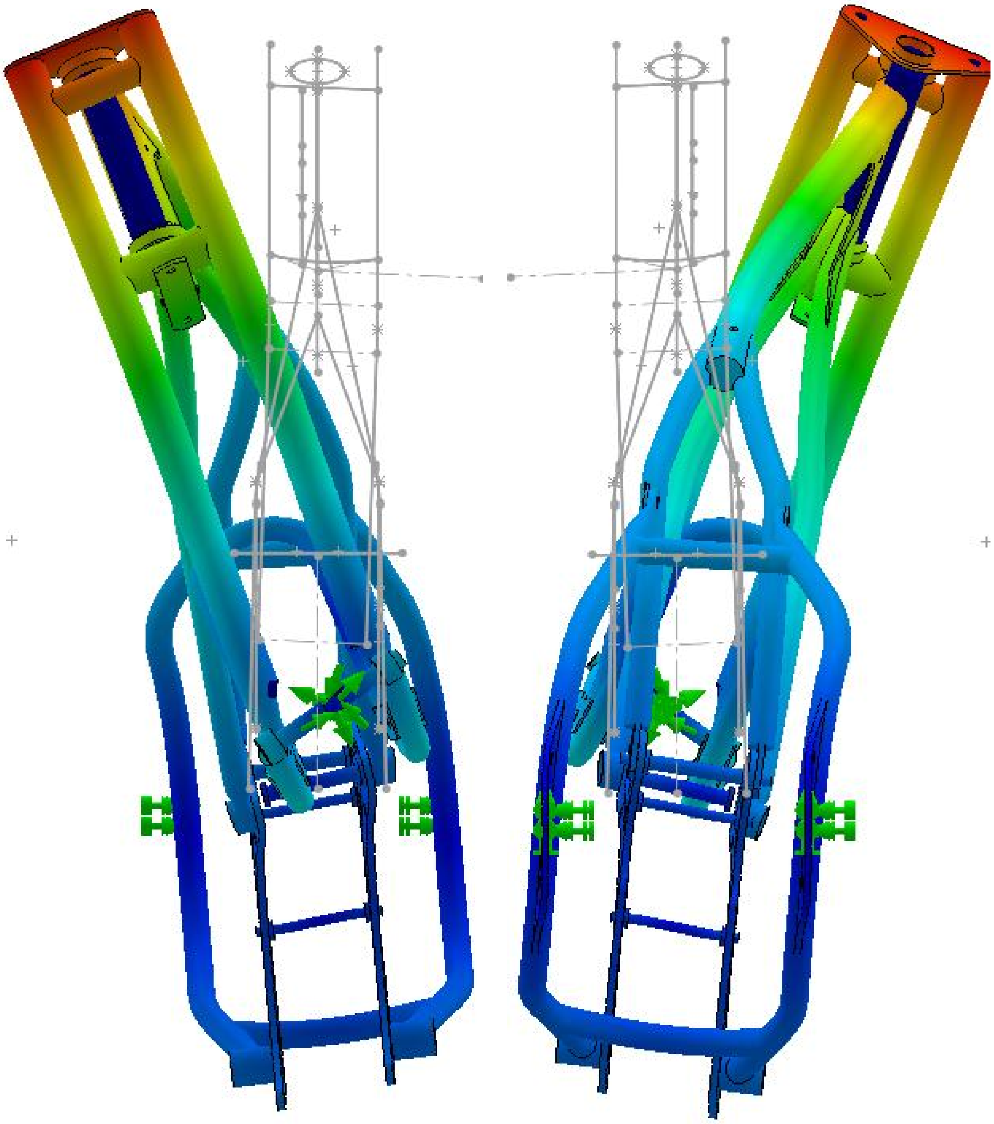
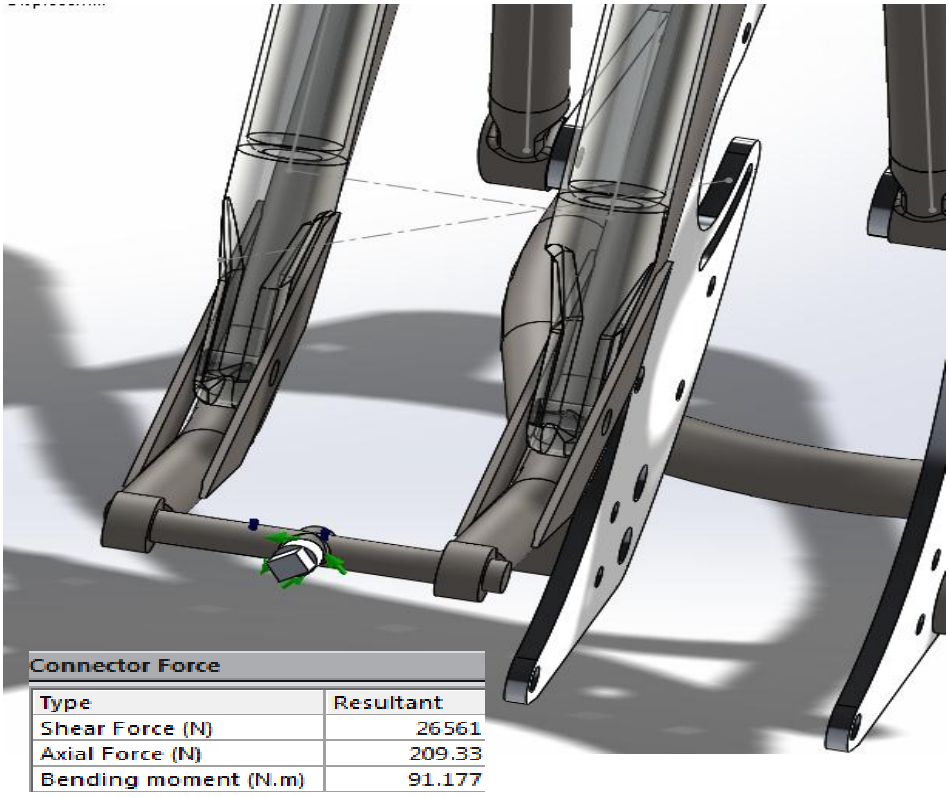


Figure 40- Deformation of the frame at 100Nm- Front and rear view

Once the FE study had successfully simulated, the principal strain and stiffness values were obtained by probing the model at the locations where a strain gauge was bonded to the frame during physical testing. This process was repeated at the LVDT locations to obtain a comparison between the displacement values of the two studies.

Figure 41 shows the rotational displacement applied to the extrusion in FEA and the torque that was applied to the FEA simulation was determined. A resultant plot was generated showing a torque of 91.77Nm at full rotational displacement and the corresponding stiffness is shown in Table 7 and compares the results obtained to the experimental values.



Connector Force

Type	Resultant
Shear Force (N)	26561
Axial Force (N)	209.33
Bending moment (N.m)	91.177

Figure 41- Resultant torque value for FEA simulation at maximum rotational displacement

Table 7- Comparison of stiffness values between FEA and experimental at full rotatioanl displacment

Experimental Data				FEA Data			
				Twist (Forced)			
Torque (Nm)	Time (s)	Twist (°)	Stiffness (Nm/deg)	/deg	/Rad	Torque (Resultant) (Nm)	Stiffness (Nm/Deg)
100	**88**	**2.933**	**34.091**	**2.933**	**0.051196**	**91.77**	**31.2852273**

A further comparison between the FEA and physical testing results is presented in Figure 42, where the principal strain values in both directions and LVDT displacement are shown.

	Principal Strain 1		Principal Strain 2	
Gauge No	FEA Model	Experimental	FEA Model	Experimental
1	1.59E-04	1.58E-04	-1.72E-05	-1.49E-04
2	5.41E-05	6.20E-05	-1.46E-04	-1.65E-04
3	5.92E-05	7.40E-05	-8.57E-05	-1.13E-04
4	3.02E-05	1.00E-05	-6.87E-05	-7.00E-05
5	3.10E-05	3.50E-05	-1.97E-05	-1.80E-05
6	3.16E-05	2.90E-05	-2.42E-06	-3.00E-06

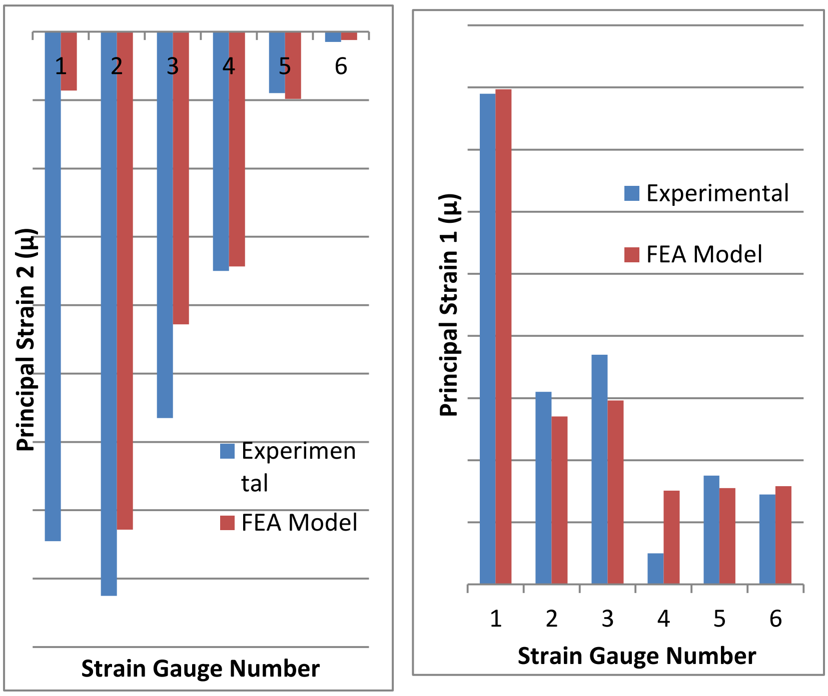


Figure 42- Comparison between FEA and physical testing results

Chapter 6- Discussion

6.1- INTRODUCTION

Chapter 6 discusses in further detail the results obtained in physical testing and simulated presented in the previous Chapter. Key frame parameters such as principal strains, torque, deflection and stiffness are analysed and a comparison between the simulated and physically tested frames is discussed.

6.2- PHYSICAL TESTING RESULTS

According to a materials stress-strain relationship, whilst a material remains within its elastic region and the applied stress is not above the yield stress, then both the stress and strain should increase linearly with torque up to the point of yield. This relationship was validated for the Speedway frame as shown in Figures 34 and 35 as all of the tested gauges present a linear relationship of strain with an increasing torque. The strain trend line for SG1 in the first principal direction (Figure 34) is significantly steeper compared to the remaining gauges, with the maximum strain also being substantially greater. This is a result of the application of load and torque to the frame in this area, hence a higher strain is experienced by the system.

The secondary principal strain, at 90 degrees to the strain axis (Figure 35) also follows the expected linear relationship, although the trend lines of the gauges are much closer together. This suggests that either the diameter size of the tube does not significantly influence the strain in this direction or that SG1 is not bonded at exactly 90 degrees to the strain axis. Figure 35 also shows that for strain gauge 6, located at the start of the rear sub-frame bend (Figure 23) a negligible amount of strain is experienced by the frame in the secondary principal strain direction and hence the beam is in uni-axial strain, suggesting that the tube is being loaded in pure bending.

Figure 36 demonstrates the displacement recorded by the LVDT's when the torque transmitted to the frame is increased. All of the LVDT's present a negative trend line suggesting that when the bike was twisted, the piston of the LVDT contracts in length. LVDT 1 which was positioned on the flat plate connecting the central horizontal tube to the lower main frame tubes presents the greatest amount of displacement. Figure 34 shows that this is to be expected as the highest levels of strain were recorded by SG1 in a similar position to the LVDT during physical testing, resulting in the greatest amount of displacement being experienced relative to the rest of the bike.

Using the gradient of the torque twist graph (Figure 38), the stiffness of the frame was calculated for the full range of torque values, as presented in Table 6 and shows that as the torque and twist increase so does the stiffness of the frame. This means that as the frame is displaced more, its resistance to deformation increases. Whilst the determined stiffness of the frames is far below the maximum strength of the material, the experiment lays the foundation for future work to be undertaken, with Cossalter (2015) discussing in his work the important role that the structural characteristics of the frame have on motorcycle dynamics and stability. Further to this, Yokomori *et al.* (1986) explains the instrumental impact of the frame characteristics on rider injury and safety and further shows the need for additional research in this area.

6.3- SIMULATED RESULTS

The deformation experienced by the bike when simulated is shown in Figures 39 and 37. As the rear of the frame was fixed, the rotational displacement was applied to the cylindrical extrusion between the front forks, resulting in significant deformation along the front forks and their adjacent tubes as shown by the grey outline depicting the original location of the frame prior to simulation. The red, orange and green colouring in these areas compared to the blue in the remaining parts of the bike further show the significant displacement of the frame as validated by the results presented by the physical testing where greater strain values were recorded in the same area.

Figure 40 demonstrated further the extensive deformation experienced by the front forks and main frame at 100Nm. In this alternative view it also shows more clearly the deformation of the rear subframe, which deforms significantly, especially the top half of the frame. The reason behind the top half of the rear subframe deforming substantially more than the bottom is that the bottom beam of the subframe is manufactured slayed out from the wheel centre and back in to accommodate for wheel movement. This results in the structure have a greater stiffer compared to the top hence there is less deformation in this area. Due to the nature of Speedway racing, this is important for Speedway bikes as the bottom part of the subframe is continuously being pushed into the ground so a greater stiffness in this area aids in the performance of the bike.

In addition, Figure 40 also shows that the main frame experiences a significant amount of bending when loaded. This in conjunction with the level of deflection experienced at such a small torque value suggests that the Speedway frame has a low stiffness. This is surprising for a Speedway bike as a greater frame rigidity and stiffness would increase the feel and responsiveness of the bike, which when racing on a loose track surface would seem preferable. However, with a greater rigidity and stiffness, the vibrational modes experienced by the bike are intensified as suggested by Foale (2006), especially if the frame has limited damping capabilities as in the case of Speedway. Work presented by Wagstaff (2011) has verified that Speedway bikes are prone to significant amounts of front end wobble or shimmy and with no rear suspension to aid in damping, using a frame with a low stiffness and rigidity may lead to the best compromised performance and safety setup currently possible.

6.4- COMPARISON OF PHYSICAL AND SIMULATED RESULTS

A comparison between the FEA simulated results and those obtained through physical testing is presented in Table 7 and Figure 42. The tables present a comparison of principal strains, LVDT displacement and stiffness values at a range of rotational displacements.

The comparison between the stiffness values of the frame obtained through physical testing and FEA (Table 7) shows that at a maximum rotational displacement of 2.933° the resulting applied torque to the frame is 100Nm and 91.77Nm in physical testing and FEA simulation respectively. On the physical frame, this corresponds to a torsional stiffness of 34.091 in comparison to the 31.285 recorded torsional stiffness value of the simulated model. Although the simulated stiffness was only determined at maximum rotational displacement, as a result of the model being linear, it can be assumed that the FE model would follow this trend for stiffness at the remaining rotational displacements applied during physical testing. The significant correlation between the stiffness values of the physical and FEA testing shows that a validated FE model of a Speedway frame has been obtained.

The validation of both models is further verified by the consistent correlation of the strain results for both the FEA and physical models as shown in Figure 42. A slight exception to this correlation is the secondary principal strain readings for SG1, where the experimental system is significantly greater. The exact reason behind the significant different is undetermined, but it is possible that it could be a result of a bad connection between the strain gauge and the Spider 8 data logging machine or potentially a defective strain gauge. The good correlation between the results suggests that this is not significant and is a mere anomaly in an otherwise good set of results.

Table 7 and Figure 42 demonstrate that the torsional stiffness, principal strains and displacement values obtained through physical testing and FEA are largely within an acceptable margin of each other with the exception of an anomaly as discussed above. This good consistent correlation validates the objective that through this research a validated model has been developed.

Chapter 7- Conclusion

During this research project, the technical and business evolution of Speedway racing was mapped,and used to assess the trends in the mainstream popularity of the sport. It identified that the majority of technical development introduced to date has bas subtle adaptations of the original concept and that revolutionary technical design and development has rarely been seen in the sport to date. The analysis of Speedway's popularity trend suggests that the business structure of Speedway has been the primary driver behind the popularity of the sport, yet also highlights the potential for technology to become a secondary driver in the future. A technology road map of Speedway was also developed to present the possible future pathways of the sport to enable technical progression and prevent further stagnation or decline.

A review of relevant literature identified the potential for technical development, resulting in physical and virtual testing to be completed. Physical testing was conducted on the frame using a torsion test rig with the strain and displacement values being measured using rosette gauges and LVDT's. The torsional testing produced linear principal strain trends in both directions, and a linear displacement trend from the LVDT's. The torsional stiffness of the physical frame was then calculated from the rotational displacement applied to the frame and compared to the torsional stiffness of the simulated model. At full rotational displacement, there is a clear correlation between both models.

The results obtained through physical testing were used to develop a validated CAD and FE model. The CAD model was created to geometrically mirror the physical system as closely as possible and was then developed into a validated model. The FEA results gathered present a good correlation with the experimental data in terms of strains, displacement and stiffness and hence the physical testing validated the FEA model developed in this research.

Chapter 8- Opportunities for Further Work

The work completed in this research lays the foundation for future work to be completed on various areas relating to Speedway. Whilst a validated FEA model of a Speedway frame was created, this could be developed further to modify the geometry and design of the frame through extensive optimisation process that would result in an increased performance of the bike whilst keeping costs low. In addition to this there is also the proposed work to be undertaken from the technology road map which would see an increase in performance of the bike and prevent the sport from further stagnation.

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Appendix

TAPE ASSISTED INSTALLATION METHOD

- *Surface Preparation*

The test specimen surface must be prepared before the strain gages and bondable terminal pads can be installed. Cleanliness is important for successful strain gage bonding. The object of preparation is to create a smooth surface which can be wetted so it can receive the adhesive. Some steps may be disregarded or modified, based on the condition of the test piece and the type of material.

- *Coarse Cleaning*

Rust, scale, paint and other contaminants must be removed from the location where strain gages will be installed. Remove any surface coating by sand blasting or by abrading with coarse grade emery paper.

- *Smoothing Surface*

Surface imperfections must be removed. Pitting, scratches, protrusions, etc can be removed by grinding, filing or other suitable methods to smooth the surface where strain gages will be installed. Follow with a light sanding with a fine grit (240 grit) silicon carbide or emery paper.

- *De-Grease the Surface*

Use a solvent, and a soft tissue to remove all excess oil and grease. Select a solvent. Check the chemical resistance of the material, making sure that the solvent will not damage the test piece.

- *Clean Surface with Metal Conditioner and Neutralizer*

Clean the surface with a mild acid or metal conditioner. Sand lightly with the metal conditioner and wipe clean with a clean tissue or gauze pad. Clean the surface with a mild base, or metal neutralizer, wipe with a clean tissue or gauze pad. Brush with lint-free brush to remove any dust particles that may have settled. Bonding Procedure Specific instructions may be provided with strain gage adhesives. Instructions may vary with the type of adhesive that has been selected. For example, a two-part epoxy may need to be mixed, clamped and cured at an elevated temperature. Some adhesives, like the cold cure SG496 (typically used for metals) and SG401 contain solvents. Check the chemical resistance of the material, making sure that the solvent used in the adhesive will not damage the test piece. For best strain gage installation results consider the following procedures.

- *Clean Tools and Surfaces*

Clean and degrease the tools that will be used to handle the strain gages. Prepare a clean and degreased work surface. A piece of glass can be used as a work surface. Do not handle the strain gages or bondable terminal pads with your hands, as you may introduce oils and contaminants that will cause bonding problems.

- *Orienting, Handling, and Bonding the Strain Gage*

Use tweezers to remove the strain gage from the package. Place the strain gage onto the work surface making sure that the ribbon leads or solder pads are facing up. Use cellophane tape, placed gently on top of the strain gage to lift it from the work surface. PTFE tape may be required for use with adhesive that will need to be cured at an elevated temperature. Position the strain gage onto the transducer or test specimen. Secure one end of the tape onto the test specimen. Gently, lift the other end of the tape, lifting the strain gage assembly being careful not to stretch the gage. Leave a hinge of tape so that access to the bottom of the strain gage is available, yet the position is fixed. Continue onto bonding of the strain gage. Adhesive can be applied to the bottom surface of the strain gage and it can be returned to the correct position. Follow instructions that were provided with the strain gages adhesive. Clamping and curing instructions vary with the adhesive selected. Repeat the procedure for the bondable terminal pad. Locate the bondable terminal pad within reach of the ribbon leads or in a convenient position for connection to the strain gage solder pads. When bonding has been completed, remove the tape. Peel the tape back carefully. Lift the edge of the tape, lay it back onto its self, and peel the tape back so that the tape is not pulling the strain gage up off the surface. You may need to use a small tool to hold the edge of the strain gage, or ribbon leads down to avoid pulling them up or damaging them.

- *Inspect the Strain Gage Installation*

Take a close look at the strain gage installation. Inspect to make sure that there are no loose edges, bubbles or voids beneath the strain gage. The color should be consistent. Check the strain gage resistance and verify that it is correct. Measure from solder-pad to solder-pad, or lead to lead. Check the resistance from the strain gage to ground. Measure from one solderpad/lead on the strain gage, to the metal test piece, to make sure that the resistance to ground is 100MΩ or higher. Replace the strain gage if any problem is found.

- *Wiring*

Remove oxidation from the bondable terminal pads. An eraser on the back of a pencil can be used to gently rub the terminal pad, making the copper tabs shinny. Tin the bondable terminal pads using rosin core solder and a small soldering pencil. If you have ribbon leads, bring the lead over to the bondable terminal pad leaving a small flex loop. Solder down onto the bondable terminal pad. Trim the end of the ribbon lead to length if required. With solder pads or tabs, you will need to make up a small jumper wire. For example, you can use the TFCP-010-50 spool of cable, and cut a small length, strip the PTFE coating from each end, tin the ends of the jumper wire. Solder one end of the jumper wire onto the strain gage solder tab, again, leave a flex loop, and bring the other end of the jumper onto the bondable terminal pad, solder it in place. Next, you will attach your insulated instrumentation wire. For example, you can use the TX4-100, which is colour coded, 4-conductor, PVC coated, shielded cable. This can be used for short 2-wire runs, 3-wire bridge (compensates for effect of temperature on the lead wire), 1⁄2 bridge, or 4-wire full Wheatstone bridge. Solder the instrumentation onto the bondable terminal pad. Again, check the strain gage resistance, now at the end of the instrumentation lead wire, and verify correct. Check the resistance from the strain gage to ground.

- *Complete the Strain Gage Installation*

Clean the area using Rosin Solvent. Allow the area to dry, and then apply protective coating.

- *Safety Precautions*

Personnel who are working with solvents, metal conditioners, neutralizers, adhesives, epoxy and cements should receive proper instruction from their company prior to handling of these materials. The strain gage installation area should be well ventilated. Personnel should avoid prolonged contact of these materials with the skin. MSDS sheets are available at omegadyne.com