1. INTRODUCTION

I am author, or co-author, of over 100 publications, and from these, I have selected 52 for this submission. Of these, 45 are on research and seven are review or survey papers. These describe aspects to the characterisation of structural composite materials, with 37 of the 52 publications motivated by providing knowledge and understanding for the reliable and safe design of primary load-bearing structures of Pultruded Fibre Reinforced Polymer (PFRP) shapes and systems. Many of the aspects in the 37 publications are covered for the first time, and in Section 2 a commentary is provided to demonstrate my major contribution to this new structural engineering subject. This substantial body of publications represents my principal work, since joining Warwick University in October 1987. In common with my other academic work, the research methodology is a synergy of full-sized physical testing and theoretical modelling.

Pultrusion is a fully automated continuous process for the economic production of advanced glass fibre reinforced polymer shapes. These shapes are used in structural engineering applications, usually when conventional construction materials are not the preferred option for sound technical reasons. Standard PFRP shapes mimic those sections we find in steel construction, while PFRP systems are formed by connecting standard or non-standard shapes together, and are therefore specific to the pultrusion process. Eleven of the 37 publications on PFRP research are papers given at international conferences, none of which overlap with the material in the submitted journal or book chapters. These eleven papers had been peer reviewed before acceptance in the conference proceedings.

The other 15 submitted papers are on topics that demonstrate my wide range of important contributions to the characterisation of structural composite materials and their structures. Four journal papers concern research, from my PhD studies at Durham University, to the theoretical analysis of laminated FRP plate problems where the influences of shear deformation and plate curvature twisting can be relevant. The next six submissions follow my work on a MOD funded project to measure, and have simple theoretical models for, the thermal conductivity and thermal expansion of phenolic FRPs used as ablative materials. My contribution to the development of modelling methodologies for advanced computational simulations using commercial finite element software is presented in four journal papers. The final submission is a key journal paper to the characterisation of compression properties of syntactic foams (a composite mixture comprising a polymer and hollow glass spheres).

None of material contained in this submission has been submitted for a higher degree in this or any other University.

2. RESEARCH PUBLICATIONS WITH PULTRUDED FIBRE REINFORCED POLYMER SHAPES AND SYSTEMS

In what follows there is a description of the impact that results from the 37 publications on PFRP structures' research are making, for us to have knowledge and understanding, of sufficient depth and breadth, to prepare a code of practice for new build PFRP structures. A majority of the research contributes to the characterisation of standard shapes used in framed structures and these 36 publications have been sub-divided into four topics, and are listed by year of publication. When, in 1988, the author commenced his work to characterise PFRP shapes there was no established University research on this subject. Of the 1400 printed publications listed in '*Literature Database on R&D with Pultruded Fibre Reinforced Plastics*', less than 60 where in print in 1991 when the author first published his work [8, 9]. The author maintains this database, and it is made freely available to the community at http://www.eng.warwick.ac.uk/staff/jtm/pfrp_latest.pdf. To place in context the author's considerable research contribution to this young subject, I have authored or co-authored 57 entries (excluding theses to students I supervised) in the database of 31st January 2007.

Commencing at the beginning of 2007 is a project, jointly managed by the American Society of Civil Engineers (ASCE) and the American Composite Manufacturers Association (ACMA), with the objective of preparing a

"*Standard for Load Resistance Factor Design (LRFD) of Pultruded Fiber-Reinforced Polymer (FRP) Structures*". In making the decision that now is the time to prepare this standard, the ASCE/ACMA project managers will have recognised that, with other prominent publishers, my research output provides a significant source of knowledge and understanding on which to build. This brand new standard is to have eight chapters, with their drafting led by an American academic. Because of my experience and expertise on PFRP structural behaviour I was invited by Professor Larry C. Bank of the University of Wisconsin-Madison to join a team of four to write the chapters on *Bending and Shear* (for beams members) and *Joints and Connections*. In presenting the 37 publications on PFRP research I have grouped them into four topics that are covered in such a standard or code of practice.

2.1 Papers on Materials and Design Philosophy [1 to 7]

To be able to calibrate design formulae in the design process for members, joints and connections, and overall frame stability, it is essential we have reliable and relevant statistical data for material properties. The first four papers [1 to 4] deal with this requirement for a standard's preparation. Papers [1] and [2] use measured compression strength data to compare various statistical distributions that are used in aerospace and civil engineering. For FRP materials the American aerospace industry uses a Weibull distribution (MIL-17 handbook), while for steel, and other traditional construction materials, the structural Eurocode suite uses the lognormal distribution (BS EN 1990-1-1:2002). Of merit from [1] and [2] is that they show that, because the coefficient of variation for compression strength variation is < 10%, it does matter which of these statistical distributions is chosen.

Because PFRP shapes are thin-walled structures a shear modulus for the orthotropic material is required to determine the deflection of members [see 8,9 and 12] and the elastic critical buckling load for instability modes of failure [see 8, 14, 16, 17, 34 and 36]. In [3] the author critically reviews publications by academics and pultruders that report shear modulus measurements. On combining the survey data with moduli predictions (3.5 to 4.5 GPa), using the micromechanical modelling approach, the author shows that the initial in-plane shear modulus can have a significant variation (3 to 5 GPa) and that the pultruders' recommended design value of 3 GPa is conservative for the purpose of code calibration. Given that an unknown part of the significant variation in shear modulus data is because different test methods are used this paper also highlights to the community the urgent requirement of developing recognised standard test methods for PFRP materials.

Paper [4] is a preliminary contribution to lifetime predictions for the residual strength of PFRP materials following hot-water accelerated ageing, which causes strength reduction with time. Its novelty is the presentation to PFRP durability researchers of the potential to use an established simple model that has its roots in the glass reinforced concrete industry.

Despite the importance of PFRP material characterisation, especially where durability is an issue, it is to be observed that this topic has been neglected because such work is not considered to have sufficient academic merit to attract external funding.

Three papers [5 to 7] show the author's ability to effectively communicate to a wider audience beyond the academic research community. Papers [5] and [6] relate to the analysis and design of PFRP connections, and they are aimed at informing non-specialist (practitioners, etc.) what is required to have universally recognised design procedures. Education of young professional civil engineers is relevant to the uptake of FRP shapes and systems in construction. Publication [6] presents an international survey in 2002 on the status of courses on FRP composites for construction throughout the world. The author is responsible for the input in this survey showing European Universities to be more advanced in incorporating a special course on FRPs for Construction.

2.2 Papers on Member Characterisation [8 to 18]

Aspects on the behaviour of thin-walled PFRP members in bending are dealt with in papers [8, 9 to 12] and [18]. Contributions in all six papers are the first on the main theme they cover. Of particular merit from this group of papers is:

- the potential, from [8], that standard I-beams might have a resistance in bending that is governed by an instability mode of failure that is not known previously, and has therefore not been characterised.
- the exposure in [9] that, from a series of physical tests on hollow box sections, published equations for calculating the resistance of PFRP box beams from section properties are not always going to be valid and that, at short spans, a local crushing failure mode cannot be designed for.
- the recognition from [10] and [11] that, for I-sections, the influence of end boundary conditions and the height of the loading on the elastic critical load for lateral-torsional buckling of unrestrained PFRP beams will have to be included in the design process. Paper [11] further shows that the critical load may be calculated on modifying a Eurocode generated formula for doubly-symmetrical steel I-sections in bending. This finding is supported by the close agreement between the physical test data in [11] and the specific finite difference solution in [10], which may be used to observe the sensitivity of the laterial-torsional buckling resistance to changes in problem variables. Such knowledge and understanding is essential to the preparation of the ASCE/ACMA standard because of the need to account for the significant reduction of resistance of laterally unrestrained beams when load is destablising and end connections are nominally pinned.
- the importance, from [12], that creep deformation (due to the viscolelasticity of PFRP materials) shall have on limiting the permanent load that a beam can be subjected to over its working life. Paper [12] also provides evidence to code writers to adopt the Findley's creep model in the development of a design procedure for the determination of beam deflection under long-term permanent loading.
- that, from [18], the Uni-strut blind-fixing method of connection cannot provide adequate shear stiffness or shear strength for a novel modular PFRP box beam system to have section properties higher than existing PFRP I- or H-shaped sections used as beam members.

The behaviour of PFRP columns to concentric loading, and the realisation of the importance to resistance of the imperfection sensitive modal coupling between the global “Euler” and local flange buckling modes, was first studied by researchers in America. A possible lack of rigour in this American work and the need for test data when loading includes the moment gradients that can be present in practice are reasons for the sub-group of four papers [13 to 17]. This research had EPSRC funding. By way of a comprehensive series of quality controlled physical tests with practical H-shaped columns, we show in [13] and [14] that the American “so-called” concentric load test data for minor-axis flexural buckling had been significantly influenced by a load eccentricity that is not quantified. This had had the consequence of making the column member's geometric out-of-straightness imperfection appear to be higher than it was, had the Americans bothered to measured this important geometric imperfection. Our new contribution to concentric column behaviour is to confirm that modal coupling occurs; its affect on reducing the flexural buckling load is shown to be much less than reported by others (even when the length of the compressed column is that for simultaneous failure in the local and global modes). The two papers [13] and [14] present a rigorous set of data that can be used to code calibrate formulae for the resistance of concentrically loaded PFRP columns.

In [15] we present the only programme of physical tests to subject PFRP columns to various moment gradient conditions, with bending about the major axis. The results of this novel research show that conventional isotropic member expressions for the deformation of beam-columns can be used to characterise the response of PFRP beam-column members. These expressions may be used in a design procedure for external columns in the preparation of the ASCE/ACMA standard.

Because PFRP materials have relatively higher strength-to-stiffness ratios and do not possess a plastic response on yielding, the highest resistance of I- and H-shaped concentrically loaded columns is given by failure through elastic local flange buckling. To develop flexural buckling curves for the design process of column members, it will be necessary to calculate this upper limit on resistance (can be seen to be equivalent to the yield (crushing) strength if the column is of steel). Having recognised this need the author in 2002 conducted a critical assessment of nine closed-formed formulae that might be used to calculate the elastic critical stress for local flange buckling. In the review the author compared the predictive performance of the formulae against experimental data, which is critically assessed in the paper for its relevance and reliability. The findings to this major contribution to standard preparation are presented in [16]. In deciding which is the best formula there is the problem of knowing the shear modulus [see 3] and the requirement by code writers to have a formula that does no require any parameters from in-house software. Based on careful consideration the author recommended a specific closed-form formula that is the orthotropic material version of the isotropic local buckling strength expression used for the classification of standard steel sections.

Following acceptance by the journal to publish [16], the author discovered a tenth formula from the theoretical modelling work by Professor Laszlo P. Kollar. The advantage of this tenth formula is that it takes account of the beneficial increase in buckling strength from the presence of a finite rotational stiffness along the web/flange junction. In discussion paper [17] I show that Kollar's formula has the potential to be adopted in the preparation of PFRP buckling curves for member design. It is noteworthy that, because of my critical assessment of the performance of the ten formulae in [16] and [17], Professor Larry Bank was given the confidence to include the resistance formulae, from the theoretical modelling work of Professor Kollar, in his textbook '*Composites for Construction – Structural Design with FRP Materials*,' Wiley & Sons, New Jersey 2006. I am acknowledged by Professor Bank for my advice and support to the preparation of Chapters 12 to 15 on PFRP profiles (what I term shapes); 14 of the 37 publications in this submission are references in this premier textbook on FRP composites in civil and structural engineering.

2.3 Papers on the Characterisation of Joints and Connections [19 to 31]

The commentary to this group of thirteen papers is sub-divided into three sub-groups. The first sub-group [22,23, 27 to 30] is for joints, which we shall define as the joining together of two or more flat panels of PFRP material. Such lap-joints are loaded in their plane and the method of connection can be by bolting [23, 27 to 30] or/and by adhesive bonding [22]. Bolting is by steel bolts with a smooth shank bearing against the PFRP connecting components. In a similar way to the style of writing in [5] and [7], the contents in [22] and [23] educate professional structural engineers who are not familiar with FRP technologies. This is an important educational process to develop confidence within the construction industry for PFRP shapes and systems to be used in primary load-bearing structural applications.

Of particular merit from this sub-group of papers on joints is:

- that, in [22] and [23], the author shows that we cannot directly transfer know-how from aerospace R&D, because in construction applications the FRP joint configurations and detailing, and material properties and material thicknesses are very different.
- that, from [27 to 30], the resistance of PFRP bolted joints is dependent on many variables and that, given the complex interaction of these variables in establishing joint strength, much more information is going to be required to prepare design guidance that will be universal in its application.
- that, from [28], there are bolted joint configurations which ensure that the mode of failure is not damage tolerant, and so design guidance shall have to consider "brittle" behaviour when determining the resistance for a range of practical joint configurations.
- that, from [28], the scope of test data on the resistance of bolted joints for PFRPs has gaps in it, such as it is limited to flat sheet material, and that much of the data is not consistent with on-site detailing (e.g. there is a clearance hole in practice).
- that, from [28], the variability in strengths of bolted lap-joints is sensitive to the specific glass fibre reinforcement arrangement in terms of the location in the PFRP cross-section of the unidirectional roving bundles and mats.

- that, from [28], there are distinct modes of failure not found elsewhere and so new design formulae are required.
- that, from [28], the increase in resistance is marginal (no > 20%) when there is more than one row of bolts (with steel components it is taken that the joint resistance is proportional number of bolts, providing the net area is adequate).
- that, from [29], the resistance of a bolted joint, as determined from a short-term static test, is higher than it can be, should the load remain permanent, say at 90% of the static value, for a period of time. This loss in joint resistance is due to the viscoelastic response of PFRP materials [see 12].
- that, from [29] and [30], the frictional force between mating PFRP surfaces cannot be relied upon to transmit all the design load when the steel bolting is tightened to a relatively high torque. This is despite the coefficient of friction for PFRP on PFRP being shown by the author in these papers to be similar to that for steel on steel. The author shows in Paper [30] that, following application of the “highest” practical bolt torque, the viscoelasticity of the PFRP material allows the through-thickness compression force to relax with time. Within a few weeks of assembling the bolted joint it is shown that the frictional force the joint can resist is going to be less than the design load when failure is governed by the bearing strength.
- that, from [27], the determination of the local stress field in the PFRP material from bolt bearing (for joints when the bolt torque is taken to be zero), might not be feasible by using commercial finite element software. One reason for this preliminary finding is the paucity in benchmarking examples to determine the numerical accuracy of the contact algorithm in the ABAQUS® code that we used to simulate reality (see also papers [48 to 51]).

Many of these findings are not reported by other researchers and constitute a major contribution to our understanding. They are to play an

important role in the preparation of the design process for PFRP bolted joints in the ASCE/ACMA standard, mentioned at the beginning of Section 2.

The author wishes to express his gratitude to the results given in paper [28] from the research conducted at Lancaster University, under the leadership of Dr Geoff Turvey.

The second sub-group of papers [19 to 21, 23, 24 to 26] are on research to understand the behaviour of nominally pinned and moment-resistant connections that are, or might be, respectively, used in the execution of framed structures. The author’s contribution focuses on the form of connections that are used to transfer the internal forces from beams into columns. This form of connection is not found in the aerospace industry and so we cannot rely on technology transfer for knowledge and understanding. Current practice with PFRP shapes is to build frames to “simple” construction, which means that the frame is braced against sway and connections have details that make them nominally pinned (i.e., cannot transmit a significant moment). By way of a small test series, funded by the EUROCOMP:EUREKA project, the author in [20] shows that beam-to-column details in the pultruders’ design manuals give a “simple” connection, with adequate rotation capacity, providing adhesive bonding is not present. This contribution forced an American pultruder to amend its design manual to take account of the new design guidance in [20]. Papers [19] and [24] present additional test data on “simple” connections to provide further confidence in their on-site application.

Because PFRP shapes have a stiffness 1/10th of the equivalent steel section, loading on a frame of “simple” construction is governed by a limit on beam deflection (see also [8] and [9]). To increase the beam loading, without increasing the member’s depth, there is the option to use moment-resistant connections, making the frame semi-continuous. This approach to frame design is advocated in the new structural Eurocode for steel buildings (BS EN1993-1-1:2005), being the outcome of much steel structures research in the 1990s. By including torsional stiffness in the connection detailing (e.g. by adding flange cleats to the web cleats used in “simple” connection detailing), it is feasible to double the load for the same deflection limit, and to make the PFRP frame’s stiffness high enough for the bracing to be removed. Given that

PFRP shapes are more costly than traditional construction members, the potential benefits of semi-continuous frame construction led the author to research this topic, with the aim of seeing the deliverables transferred into practice. My work to characterise moment-resistant beam-to-column connections is covered in [19, 21, 24, to 26], and the main contributions from this sub-group of five papers are:

- that [19, 21, 25], when the PFRP connection detailing mimics that for bolted connections in steelwork, the failure of the PFRP cleats limits either the moment capacity or rotation capacity of the connection. When connection components are of FRP material it is found that there is a moment, below its ultimate value, when one or more of these FRP components loses stiffness by progressive delamination failure (this led to the author to propose the concept of “first failure” moment, which is a design property of the moment-resistant connection). On the one hand the research shows that the presence of this progressive failure provides these connections with a degree of deformability that gives the moment-rotation curve the required non-linear softening characteristics. On the other hand, however, the author observes that the presence of the delamination failure provides sites for material degradation by an aggressive environment, and so the connection does not possess structural integrity.
- that [25 and 26], detailing for semi-rigid connections could be developed providing the flange cleat components are not fabricated from standard pultruded leg-angle shapes. For the physical testing reported in [25] a novel FRP cleat component is made using compression moulding for a bolted detailing, and, in [26], we present a study using an adhesively bonded connection detailing, with no mechanical fastening, that we invented. Both “all” FRP moment-resistant connections are shown to have a moment-rotation curve with promising characteristics for semi-continuous frame design, but neither is practical for the reasons presented in the papers.

- that [25], steel flange cleats give connection detailing with moment-rotation characteristics that would be acceptable for semi-rigid action to be seriously considered in frame design.
- that [21, 25], it is essential that those involved in the search for a commercial and safe solution to practical moment-resistant connections for PFRP structures recognise the importance of achieving an acceptable balance between the connection properties of stiffness, first failure moment, ultimate moment and rotation capacity.

It is of interest to reflect that, over the last 10 years, little new progress on developing practical FRP connections, with suitable moment-rotation characteristics, has been made. For the ASCE/ACMA standard in preparation it has been decided by the project team that its scope shall be limited to the design of frames that are of “simple” construction, and that connection components may be of stainless steel. This very recent decision increases the significance of the author’s contribution in papers [19 to 21, 23, 24 to 26] to our understanding of how to design for safe and reliable joints and connections in PFRP frames.

For the third sub-group in Joint and Connections there is paper [31] on a non-conventional method of joining PFRP shapes to form structural systems. The contents of this paper relate to [18], and a modular box beam concept that has the possibility of allowing “smaller” open-sectioned shapes to be joined together to form a “larger” closed-sectioned beam, with section properties in access of what can achieved economically from a single pultrusion. To join together separate web and flange components to form a box we use mechanical fasteners known as Uni-strut connectors. In [31] we report how physical testing of this blind-fixing method is used to characterise four connection properties, for the off-the-shelve M10 sized connector, required in a partial-shear interaction theory to determine the stiffness in flexure of the modular beam (this aspect is covered in [18]). Papers [31] and [18] present results from a unique study for second-generation PFRP systems. It is noteworthy that the UK Company STARTLINK is currently developing a PFRP modular system for housing that uses our characterisation results because components in the system are joined by the Uni-strut method of connection.

2.4 Papers on Frame Analysis and Design [32 to 36]

To design a frame structure that will be fit for purpose it is necessary to know how it, and its sub-assemblies, will behave to loading. Furthermore, knowledge of the elastic critical buckling load for overall frame instability is a requirement to complete the design process. Aspects of frame analysis and design are dealt with in papers [32 to 36].

My early thoughts on the design of PFRP framed structures are to be found in [32], which is published in a Russian journal. Paper [33] reports a unique experimental study on beam-to-beam sub-assemblies that are found in PFRP walkways. Its principal contribution is to show that a simple theoretical model can be used to predict accurately the measured stiffness of such sub-assemblies, in which the relative length of members has an affect on the torsional stiffness of the web-cleated connections. This finding is relevant to practice where the design of a PFRP structure is governed by a serviceability limit state. Ultimate failure of the laterally unrestrained transverse beam was by lateral-torsional buckling and we show that the modified Eurocode 3 formula in [11] is able to provide an accurate prediction to beam resistance.

The sub-group of three papers [34 to 36] is for the development of a matrix-stiffness analysis that can determine the geometric non-linear deformation and the elastic critical buckling load of frames that have shear-flexible members and moment-resistant connections. The novelty of the author’s work lies in the ability of the theoretical modelling to include shear-flexibility, both in the beam-column members and, through involving shear-flexible stability functions, to allow for the second-order P-Δ effect required for frame instability to be analysed. Of significance to this theoretical work is to know which shear-flexible stability functions to use, and when they are to be used, and these issues are addressed in [35]. On observing that the shear-flexibility functions in previous publications had an incompatibility limitation, the author formulated the new functions presented in [35], which remove this modelling problem.

Numerical results are given in [34] to show that should PFRP frames, irrespective of the connection’s torsional stiffness, be executed with continuous beams, instead of continuous columns, the loading for a limited beam deflection will increase, thereby giving a more economical frame design under serviceability loading. Novel numerical results in [36] for the elastic critical buckling load of simple portal frames with inclined rafters give a major new finding. It is shown in this paper that, for a reduction in buckling load to occur with an increase in member shear-flexibility, the modelling must use the new shear-flexible stability functions, given first in [35]. Modelling the same frame problems with the conventional shear-flexibility functions is shown to give a higher bucking load on increasing member shear-flexibility; this is contrary to the physics of the structural problem. A review of papers on shear-flexible frame analysis has not overturned the possibility that the new functions by the author in [35] should be the analyst’s preference.

The new contributions given in the five **Frame Analysis and Design** papers will be required in the preparation of the ASCE/ACMA standard. For example, numerical analysis will be sought to establish that non-sway frames possess an overall elastic buckling resistance of sufficient magnitude for this form of structural failure to be removed from the design process.

2.5 Paper on PFRP and concrete [37]

In [37] we report a preliminary study for beam or slabs using a non-standard PFRP shape to provide concrete with combined tension reinforcement and permanent formwork. The concrete is cast on a layer of epoxy mortar that, on curing, gives an adhesive bond for compatibility between the two materials. Previous research with external FRP reinforcement and permanent formwork had tried to optimise such a hybrid system by ensuring that the concrete layer is all in compression. This approach maximises the longitudinal shear, and so there are difficulties in ensuring that the bondline between concrete and PFRP is robust enough. To reduce the maximum longitudinal shear force to be resisted, we decided in the study to; increase the surface area between concrete and PFRP, have mechanical interlocking between the two materials and to have an increased concrete depth. Through a combination of physical testing and computational modelling (using the well-known Geymayer approach for concrete) we show that the longitudinal shear forces can be resisted without the addition of shear connectors, making our proposed hybrid system a practical option, say for floor units. Others have followed the concept proposed in [37] to develop further this form of FRP-concrete hybrid system for introduction into the marketplace.

3. OTHER RESEARCH PUBLICATIONS ON CHARACTERISATION OF COMPOSITE STRUCTURES

3.1 Papers on Analysis by Laminated Plate Theories [38 to 41]

This sub-group of four papers is a contribution made by way of my studies for a PhD at Durham University. The project involved a feasibility study for the aerospace industry on a proposed biaxial stress test method for mulit-layered laminated FRP plates, which are reinforced with carbon fibres. Papers [38] and [39] present a finite element analysis that I formulated, and to assess the geometric non-linear version there is a comparison with experimental measurements in [39]. To my knowledge there are but a handful of papers in which such computational analysis is assessed against reality. The work in [40] and [41] continued the PhD studies, and is focused on the performance of higher-order theories to predict the shear deformable response of general laminated plates [40] and strips [41]. Of particular merit in [41] is that I show that, contrary to previous writings, in three point bending flexure the omission of shear coupling has a more profound affect on the theoretical predictions than if the modelling assumes twisting curvature can be neglected.

3.2 Papers on Characterisation of Thermal Transport and Expansion Properties of Fibre Reinforced Polymers Materials [42-47]

An MOD funded project required the author, as a Research Assistant at UMIST, to characterise thermal properties of specific fibre reinforced phenolic polymer composites, used as ablative materials with a very high temperature capability (> 2000^{o}C). My work was to measure and theoretically model the

properties from room temperature to 400^{o}C. Five papers [42 to 47] are the deliverables from this project, and coming directly from the MOD work are [42] and [43] that present, respectively, the measurement of thermal diffusivity and thermal conductivity is predicted using closed-form formulae and constituent properties. A new experimental methodology is given in [42] using the flash laser method to measure diffusivity of the FRP materials from room temperature. In [43] experimental data from [42] is used to develop models of sufficient accuracy for their use in the design of components.

After joining the staff at Warwick University the author was invited in 1990, by co-author Dr Roy Taylor of UMIST, to write a chapter on *Thermal Transport Properties* [44] for the *International Encyclopaedia of Composites*, published by VCH publishers. To restrict scope, the chapter deals with composite materials comprising of two-phase systems, where the dispersed phase is either particulates (e.g. spheres) or continuous rods (i.e. representing the aligned fibres in a unidirectional composite). A survey is made of closed-formed micromechanical formulae for the determination of thermal transport properties and, for the first time, the author rearranged, where possible, the published expressions using a common form and notation. This process showed that, on occasions, what seemed to be very different formulae are in fact identical. Because of its important in the modelling process the review focuses on the determination of conductivity in the transverse direction to aligned rods (or continuous fibres). Another major contribution in this article is a numerical comparison between formulae that are for upper and lower bound solutions to first- and higher- (to fourth) order modelling approximations.

Following publication of this encyclopaedia chapter, the UK editor of the journal *Materials and Design* invited the author to present in [46] and [47] his nomograms [44] that enable design engineers a quick way to look up the value of the thermal conductivity of a composite system, given knowledge of the constituent properties. A further contribution made by presenting these new nomograms is to show that, no matter how high or low is the thermal conductivity of the dispersed phase, the transverse conductivity of the two-phase composite material with an impenetrable disperse phase has an equivalent peak value.

Thermal expansion response of an ablative phenolic polymer and its composite materials was measured during the MOD project. Our new results could not be published because we could only speculate on why there was a very significant specimen variation, which disappeared on repeated thermal cycling. Dr Brian Geary, under the supervision of Dr Taylor and the author, conducted an additional series of thermal expansion measurements on pure phenolic specimens, whose locations within a single block of cast resin are known. Our new contributions in [48] are to show that thermal expansion of a thermoset can be highly dependent on the local curing conditions, that the bulk phenolic response may not be the same as the resin in the FRP material, and that, by post-curing at a temperature (say 250^{o}C) to drive off absorbents, a reliable measurement of the coefficient of thermal coefficient can be made.

3.3 Papers on Finite Element Modelling Methodology for Analysis of Complex Composite Structures [48 to 51]

For twenty years the author has taught students the fundamentals of Finite Element Analysis (FEA) to structural problems, and in 1996 co-authored a textbook (not submitted in this thesis), which has as many pages on how FEA is used in practice, as it does give to the theory on which the numerical methods are formulated.

Two research projects have given the author the opportunity to work on modelling methodologies for very taxing and complex engineering problems. For his PhD work, at EMPA in Switzerland, Andreas Winistörfer wanted to maximise the tensile capacity of a pin-loaded strap of carbon FRP material, where the individual layers of 0.125 mm thickness are able to slide over each other. To complement his comprehensive materials development programme we used the MARC finite element code to find out if a highly non-linear FEA could be used to obtain, for failure evaluation, the peak stresses where the strap and the two steel circular pins make contact. The negative findings of this unsuccessful FEA are given in [48]. It is noteworthy that one of the referee commented that the main "weakness" with this paper "is that all conclusions are negative". If, by publishing what we found, others have not used FEA when it cannot add value the contribution in [48] has had the impact we knew it would.

The second FEA project is given in [49 to 51], and is our deliverables from the multi-partner DTI/EPSRC project called STASIS, under the *Foresight Vehicle Link Programme*. Warwick University's input to this "smart" tyre project was to develop the modelling methodology using the LS-DYNA® explicit solver to compute the transient response of a rolling car tyre. Our industrial project partners required this advanced analysis to be done because they wanted to know the transient strains and displacements at locations within the tyre where embedded sensor technology could be located. A sound knowledge of finite element numerical techniques was required because we needed to verify that the numerical results are accurate in the region of the contact patch. This research is a team effort to which the author gave the engineering science support to the development and verification of the FEA carried out by Wayne Hall. Contributions of merit from these tyre research papers are:

- that, in [49], we offer a unique set of experimental stress profiles for a rolling "experimental" car tyre which, because the tyre's modelling details are known [50 and 51], can be used to verify future FEA. Benchmarking is important and the tyre research literature cannot provide information of the same scientific quality.
- that, in [49], we highlight the significant differences in "equivalent" rolling tyre stress measurements using a "slow" horizontal test rig and a "fast" rotating drum test rig. Following the closure, during the STASIS project life, of the last UK tyre research laboratory (where Dennehy and Hall did the STASIS project measurements), no new stress profile measurements can be made nationally.
- that, in [51], we present, in detail, the modelling methodology that, with the LS-DYNA solver, enables us to successfully simulate a rolling car tyre and wheel to obtain transient displacements, strains and stresses at the microscopic level. It is noteworthy that this is a very intensive

computing problem with over 2 billion nodal calculations, and that until the release of a version of LS-DYNA with double precision (for 64 bits) our runs crashed because of numerical instability before the required one revolution of wheel rotation is achieved.

- that, in [50], we report, for the first time, transient strains from within the wall of a car tyre and compare these with the numerical predictions for equivalent strains at the contact interface.
- that, in [50] and [51], we use the rolling test rig stress measurements from a tri-axial transducer to assess the performance of the numerical simulations. By way of this comparison we show that the finite element analysis always overestimated the contact patch size, and thereby underestimated the peak contact stresses. Given that a sensor's response is dependent on the transient stress distribution over the actual contact patch area this finding is significant to the possibility of developing a FE model that might give the required one-to-one relationship for the transfer function for "SMART" tyre development.

All the findings given above have not been reported elsewhere and they make a major contribution to the development of advanced tyre models for finite element simulations when the local response is required for vehicle design. Our research findings will have most impact on the engineering development by professional FE analysts because tyre manufacturers do most of the rolling tyre FEA work.

3.4 Paper on Characterisation of Syntactic Foams [52]

This single publication from an undergraduate project sponsored by Westland Helicopters has become a key paper to those researchers characterising the properties of composite materials known as syntactic foams. In [52] we show that there are processing factors to achieve a thorough mixing of glass hollow spheres and epoxy resin for the required uniform syntactic foam. Because of the manufacturing limitations reported the compressive strength characterisation of syntactic foams shows an upper strength limit that can be achieved.

4. LIST OF THE PUBLICATIONS SUBMITTED

Pultruded Fibre Reinforced Polymer Shapes and Systems

Materials and Design Philosophy (Education)

1. J. T. MOTTRAM, 'Compression strength of pultruded flat sheet material,' *Journal of Materials in Civil Engineering*, American Society of Civil Engineers, **6** 2, 1994, 185-200. ISSN 0899-1561

2. J. T. MOTTRAM, 'Compression strength of pultruded flat sheet material,' *Closure on Discussion*, *Journal of Materials in Civil Engineering*, American Society of Civil Engineers, **8** 1, 1996, 60-61. ISSN 0899-1561

3. J. T. MOTTRAM, 'Shear modulus of standard pultruded FRP material', *Journal of Composites for Construction,* American Society of Civil Engineers, **8** 2, 2004, 141-147. ISSN 1090-0268

4. (**Peer-Reviewed**) J. Beddows, P. Purnell and J. T. MOTTRAM, **'**Application of GRC accelerated ageing rationales to pultruded structural GRP', *in Proceedings 9th Internationals Conferences on Fibre Reinforced Composites (FRC 2002)*, Composite Design Consultants, 2002, 215-221**.** ISBN 0-9540459-2-0

5. J. T. MOTTRAM, 'Design guidance for joints using polymeric composite materials', *in Proceedings Internationals Conferences on Composite Construction - Conventional and Innovative*, Innsbruck, Sept. 16-18 1997, IABSE, Zurich, 1997, 313-318. ISBN 3-85748-092-4

6. A. Mirmiran, L. C. Bank, K. W. Neale, J. T. MOTTRAM, T. Ueda and J. F. Davalos, 'A World Survey of Civil Engineering Programs on FRP Composites for Construction', *Journal of Professional Issues in Engineering Education and Practice,* American Society of Civil Engineers, **129** 3, 2003, 155-160. ISSN 1052-3928

7. **(Peer-Reviewed)** J. T. MOTTRAM, 'Analysis and design of connections for FRP shapes and systems', *in Composites in Construction: A Reality*, *Proceedings of the International Workshop*, American Society of Civil Engineers, **Special Publication**, Reston, 2002, 250-257. ISBN 0-7844-0596-4

Member characterisation

8. (**Peer-Reviewed**) J. T. MOTTRAM, 'Structural properties of a pultruded E-glass fibre-reinforced polymeric I-beam,' *in Proceedings 6th International Conference on Composite Structures,* Elsevier Applied Science, 1991, 1-28. ISBN 1-85166-647-1 & ISSN 0263-8223

9. J. T. MOTTRAM, 'Evaluation of design analysis for pultruded fibre-reinforced box beams,' *The Structural Engineer*, **69** 11, 1991, 211-220. ISSN 0039-2553

10. J. T. MOTTRAM, 'Lateral-torsional buckling of thin-walled composite I-beams by the finite difference method,' *Composites Engineering*, **2** 2, 1992, 91-104. ISSN 0961-9526

11. J. T. MOTTRAM, 'Lateral-torsional buckling of a pultruded I-beam,' *Composites*, **23** 2, 1992, 81-92. ISSN 0010-4361

12. J. T. MOTTRAM, 'Short- and long-term structural properties of pultruded beam assemblies fabricated using adhesive bonding,' *Composite Structures*, **25** 1-4, 1993, 387-395. ISSN 0263-8223

13. A. Lane and J. T. MOTTRAM, 'The influence of modal coupling upon the buckling of concentrically pultruded fibre-reinforced plastic columns,' *Proceedings of the Institution of Mechanical Engineers Part L: Journal of Materials - Design and Applications*, **216** (L2), 2002, 133-144. ISSN 1464-4207

14. J. T. MOTTRAM, N. D. Brown, and D. Anderson, 'Physical testing for concentrically loaded columns of pultruded glass fibre reinforced plastic profile', *Proceedings of the Institution of Civil Engineers: Structures and Buildings Journal*, **156** 2, 2003, 205-219. Paper 12539 ISSN 0965-0911

15. J. T. MOTTRAM, N. D. Brown, and D. Anderson, 'Buckling characteristics of pultruded glass fibre reinforced plastic columns under moment gradient', *Thin-Walled Structures,* **41** 7, 2003, 619-638. ISSN 0263-8231

16. J. T. MOTTRAM, 'Determination of critical load for flange buckling in concentrically loaded pultruded columns,' *Composites Part B: Engineering,* **35** 1 2004, 35-47. ISSN 1359-8368

17. J. T. MOTTRAM, *Discussion on* ("Local buckling of fiber reinforced plastic composite structural members with open and closed cross sections," by L. P. Kollár, in *J. Structural Engineering*, American Society of Civil Engineering, November **129**, 11, 2003, 1503-1513.) **131** 5, 2005, 851-853. ISSN 0733-9445

18. **(Peer-Reviewed)** M. C. Evernden, and J. T. MOTTRAM, 'Theoretical and experimental analysis of a modular PFRP box beam concept constructed of separate plate elements and mechanical fasteners,' *in Proceedings of the 3rd International Conference on Advanced Polymer Composites for Structural Applications in Construction* (ACIC07), 1997, p. 10. (*to appear*)

Characterisation for Joints and Connections

19. A. J. Bass and J. T. MOTTRAM, 'Behaviour of connections in frames of fibre reinforced polymer section,' *The Structural Engineer*, **72** 17, 1994, 280-285. ISSN 0039-2553

20. (**Reviewed**) J. T. MOTTRAM, ‘Tests on nominally pinned connections for pultruded frames for the EUROCOMP project,’ *in Structural Design of Polymer Composites - EUROCOMP Design Code and Handbook*, *J.L. Clarke (Ed.)*, E. & F. N. Spon, London, (1996), p 703-718. ISBN 0-419-19450-9

21. J. T. MOTTRAM and Y. Zheng, ‘State-of-the-art review on the design of beam-to-column connections for pultruded frames,’ *Composite Structures*, **35** 4, 1996, 387-401. ISSN 0263-8223

22. J. T. MOTTRAM, ‘*Chapter 5: Bonded Connections’*, In State-of-the-art review on design, testing, analysis and application of polymeric composite connections,' J. T. MOTTRAM, and G. T. Turvey, (Eds.), European Commission, Office for Official Publications of the European Communities, Brussels & Luxembourg, 1998, pp. 56-70.

23. J. T. MOTTRAM, ‘*Chapter 8: Design Guidance*,’ In State-of-the-art review on design, testing, analysis and application of polymeric composite connections,' J. T. MOTTRAM, and G. T. Turvey, (Eds.), European Commission, Office for Official Publications of the European Communities, Brussels & Luxembourg, 1998 pp. 93-97.

24. J. T. MOTTRAM and Y. Zheng, ‘Further tests on beam-to-column connections for pultruded frames: Web-cleated,’ *Journal of Composites for Construction*, American Society of Civil Engineers*,* 3 1, 1999, 3-11. ISSN 1090-0268

25. J. T. MOTTRAM and Y. Zheng, ‘Further tests on beam-to-column connections for pultruded frames: Flange-cleated,’ *Journal of Composites for Construction*, American Society of Civil Engineers*,* **3** 3, 1999, 108-116. ISSN 1090-0268

26. (**Peer-Reviewed**) A. P. Smith, N. D. Brown and J. T. MOTTRAM, ‘Adhesively bonded beam-to-column connections for primary load bearing pultruded frames,’ *in Proceedings 1st Internationals Conferences on Composites in Construction – CCC2001*, A.A. Balkema Publishers, (Swets & Zeitlinger) Lisse, 2001, 159-164.
ISBN 90-2651-8587

27. (**Peer-Reviewed**) C. Lutz and J. T. MOTTRAM, ‘Pin-bearing behavior of notched pultruded plate’, *in Proceedings 3rd International Conference on Composites in Infrastructure (ICCI’02)*, Omnipress, Madison, 2002, Paper 045, p. 12. CD-ROM

28. (**Commissioned**) J. T. MOTTRAM and G. J. Turvey, ‘Physical test data for the appraisal of design procedures for bolted joints in Pultruded FRP structural shapes and systems,’ *Progress in Structural Engineering and Materials,* **5** 4, 2003, 195-222. Online ISSN: 1528-2716 Print ISSN: 1365-0556

29. **(Peer-Reviewed)** J. T. MOTTRAM, C. Lutz and G. C. Dunscombe, ‘Aspects on the behaviour of bolted joints for pultruded fibre reinforced polymer profiles,’ *in Proceedings 2nd International Conference on Advanced Polymer Composites for Structural Applications in Construction* (ACIC04), Woodhead Publishing Ltd., Cambridge, 2004, 384-391. ISBN 1 85573 736 1

30. J. T. MOTTRAM, 'Friction and load transfer in bolted joints of pultruded fibre reinforced polymer section,' *in Proceedings of the 2nd International Conference on FRP Composites in Civil Engineering*, Taylor & Francis plc, London, 2005, 845-850. ISBN 90 5809 638 6

31. **(Invited)** M. C. Evernden and J. T. MOTTRAM, 'Characterisation of Unistrut connection method with pultruded fiber reinforced polymer channels,’ Special Issue: Innovative Materials and Technologies for

Construction and Restoration, *Journal of Materials in Civil Engineering,* **18** 5, 2007, 700-709. ISSN 0899-1561

Frames Analysis and Design

32. J. T. MOTTRAM, ‘Recommendations for the optimum design of pultruded frameworks,’ *Mechanics of Composite Materials*, **29** 5, (1993), 675-682. ISSN 0191-5665

33. (**Peer-Reviewed**) J. T. MOTTRAM, D. Prangley and E. S. Knudsen, ‘Behaviour of pultruded FRP beam-to-beam sub-assemblies connected by bolted web cleats,’ *in Proceedings 1st International Conference on Innovative Materials and Technologies for Construction and Restoration (IMTCR04)*, Liguori Editore, Naples, 2004, Vol. 1, 633-645. ISBN 88 207 3678 0

34. (**Peer-reviewed**) J. T. MOTTRAM and Y. Zheng, 'Analysis of a pultruded frame with various connection properties,' *in Proc. Fiber Composites in Infrastructure, 2ndInternational Conference on Composites in Infrastructure*, University of Arizona, 1998, Vol. II, 261-274. ISBN 1-890743-02-X

35. J. T. MOTTRAM and M. Aberle, ‘When should shear-flexible stability functions be used in elastic structural analysis?*’ Proceedings of the Institution of Civil Engineers, Structures and Buildings Journal*, **152** 1, 2002, 31-41. ISSN 0965-0911

36. **(Peer-Reviewed)** J. T. MOTTRAM, 'Stability analysis of plane frames of fibre reinforced polymer having semi-rigid joints and shear-flexible members' *in Proceedings of the 3rd International Conference on Advanced Polymer Composites for Structural Applications in Construction* (ACIC07), 2007, p. 7. (*to appear*)

PFRP With concrete

37. J. E. Hall and J. T. MOTTRAM, ‘Fiber-reinforced plastic (FRP) concrete members having combined tensile reinforcement and permanent form-work: Short-term behavior,’ *Journal of Composites for Construction*, American Society of Civil Engineers, **2** 2, 1998, 78-86. ISSN 1090-0268

Other Research Publications on the Characterisation of Composite Structures

For analysis by laminated plate theories

38. J. T. MOTTRAM, and A. R. Selby, ’Bending of thin laminated plates,’ *Computers and Structures*, **25** 2, (1987), 271-280. ISSN 0045-7949

39. J. T. MOTTRAM, ‘A simple non-linear analysis of multi-layered rectangular plates,’ *Computers and Structures*, **26** 4, 1987, 597-608. ISSN 0045-7949

40. J. T. MOTTRAM, ‘High-order analysis of generally symmetrical laminated plates under transverse loading,’ *Composite Structures*, **12** 3, 1989, 211-237. ISSN 0263-8223

41. J. T. MOTTRAM, ‘Flexural testing of general multi-layered composites,*’ Journal of Composite Materials,* **25** 9, 1991, 1108-1126. ISSN 0021-9983

Characterisation of Thermal Transport and Expansion Properties of Fibre Reinforced Polymers Materials

42. J. T. MOTTRAM and R. Taylor, ‘Thermal conductivity of fibre-phenolic resin composites. Part I: Thermal diffusivity measurements,’ *Composites Science and Technology*, **29**, 1987, 189-210. ISSN 0266-3538

43. J. T. MOTTRAM and R. Taylor, 'Thermal conductivity of fibre-phenolic resin composites. Part II: Numerical evaluation,' *Composites Science and Technology*, **29**, 1987, 211-232. ISSN 0266-3538

44. (**Referred**) J. T. MOTTRAM and R. Taylor, *'Thermal transport properties'*, in S.M. Lee (Ed), International Encyclopaedia of Composites, VCH publishers, Vol. **5**, 1991, 476-496. ISBN 0-89573-290-4

45. J. T. MOTTRAM, B. Geary and R. Taylor, 'Thermal expansion of phenolic resin and phenolic/silica- and carbon-fibre composites,' *Journal of Material Science*, **27**, 1992, 5015-5026. ISSN 0022-2461

46. J. T. MOTTRAM, 'Design charts for the thermal conductivity of particulate composites,' *Materials & Design*, **13** 4, 1992, 221-225. ISSN 0261-3069

47. J. T. MOTTRAM, 'Design charts for the thermal conductivity of continuous fibre-reinforced composites,' *Materials & Design*, **13** 5, 1992, 279-284. ISSN 0261-3069

Finite Element Modelling Methodology for Analysis of Complex Composite Structures

48. A. Winistörfer and J. T. MOTTRAM, 'Finite element analysis for the development of non-laminated composite pin-loaded straps in civil engineering,' *Journal of Composite Materials*, **35** 7, 2001, 577-602. ISSN 0021-9983

49. W. Hall, J. T. MOTTRAM, D. J. Dennehy and R. P. Jones, 'Characterisation of the contact patch behaviour of an automobile tyre by physical testing,' *International Journal of Vehicle Design* (*IJVD*), **31** 3, 2003, 354-376. ISSN 0960-1406

50. W. Hall, J. T. MOTTRAM and R. P. Jones, 'Finite element simulation for macroscopic tyre behaviour,' *Proceedings of the Institution of Mechanical Engineers Part D: Journal of Automobile Engineering*, **218** 12, 2004, 1393-1408. ISSN 0954-4070

51. W. Hall, J. T. MOTTRAM and R. P. Jones,' Tire modeling with the explicit finite element code LS-DYNA', *Tire Science and Technology,* **32** 4, 2004, 236-261. ISSN 0090-8657

Characterisation of Syntactic Foams for Westland Helicopters

52. P. Bunn and J. T. MOTTRAM, 'Manufacture and compression properties of syntactic foams,' *Composites*, **24** 7, 1993, 565-571. ISSN 0010-4361

5. CONTRIBUTION OF THE CO-AUTHORS

Much of my research work has been concerned with pultruded fibre reinforced polymer (FRP) shapes and systems and, because I was at the start of academic research for PFRP structures, many of my publications are single authored or co-authored with a research student I supervised. Other publications are the result of funded projects by EPSRC (or SERC) and these naturally involved collaborative work with colleagues. I will deal with the extent of the contributions of my co-authors; the numbers in what follows refer to the publication numbers, as given in **Section 4**. When a number does not appear the publication is not co-authored. Of the 28 co-authored publications I wrote 19 of them; I was not the principal author to publications [4, 6, 13, 18, 27, 31, and 48 to 50].

Materials and Design Philosophy

4. Miss Jan Beddows was a PhD Research Student (RS) supervised by colleague Dr Phil Purnell (Division of Civil and Mechanical Engineering). Her PhD work for the Cement Association was on the strength degradation with time of glass reinforced cement materials. I suggested to Dr Purnell that we apply the "Purnell" approach to model

the residual strength of pultruded fibre reinforced material following strength testing following accelerated ageing.

6 My co-authors to this world survey paper are senior Civil Engineering academics who work on FRPs for construction. The survey was led by Professor Amir Mirmiran of North Carolina State University, USA, and the other four co-authors are: Professor Larry C. Bank of University of Wisconsin, USA; Professor Ken W. Neale of University of Sherbrooke, Canada; Associate Professor Tamon Ueda of Hokkaido University, Japan and Professor Julio F. Davalos of West Virginia University, USA. Information reported in the publication not from the European survey was a contribution from one of the co-authors.

Member Characterisation

13. Mr Andrew Lane was an EPSRC funded RS student working for a PhD by research under my direction on the study described in the paper. Andrew wrote the paper.

14. Dr Nigel D. Brown was the Research Assistant (RA) on an EPSRC project that I was the Principal Investigator (PI). This project was given technical support from colleague Professor David Anderson (Division of Civil and Mechanical Engineering), because of his expertise on the behaviour of the thin-walled steel members was relevant to the research described in this publication, and in [15]. Nigel conducted the series of column tests, as a team we analysed the results, and I wrote the publication.

15. Nigel Brown and David Anderson: see 14. Nigel conducted the series of column tests, as a team we analysed the results, and I wrote the publication.

18. Mr Mark C. Evernden was an EPSRC funded RS student working for a PhD by research under my direction on the study described in the paper. He also co-authored the worked that preceded this study in [31].

Joints and Connections

19 Miss Andrea J. Bass was an EPSRC funded RS student working for an MSc by research under my direction on the study described in the paper.

21. Mr Youxin Zheng was a self-funded RS student working for a PhD by research under my direction on the study described in the paper, and in the co-authored publications [24, 25] and [34].

24 & 25. See 21.

26. Mr Andrew Smith was an undergraduate Civil Engineering student whose final year project work was supervised by Nigel Brown (see [14]), who was then on a fixed term lectureship. I suggested the topic for the research project and gave guidance to Nigel and Andrew for the study described in the publication that I wrote.

27 Mr Cyprien Lutz was an EPSRC RA, and a RS working for a PhD by research under my direction on a programme linked to the study described in the publication. He is also a co-author to publication number 29.

28. Dr Geoff J. Turvey was Senior Lecturer in the Department of Engineering at Lancaster University. Under the *Structural Integrity Managed Programme* we worked on a joint EPSRC funded project to study the behaviour of PFRP bolted joints. His contribution to this paper was to provide editorial input after I had prepared a full-working version.

29. Cyprien Lutz: see 27. Mr Guy C. Dunscombe was an undergraduate Civil Engineering student whose final year project work, contributing to Lutz's EPSRC funded research, was under my supervision. I wrote the publication.

31. Mark Evernden: see 18.

Frame Analysis and Design

33 Mr Guy C. Dunscombe was an undergraduate civil engineering student whose final year project work was under my supervision. Mr Eric S. Knudsen was Technical Manager at Fiberline Composites A/S, Denmark,

34 Youxin Zheng: see 21.

35 Mr Marcus Aberle was a PhD student at Cambridge University who gave technical support (from German language publications) to my research described in this publication He also assisted me by providing his internal research reports to aid my understanding of the behaviour of shear flexible beam-column members.

PFRP and Concrete

37 Miss Jo E. Hall was a teaching Assistant and RS student working for a PhD by research under my direction on the study described in the paper.

Other topics

Laminated plate theory

38 Dr Alan R. Selby was a lecturer in the Department of Engineering at Durham University. He provided me with background theory to my PhD work that led to me writing a FORTRAN programme to analysis the geometric non-linear response of laminated FRP plates for the development of a novel biaxial stress test method. He was not my PhD supervisor.

Thermal transport properties

42. Dr Roy Taylor was a Reader in the Department of Materials Science at UMIST. He was the PI to the MOD funded project, on which I worked as the Research Assistant. He is also co-author of publications 43 to 45.

43 & 44: Roy Taylor: see 42.

45. Roy Taylor: see 42. Dr Brian Geary was a Research Assistant in the Department of Materials Science at UMIST. After my RA position at UMIST had been completed he conducted, under my supervision, an additional series of physical tests to determine the thermal expansion response of a phenolic polymer for FRP ablative materials. His contribution enabled me to prepare this publication to explain why my earlier test programme had shown a high variation in expansion response from a batch of nominally identical specimens. These had been independently prepared by the MOD.

Finite element modelling methodology

48. Mr Andreas Winistörfer was a PhD student at Warwick University working under my supervision. He worked full-time at the Swiss Federal Laboratories for Testing Materials and Research (EMPA), Duebendorf, in the Novel Structures team lead by Professor Urs Meier. Andreas developed the finite element modelling methodology reported in the publication under my guidance. His R&D project supported by EMPA was to develop pin-loaded straps of FRP material for tension members (later used on a Swiss winning entry to the Admiral Cup). I wrote the publication from Andrea's PhD thesis.

49. Mr Wayne Hall was an EPSRC RA and PhD RS working under the joint supervision of Dr Peter Jones (Member of Electrical and Electronics Division) and myself. I was solely responsible for the supervision of Wayne's work to develop a Finite Element (FE) modelling for a rolling car tyre. I helped with the interpretation of experimental data using the

test facilities at Dunlop Tyres Research Centre, in Birmingham. Hall and Jones are co-authors of publications [50] and [51] that reported the team's FE modelling methodology. Mr Danny J. Dennehy, who was an MSc student supervised by Dr Jones, worked with Wayne Hall at Dunlop Tyres Research Centre to obtain the measurements reported in the publication.

Syntactic foam

52. Mr Phil Bunn was given a final year undergraduate project by his sponsoring company Westland Helicopter on the Isle of Wight. I supervised the project and wrote the publication because I recognized that the results of his project work were worthy of publication.

Appendix

J. T. MOTTRAM - CURRICULUM VITAE

QUALIFICATIONS

B.Sc. (Engineering Science), Ph.D.

DEGREES

B.Sc. in Engineering Science, Durham University, 1979.

Ph.D. in Engineering Science, Durham University ,1984.

CAREER DETAILS

1983-1985 : Research Assistant, Department of Materials Science, UMIST (MOD funded project).

1985-1987 : Temporary lecturer in Engineering, Univ. of Durham.

1987-1995 : Lecturer in Structural Mechanics, Department of Engineering, Warwick University.

1995-1999 : Senior Lecturer, School of Engineering, Warwick University.

1999 to date : Reader, Civil and Mechanical Engineering Division, School of Engineering, Warwick University.

RESEARCH CONTRACTS

Principal Investigator indicated in **bold** if not **Dr Mottram**

Source of funds	Title of Project	Duration Months	Starting Date	Total value	Names of other holders	Comments
Alvis Ltd.	*Elevated platform system study*	6	Jun. 88	1.5k.	A. J. Cartwright	Joint
TRW Nelson.	*Shear connector tests*	18	Oct. 88	7.5k	**R. P. Johnson**	
SERC. GR/F/86175.	*Artificial neural networks for ultrasonic testing*	36	Oct. 90	98k	**D. A. Hutchins** E. L. Hines	
SERC GR/H13697	*Non-contact ultrasonic imaging of fibre-reinforced composites*	36	Oct. 91	89k	**D. A. Hutchins** G. Hayward (Strathclyde)	
Crompton Stud Welding Ltd.	*Three push-test with through deck welding*	15	Feb. 92	1.5k		

Source of funds	Title of Project	Duration Months	Starting Date	Total value	Names of other holders	Comments
Continued						
SERC. GR/J09406.	*Non-contact ultrasonic imaging of defects in fibre-reinforced polymer composites*	36	Oct. 93	76k	**D. A. Hutchins**	
Steel Construction Institute (SCI)	*Push tests with steel fibre concrete*	18	Jun. 93	3.2k		For N.V. Bekaert S.A.
EU468: EUROCOMP	*Six connection tests for pultruded frameworks*	18	Aug. 93	6k		

(Development of a practical design code, EUREKA funded project. Total funding was 860k. There were 17 European partners and Halcrows Polymeric Ltd., UK, managed the project.)

SERC GR/J21774.	*Further development of an ultrasonic inspection system for advanced polymer composites using neural networks*	36	Oct. 93	120k	**D. A. Hutchins** E. L. Hines	
EC Network	*Advanced materials characterisation by photo-acoustic and photo-thermal methods*	36	93	36.5k (ECU)	**D. A. Hutchins**	

(Total project funding was 333,000 ECU, of which 36.5k ECU was the WU contribution.)

SERC GR/J68304.	*Pilot study - Moment-Rotation behaviour of connections in pultruded frames*.	12	Aug. 94	10k	D. Anderson	
EPSRC GR/K52768	*The behaviour of columns for the design of pultruded frames*	24	Jan. 97	74k	D. Anderson	

(Built Environment Managed Programme - *Materials for a Better Construction Programme*: *Phase I*)

Pneutek (Europe) Ltd.	*Push tests for composite steel-composite beams with pin-connected shear*	18	Jun. 97	6.7k	D. Anderson	
DERA.	*Embedded micro-machined ultrasonic sensors*	24	Jan. 98	79k	**D. A. Hutchins** D. C. Dyer J. W. Gardner	
Coventry and Warwickshire Hospital	*Screw fixation in bone – feasibility study*	18	Oct. 99	5k	E. L. Hines	
DERA	*Rapid air-coupled testing of composites*,	6	Jan. 00	15.6k	**D. A. Hutchins** D. R. Billson	

Source of funds	Title of Project	Duration Months	Starting Date	Total value	Names of other holders	Comments
EPSRC GR/M86835 140k Foresight Vehicle LINK programme	*STASIS - Smarter Tyres* using *Advanced Sensors* for *Improved Safety*	36	May 00	140k	**R. P. Jones** D. R. Billson	

Collaborators were Dunlop Tyres Ltd., DERA, Avon Developments Ltd., Ove Arup & Partners, Rover Group,), Project total is £690k. *Goodyear decided in Oct. 2000 not to continue Dunlop Tyres Ltd. support to the project.*

EPSRC GR/N11797	*Structural Integrity of Bolted Joints for Pultruded GRP Profiles*	24	Dec. 00	127k		

Joint project with Dr G. J. Turvey of Engineering Department, Lancaster University, under 2nd Structural Integrity Programme, £126k to Lancaster.

Modula 2000 Ltd.	*Advanced building system study*	24	Oct. 03	24k		studentship
Maidstone Borough Council	*Forensic engineering evaluation of carbon fibre reinforced polymer parapet posts on the Lockmeadow Bridge, Maidstone'*	9	Mar. 04	7.8k		

EXTERNAL COMMITTEES (excluding term-of-office completed before 2000)

1. Past member of International Scientific Committee organising conference on the *Non-metallic reinforcement for concrete structures – FRPRCS-5*, Cambridge, 16-18th July 01.
2. Past UK representative and Member of Management Committee for European Commission COST C12 action on *Urban buildings - Quality by new technologies*, May 00- May 01.
3. Past member of the National Steering Committee organising the *1st International Conference on Advanced Composites in Construction – ACIC 2002*, Southampton 15-17th April 02.
4. Served as member on the Project Steering Group, EPSRC Network on *Advanced Polymeric Composites for Structural Applications in Construction (CoSACNeT)*, (Jan. 01 -Dec. 03). EPSRC GR/N65462/01.
5. Past Member of International Scientific Committee for the *International* Conference on *Innovative Materials and Technologies for Construction and Restoration –IMTCR03*, University of Lecce, Italy, 6-9th June 04.

6. Served as an elected Member-at-large on Executive Committee to the newly formed *International Institute of FRP in Construction* (*IIFC*) (Jun. 03-Dec. 04).
7. Past member of the National Steering Committee for the *2nd International Conference on Advanced Composites in Construction – ACIC 2004*, Surrey, 20th-23rd April 04.
8. Past member of International Advisory Committee for the *2nd International* Conference on *FRP Composites in Civil Engineering – CICE 2004*, Adelaide, Australia, 8-10th December 04.
9. Invited contributor to the National Composite Network technology roadmap exercise for the construction industry on the improved use of composites (FRP) in construction applications. NGCC and NCN organised workshop held at TWI on Thursday 22nd June 2006.

CURRENT:

10. Member of Midland Counties Branch Committee to The Institution of Structural Engineers (96 to date)
11. Member (and founding) on the International Editorial Board of the American Society of Civil Engineers J*ournal of Composites for Construction* (97 to date).
12. Member of EPSRC Peer Review College (Jan. 00–Jan. 09).
13. Member on Editorial Board to the journal *The Structural Engineer*, IStructE, UK (05-). Responsibilities are to develop the business plan and acting as a reporter to papers after they have been peer reviewed.
14. Elected Member to Council for the Institution of Structural Engineers (06-09).
15. Member of NGCC R&D Group (Jan. 04-). This is the UK's Network Group for Composites in Construction. This research and development group, with academic and non-academic members, has the role of linking academia and industry.
16. Member of the International Organising Committee for the 3rd International Conference on *Advanced Composites in Construction – ACIC 2007*, Bath, 2nd-4th April 07.

HIGHER DEGREE EXTERNAL EXAMINER

1. School of Engineering and Applied Sciences, University of Durham
2. Department of Engineering, University of Lancaster
3. Department of Civil Engineering, University of Newcastle-upon-Tyne
4. Ship Engineering Department. University of Southampton
5. Department of Mechanical Engineering, University of Leeds
6. Department of Civil Engineering and Geoscience, University of Newcastle-upon-Tyne
7. Department of Mechanical Engineering, Nottingham University
9. Department of Engineering, Cambridge University
10. School of Engineering, Coventry University
11. Department of Civil Engineering, Southampton University
12. Department of Mechanical Engineering, Deakin University, Australia

REVIEWING

I am a reviewer of papers for several international journals including the following:-

Advances in Structural Engineering,
Composites Part A: Applied Science
Composites Sciences and Technology
Engineering Composites
Journal of Composites for Construction (Journal of the American Society of Civil Engineers)
Journal of Composite Materials
Journal of Materials in Civil Engineering (ASCE)
The Structural Engineer (Journal to the Institution of Structural Engineers)
Structures and Buildings (Journal to the Institution of Civil Engineers)
International Journal Solids and Structures.

FULL LIST OF PUBLICATIONS

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2. J. T. MOTTRAM, and C. T. Shaw, *'Using Finite Elements in Mechanical Design'*, McGraw-Hill, Maidenhead, (1996). ISBN 0-07-709093 4
3. J. T. MOTTRAM, and G. T. Turvey, (Eds.), *'State-of-the-art review on design, testing, analysis and application of polymeric composite connections*,' Polymeric Composite Structures Working Group 7, COST C1 Project on *Behaviour of Civil Engineering Structural Connections*, DG XII, European Commission, Office for Official Publications of the European Communities, Brussels & Luxembourg, (1998), p. 99, in print. (Principal editor)

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11. J. T. MOTTRAM, and R. P. Johnson, 'Push tests on studs welded through profiled sheeting', *The Structural Engineer*, **68** 10, (1990), 187-193. ISSN 0039-2553
12. J. T. MOTTRAM, 'Evaluation of design analysis for pultruded fibre-reinforced box beams', *The Structural Engineer*, **69** 11, (1991), 211-220. ISSN 0039-2553
13. J. T. MOTTRAM, 'Flexural testing of general multi-layered composites', *Journal of Composite Materials,* **25** 9, (1991), 1108-1126. ISSN 0021-9983
14. J. T. MOTTRAM, 'Lateral-torsional buckling of thin-walled composite I-beams by the finite difference method', *Composites Engineering*, 2 2, (1992), 91-104. ISSN 0961-9526
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44. J. T. MOTTRAM, ‘Shear modulus of standard pultruded FRP material’, *Journal of Composites for Construction,* American Society of Civil Engineers, **8** 2, (2004), 141-147. ISSN 1090-0268

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Proc 2nd International Conference on Advanced Composite Materials in Bridges and Structures, Canadian Society of Civil Engineers, Montreal, (1996), 751-758. ISBN 0-921303-64-5

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74. A. Winistoerfer and T. MOTTRAM, ‘The future of pin-loaded straps in civil engineering applications,’ in Proc. US-Canada-Europe Workshop on Recent Advances in Bridge Engineering - Advanced Rehabilitation, Durable Materials, Nondestructive Evaluation and Management, EMPA, Duebedorf, (1997), 113-118.
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83. (**By invitation**) J. T. MOTTRAM, ‘Design guidance with an emerging construction material,’ *in Proc. COST C1 International Conference on the Control of the Semi-rigid Behaviour of Civil Engineering Structural*

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J. T. Mottram 26th January 2007