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Rear Suspension Redesign For Wheelchair Accessible Vehicles

A Knowledge Transfer Partnership Approach

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Abstract—**This paper describes how by working with local university under a UK Knowledge Transfer Partnership (KTP) grant a low cost strategy for the redesign of rear suspension systems has been determined. This strategy includes software to design and analyse vehicle performance, modern metrology methods and innovative low cost techniques to experimentally assess vehicle dynamics.**

The wheelchair accessible vehicle (WAV) industry is relatively young and as a result the development of technical advancements has recently gathered pace. Competition in the marketplace is high and as most companies in this sector are small to medium enterprises (SMEs) any advantage, whether through a new product or component, has the potential to make a big impact on their success and their position in the marketplace.

To date, most vehicles that are converted for wheelchair access are of the multipurpose vehicle (MPV) type and as such are often quite large. It is recognised that a smaller WAV would be welcomed as an alternative option by customers. A typical WAV conversion involves replacing the centre rear floor section with a lower, dropped floor but as multilink rear suspension systems become increasingly popular, lowering the floor without modifying the suspension becomes problematic. The suspension systems often occupy the space envelope required by the lowered floor and so the suspension needs to be redesigned with smaller packaging requirements whilst matching the kinematic and dynamic performance of the original suspension system.

Keywords; vehicle; suspension; metrology; dynamics; knowledge transfer

I. Introduction

The wheelchair accessible vehicle (WAV) market has become increasingly competitive with currently over 25 vehicle converters trading in the United Kingdom (UK) on the Mobility Scheme. The Scheme enables disabled people to lease a vehicle, powered wheelchair or scooter simply by using their government funded mobility allowances. Customers exchange their allowance for a mobility package including [1]:

- Vehicle, powered wheelchair or scooter.
- Insurance.
- Servicing.
- Tyres.
- Breakdown cover.
- Adaptations and wheelchair accessible vehicles are also available.

Conversion companies have been actively promoting improved mobility for wheelchair occupants for over 40 years and investing heavily in design and development to ensure functionality, usability and safety standards are of the highest levels [2].

WAVs are typically fitted with either a ramp or a lift granting wheelchair access from the rear or side of the vehicle. Electric winches can be used to aid with entering the vehicle and many WAVs have a lowered floor to give greater head room and reduce the angle and length of the required ramp easing access. However, this can mean that ground clearance is reduced. A lowered floor also usually means that the fuel tank needs to be replaced, often reducing its size or changing its shape. This can result in WAVs having a reduced range. Some WAVs have lowering rear suspension again to reduce the angle of a ramp and allow easier access [1].

Traditionally vehicles considered suitable for converting for wheelchair access have been large to medium sized vans. As choice of vehicle and the number of converters grow within the industry there is increasing demand for smaller multipurpose vehicle (MPV) type WAVs to be designed. The technical development of this type of vehicle is more challenging due to suspension packaging constraints and the need in maintaining a suitably sized entrance.

II. Knowledge Transfer Partnerships

Knowledge Transfer Partnership (KTP) is a UK wide programme helping businesses to improve their competitiveness and productivity through the better use of knowledge, technology and skills that reside within the UK knowledge base. A KTP achieves this through the forming of a partnership between a business and an academic institution (such as a university, further education college or research and technology organisation), enabling access to embedded skills, resources and expertise to help businesses develop. The knowledge sought is embedded into the business from the knowledge base through a project, or projects, undertaken by a recently qualified person (known as the associate) recruited to specifically work on that project.

A KTP serves to meet a core strategic need and to identify innovative solutions to help businesses prosper and grow. KTPs often deliver significant increased profitability for business partners as a direct result of the partnership through improved quality and operations, increased sales and access to new markets.

There are three principal parties within a partnership:

- Company partner.
- Knowledge base partner (university).
- KTP associate (graduate with at least a 2.1 honours degree).

The rationale for KTPs is that effective innovation often involves knowledge, technology, skills and adaptability to implement it, which is not always embodied in equipment or in an easily transferable form. People embody the skills and often the real knowledge to cause innovative change in businesses. Knowledge developed or improved in academic institutions (knowledge bases) may need extensive or intensive adaptation to particular business applications. An appropriately qualified graduate with a direct link to the academic source is the ideal agent to carry out the knowledge transfer [3].

The outcome of KTP is:

- There are over 1000 partnerships running at any one time and over 1100 associate projects.
- For every £1m of government spend the average benefits to the company amount to a £4.25m annual increase in profit before tax, £3.25m investment in plant and machinery with 112 new jobs created and 214 company staff trained as a direct result of the project.
- For the knowledge base partner (higher education institutions mainly) each KTP associate project produces 3.6 new research projects and 2 research papers.
- For the associate 60% are offered and accept a post in their host company on completion of their KTP project, 41% register for a higher degree and 67% of these are awarded a higher degree [3].

III. A KTP Case Study: Lewis Reed

Lewis Reed is classed as a SME (small and medium enterprise) in Wirral, England and has developed a number of practical engineering methods to convert commercial passenger van type vehicles for wheelchair occupants. The design department comprises one graduate mechanical engineer, one HND (sub degree) educated mechanical engineer and an internally trained engineer with several years practical experience. The department has some specific automotive experience but little knowledge of automotive suspension theory and design.

To successfully compete in the WAV conversion market the company implemented the solid modelling package SolidWorks [4] to control its design and manufacturing functions which has improved the quality and efficiency of the conversion process. For the SolidWorks methodology to be successfully exploited, efficient reverse engineering methods are needed to extract key geometric data from the original vehicle, from which the conversion design and manufacturing drawings can be created. Prior to the KTP reverse engineering was recognised as a manufacturing bottle neck and the company required faster, accurate measuring methods to create a better solid model. In addition, to penetrate new markets the company required advanced engineering knowledge to convert smaller MPVs for wheelchair use. Converting these types of vehicles dictates an investigation into the functional performance of the original rear suspension to be undertaken. Using this knowledge will enable the kinematic design of a bespoke replacement suspension to determine if sufficient working space is available to convert the vehicle for wheelchair occupants.

The goal of the KTP is to couple advanced engineering theory and design with strategic commercial decision making. Technical challenges arise in understanding and applying theoretical knowledge of suspension theory [5], mechanism theory [6] and multi body vehicle dynamics [7] to ensure that the converted vehicle provides good ride and handling characteristics for the wheelchair occupant. Commercial decision making is needed to temper advanced engineering solutions with market pragmatism.

A. *Practical Requirements of a Wheelchair Accessible Vehicle*

Given the wide range of WAVs available on the market, the level of choice consumers now have is such that the properties of the original base vehicle are more important than ever. Factors such as price, brand, perceived reliability and quality, colour, size etc. are every bit as important in the WAV industry as in the unconverted vehicle market.

From a functional viewpoint a WAV must facilitate the safe, secure transport of wheelchairs and their occupants. This is arguably the most important aspect of converting vehicles. Companies wishing to supply WAVs through Motability have to meet rigorous standards for each of their conversions in order to be accredited [1]. Automotive EC Directives and ECE Regulations require third party approval testing, certification and production conformity assessment by an independent body before WAVs may be sold [8]. In Fig. 1 a converted vehicle is shown being subjected to a pull test to simulate its behaviour in a crash.

The vehicle must be accessible to wheelchairs and their occupants. This is usually catered for by the implementation of either a hydraulic lift or a pivoting ramp. In Fig. 2 both the ramp and the internal dropped floor can be seen.

Figure 1. Vehicle subjected to a pull test.

Figure 2. Vehicle with a pivoting ramp for wheelchair access.

Fuel consumption is also an area that requires consideration as many vehicles require the original fuel tank to be replaced with a bespoke tank designed to accommodate the dropped floor and provide a practical range for the vehicle.

As with any vehicle, ride and comfort are important considerations and this can be especially true for wheelchair occupants in WAVs with dropped floors. By altering the floor structure and chassis the rigidity and handling characteristics of the vehicle change. The weight distribution of the vehicle is also likely to be altered by the conversion, this too affects the handling and perceived ride quality of the vehicle.

The Lewis Reed WAV design process for some vehicles consists of two stages; stage one concerns itself with the wheelchair occupants' entry and security whilst stage two focuses upon suspension redesign. For example without considering the replacement of the rear suspension, creating the design space to accommodate the new dropped floor can become very expensive. In Fig. 3 it can be seen how the pivot points of multilink rear suspensions invade the design space whilst in Fig. 4 it can be seen how the replacement suspension system is outside the design space. Redesigning rear suspensions allows the conversion of smaller MPV type vehicles.

To date it has been impossible to obtain vehicle data from vehicle manufacturers and so reverse engineering metrology becomes necessary. For suspension system redesign it is vital to obtain accurate measurements of the original suspension's pivot points as the location of these describe the kinematic behaviour of the system. Using this data, the original system can be modelled and knowledge of its kinematic behaviour in terms of toe/camber change with bump, anti squat etc. [9] can be described after which a replacement system to satisfy the original characteristics can be investigated.

Figure 3. Vehicle with original suspension.

Figure 4. Vehicle with replacement suspension fitted.

B. *Pre KTP Suspension Redesign Process*

Prior to the KTP the company had developed strategies for WAV design but these were heuristic, time consuming and relatively expensive requiring a number of iterations to reach a solution. In particular, the creation of the solid models relating to the design space needed for the conversion was a protracted and error strewn process. Also vehicles that had suspension geometries which encroached upon the design space required for the dropped floor were generally deemed as being outside the company's design capability due to a combination of crude measurement methods and a lack of theoretical knowledge of suspension system design. A block diagram illustrating this process is shown in Fig. 5 and it is noticeable how many iterative loops are required to reach a solution.

C. *The KTP Suspension Redesign Process*

Through the KTP a number of practical and theoretical tools have been developed and embedded into the company's design process. A digital measuring arm has been used to accurately measure vehicles' interiors, rear bumpers and rear hatch geometry from which accurate solid models of the design space can be created. Accurate models allow correct production drawings and this has completely eliminated the iterative requirements as seen in Fig. 5 and this has significantly reduced the conversion lead time and conversion costs. The block diagram for the updated design process is shown in Fig. 6.

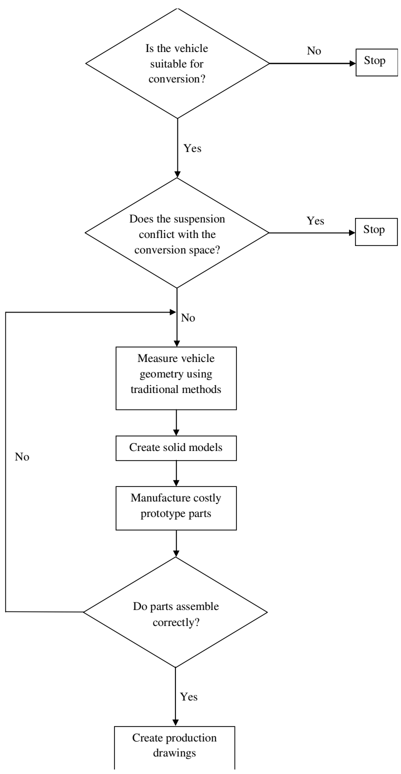

Figure 5. Pre Knowledge Transfer Partnership design process.

The digital measuring arm was also used to measure the original suspension geometry which was then virtually recreated in the software packages SusProg3D [10], Lotus SHARK [11] and SolidWorks [4]. Thus it has become possible to compare the original vehicle's suspension performance with bespoke alternatives.

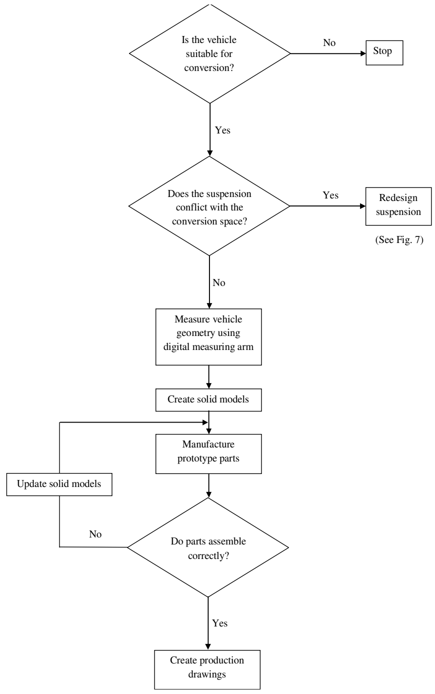

Figure 6. Post Knowledge Transfer Partnership design process.

Complementary theoretical models of quarter and half vehicle suspensions have also been developed using the open source package ScicosLab [12] allowing the designers to investigate the effect of different spring rates and damper characteristics to tune the replacement suspension to match the characteristics of the original. In Fig. 7 the block diagram of the suspension redesign process is presented.

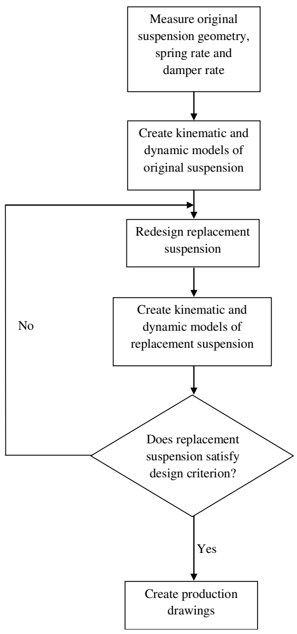

Figure 7. Suspension redesign process.

Another outcome from the KTP is the provision of a low cost solution to undertake measurements of pre and post conversion vehicle dynamics using the Nintendo® Wii™ controller. This controller cost £30 and using the open source software package g-force Analyzer [13] and a Bluetooth™ connection to a laptop computer has enabled the measurement of roll, pitch and vertical vibration. This approach costs significantly less than traditional methods of acquiring wireless motion data. In Fig. 8 a sample of the vehicle's dynamic signature is presented for both pre and post conversion.

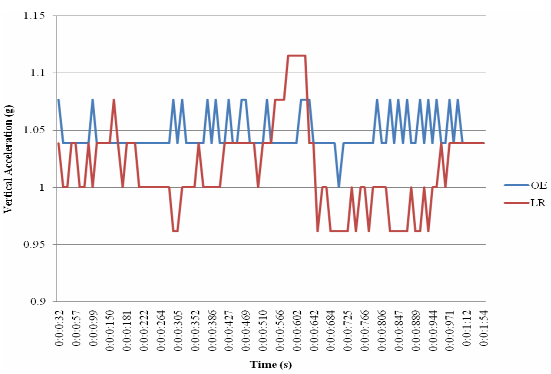

Figure 8. Vehicle motion data sample.

IV. Discussion

Using both the developed practical and theoretical knowledge and skills it is now possible to predict the cost of a vehicle conversion. This means that prior to parts being ordered or vehicles being modified, the cost of various vehicle conversions can be assessed and compared in order to determine the best return on investment.

The techniques developed during the KTP have led to significant reductions in the time it takes to design and manufacture a WAV conversion. The creation of an accurate solid model has reduced design time by up to eight weeks for Lewis Reed and virtually eliminated the need to manufacture a number of prototype components. This equates to a time reduction of around 30%.

Prior to the KTP the company could only undertake conversions of vehicles if the conversion space did not interfere with the vehicle's rear suspension geometry. This meant that a large number of smaller MPV type vehicles which customers would like to be converted were outside the remit of the company. This constraint has now been overcome.

Via the KTP metrology methods, theoretical knowledge and software tools are now embedded within the design team and these have enabled the rapid kinematic modelling of the original suspension characteristics and the subsequent redesign of a replacement system that satisfies predetermined goals.

A major difficulty that confronts all SMEs is the cost of buying and supporting software tools. An objective of this KTP is to leave the company with low cost software and ideally open source software. For example, when devising dynamic simulations the open source package ScicosLab was adopted instead of MATLAB® Simmulink®. When investigating suspension kinematics the low cost Australian package SusProg3D ($150 AUS) was used. This package does not have the full functionality of Lotus SHARK but since Lotus SHARK has a £12k per annum license fee it is financially prohibitive for a SME. Suspension kinematics and dynamics have also been investigated using SolidWorks. Caution is urged when using SolidWorks to create detailed dynamic simulations because it has been found to be a protracted and very time consuming exercise.

A key driver for any KTP is to change the culture in the company to recognise and understand that academic knowledge has practical merit within a business enterprise and that knowledge bases are host to a wealth of resources that can be exploited. Within this KTP this is still ongoing but a change has been seen in the company and individual's attitudes towards improving product performance via academic knowledge bases.

One of the most important legacies of a KTP is the quality and quantity of training materials that are developed for staff to use. In this KTP online staff tutorials have been developed and evaluated for, vehicle & suspension geometry measuring, wheel arch measuring with a digital measuring arm and motion measuring with a Wii™ remote.

V. Conclusion

In the UK there is clear evidence to demonstrate the usefulness and effectiveness of KTPs particularly in the SME sector. At Lewis Reed the KTP objectives of aligning academic expertise with commercial routines has been realised in this program of work. Academic techniques have been embedded into the company with up to 30% time improvements in the design cycle.

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