ME40321 – Tips for PSP

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Housekeeping

- Meet with supervisor to refine aims and objectives
- Technician surgery – ALL STUDENTS

ME40321 – Assignment 1

Submission requirements

1. Project scoping and planning
2. Hazard evaluation safety approval form
3. Risk assessment (if appropriate)
4. Chemical Hazard form (if appropriate)

Item 1 on Moodle AND Faculty Students Centre
Items 2-4 on Moodle, to be completed with supervisor (staff and student signature required)

ME40321 – Assignment 1

Submission method(s):

- Faculty Students Centre by 16:00 on 27 November 2019
- Moodle by 16:00 on 27 November 2019

ME40321 – Project scoping and planning

Word limit 2,500 words (a LIMIT not a target)

- Cover page
- Summary
- Background
- Aims and objectives
- Workplan
- References

ME40321 – PSP Summary

Approx 300 words – must include short background and research question/ aim of the study

A novel *in-vitro* approach for the dynamic assessment of spine biomechanics

Most adults experience back pain, and the resulting disability is the single greatest cause of work absence in the U.K. Back pain is associated with disruption of spinal tissues, particularly the intervertebral discs, and although age and genetic inheritance influence tissue strength, applied mechanical loading remains the most important modifiable factor leading to tissue disruption and pain.

Understanding how spinal structures can become damaged is one of the main aims of biomechanical investigations of the spine. However, there is also a growing need to assess the performance of the ever-increasing range of prostheses and procedures used to treat chronic back pain. Both of these aims require apparatus that can apply to spine specimens the complex patterns of loading arising from activities of daily living.

The non-linear and viscoelastic properties of many spinal tissues require that the magnitude and rate of application of loading in-vitro must be physiological, and that the stabilising influence of back muscles and ligaments, several of which span several vertebrae, is accurately reproduced. Under current test protocols, short segments of the spine (2 or 3 vertebrae and connecting structures) may be subjected to quasi-static moments that induce flexion and extension of the segments, enabling resistance to movement and range of motion to be evaluated. However, this type of investigation is not adequate to reproduce realistic mechanisms of injury, or to rigorously evaluate new devices and surgical procedures. Dynamic testing can more closely simulate in vivo loading conditions, but because of the propensity for long sections of spine to buckle, such tests are normally confined to single motion segments, which preclude any evaluation of adjacent level effects. This is a considerable limitation in the testing of spinal implants where altered mechanics at other spinal levels is of particular interest because of the risks of adjacent segment degeneration.

The present proposal is aimed at developing a novel spine testing device capable of replicating realistic movements and loading patterns on long segments of human spines. This device will include the effect of stabilising muscle forces and will be validated by comparing movements and loading of spine segments in-vitro with those observed in-vivo. The outcome of this research will be to provide a facility capable of evaluating novel spine prostheses and surgical procedures with unprecedented accuracy and rigour.

ME40321 – PSP Summary

SUMMARY

This project will address the fundamental issue that radial turbomachinery needs to be designed for highly transient operating conditions so that optimal performance and efficiency can be achieved. Current practice focuses on steady state conditions, which limits the potential gains. New transient experimental and theoretical approaches will be combined to give a new perspective on understanding of the joint operation of turbomachinery and internal combustion engines.

The outcomes from this work will provide the necessary knowledge and design tools to produce future turbomachinery optimised for the dynamic conditions observed when in-service. This will also provide a platform from which a transient approach to other engine systems research

ME40321 – PSP Background

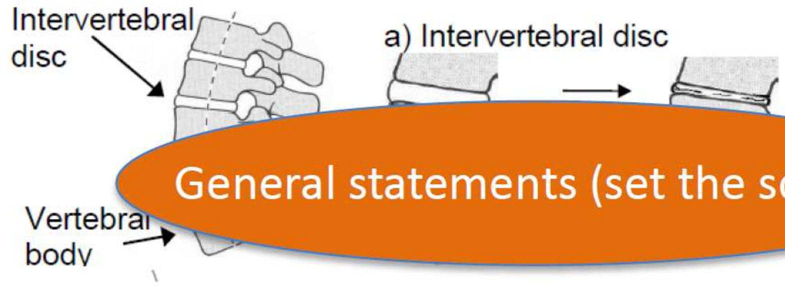
Context of the research:

- Why is it important
- State of the art
- Where your work will fit in (added value)

It should be obvious from reading this that your project is necessary to advance current knowledge

BACKGROUND

Back pain is a common complaint affecting approximately four out of five adults at some point in their life [1] and the resulting disability is the greatest single cause of work absence in the U.K. [2]. Back pain is often associated with disruption of the intervertebral discs in middle age, and with vertebral fractures in old age (**Figure 1**). In many cases, its origins are obscure and may be attributable to localised stress concentrations that can elicit pain from innervated tissues, but which are not sufficient to cause structural damage [1;3]. It is known that back pain can be associated with abnormal load transfer arising from changes in the spine itself or from altered muscle recruitment [3;4]. Due to the prevalence of back pain among the adult population, and the proven clinical relevance of biomechanical studies, the behaviour of the spine under load has been a topic of research for many years (see for example [5-7]) and it remains a key area of investigation [8;9]. Recent advances in spinal treatment have contributed to an increased research effort the evaluation of novel surgical procedures and implants. This has resulted in a renewal of interest in the in-vitro investigation of the loading response of the normal and injured spine and in the evaluation of spinal surgical procedures (see for example [10-13]) and the diversity of the approaches used has led to repeated calls for rationalisation of the test methodologies used [8;9;14;15].



General statements (set the scene)

Figure 1: the human spine is susceptible to a) intervertebral disc disruption and b) vertebral body fracture

Review of current testing methodologies

Three approaches are currently used for biomechanical testing of the spine:

Detail (and organise thoughts)
TAXONOMY

1. <u>Static testing</u>

ME40321 – PSP Background

Also need to provide justification for the methodology chosen….

Stochastic Uncertainty Quantification (UQ) is one of the most common approaches to analyse performance uncertainty by propagating input uncertainty through the system model to predict probability of failure [35]. In the past, such stochastic analyses of entire component parts were unfeasible due to the huge computational cost of classical methods, such as Monte Carlo (MC) simulation [27]. However, the advent of several alternative and more computationally efficient methods [39, 48, 31] is now making such analyses possible. In particular, the idea of multilevel Monte Carlo (MLMC) simulation [23, 2], where a hierarchy of successively smaller and cheaper models is used to draw samples, essentially allows for stochastic UQ of a complex, large scale system at the computational cost of a few tens or hundreds of fine scale computations, but with the same accuracy for which millions of fine scale samples would be necessary in standard MC.

While the main aim of stochastic UQ is of course to significantly reduce the reliance on experimental tests, such tests should still be used to reduce uncertainty in the models. Most probabilistic approaches in manufacturing still do not take this into account, although there are some first developments [30, 43]. The typical probabilistic approach is a Bayesian one, more commonly known as Monte Carlo Markov Chain (MCMC), where a so-called *prior distribution* of the input uncertainties is "conditioned" on the test data to produce a *posterior distribution* that "fits" the data (in a probabilistic sense) and thus reduces uncertainties in the system [38]. Like standard Monte Carlo, MCMC methods are notoriously slow to converge and thus infeasible for large scale problems [26]. A recent breakthrough in [7] means that multilevel variants of MCMC methods that will allow for efficient treatment of large scale systems are now also available. The most important input uncertainty in the proposed work is the volume and geometry of defects within the laminate and their correlations. Here, we can build on existing work in ceramic laminates [24].

ME40321 – PSP Background

Context of the research:

- …
- …
- Where your work will fit in (added value)

It should be obvious from reading this that your project is necessary to advance current knowledge

No harm in being explicit!

ME40321 – PSP Background

Rationale and summary of the proposed research

It is apparent that an apparatus for the in-vitro testing of spinal segments should display the following characteristics: it should be capable of holding and stabilising spine segments of 3-5 vertebrae using some form of muscle actuation; it should have the capacity to apply maximum moments and compressive forces at least 20 Nm and 3kN respectively; and it should be able to apply combined loading (and remove it) in less than 2 sec, the time it takes in life to bend down and straighten up again. Also, the apparatus must allow free access to the spine being tested, so that additional instrumentation can be used to measure parameters such as intra-discal pressure [32] and vertebral bone strain [33].

The applicants propose to develop a novel spine testing facility, capable of meeting the demands identified above

ME40321 – PSP Aims and objectives

Frame the research question

- A few lines
- …

ME40321 – PSP Aims and objectives

Aim and objectives

This study aims to develop a novel spine testing facility that ultimately will enable spine prostheses and surgical procedures to be evaluated with unprecedented accuracy and rigour. This aim will be achieved through the following objectives:

1. Construct a test frame capable of accommodating human (and sheep) spine segments of varying lengths;
2. Develop a hexapod system that can apply combined loading at physiological magnitudes and loading rates;
3. Incorporate additional hydraulic actuators to reproduce the stabilising influence of specific muscles;
4. Design control software that replicates loading conditions during specific activities in-vivo;
5. Calibrate the test apparatus relative to reliable industry standards, using sheep spines;
6. Apply complex physiological loading to human spine specimens, and compare vertebral movements and intradiscal pressures with published in-vivo measurements;
7. Demonstrate the advantages of the new facility by a) comparing specimen resistance to bending at small (as used previously) and high bending moments, and b) comparing resistance to bending with small and high compressive pre-loads.

ME40321 – PSP Aims and objectives

RESEARCH HYPOTHESIS AND OBJECTIVES

The aim of the research is ***to characterise heat transfer in radial turbomachinery under transient operating conditions***, such as those observed when used in conjunction with reciprocating internal combustion engines. The project will combine novel dynamic experiments and state-of-the-art thermal modelling approaches to understand how the design and distribution of thermal inertia influences transient performance. The importance of transient dynamics will be quantified and captured in novel models to better inform mechanical and controller design processes. To achieve the aim of this project, the objectives are:

(a) To build eight instrumented turbomachinery housings to isolate heat flows from work transfers and measure gas and metal temperatures for a range of thermal inertias.

(b) To design dynamic experiments on an engine test facility specifying gas flow rates and temperatures representative of in-service operation of turbomachinery.

(c) To measure the thermal behaviour of the turbomachinery housings under a range of transient conditions specified in (b) and to quantify measurement uncertainty under these conditions.

(d) To build theoretical models of the turbomachinery to predict heat fluxes and gas temperatures under a range of transient conditions specified in (b).

(e) To integrate the theoretical models from (d) with existing engine performance simulations to demonstrate improvements in prediction against measured engine data.

ME40321 – PSP Aims and objectives

3. RESEARCH HYPOTHESIS AND OBJECTIVES

An important objective of complex engineering system development is to minimise the probability of failing the certification test. Modelling technologies and testing at various stages of development are all orchestrated toward this objective, which has been heuristically developed over the last decades without a clear understanding of how each player contributes to uncertainty reduction.

> **Overarching Aim.** This project will develop multiscale mathematical and stochastic models and use high performance scientific computation to increase the quality of carbon fibre laminate manufacture whilst challenging conservatism and reducing expensive empirical testing.

Objectives

1. To develop new process models for low defect design and low defect manufacture of high-quality carbon fibre composite parts.
2. To develop multiscale structural performance models that replace/reduce the need for physical tests.
3. To use CT scanning to characterise defects and numerically verify small-scale parts.
4. To use multiscale modelling and numerical upscaling for entire large-scale components building on and aiming to reduce the computational effort in 2 and 3.
5. To develop novel multiscale statistical methods for quantification of uncertainty to predict the probability of certification and in-service failure of complete, as-manufactured components.
6. To increase, through uncertainty reduction, operational strain levels thereby reducing structural weight of aerospace structures and ultimately fuel consumption of aircraft.

ME40321 – PSP Workplan

How you will achieve your aim

- Provide methodology with timescales
- It helps if this section reflects objectives outlined in previous section
- Provide a Gantt chart or similar

ME40321 – PSP Workplan

PROGRAMME AND METHODOLOGY

The research programme includes extensive experimental and theoretical modelling activities that need to consider the complex interactions between turbomachinery and internal combustion engines. These interactions result from the joint air path; the shared lubricating and cooling fluids; and the mechanical coupling of the two devices. The resultant behaviour involves convection, conduction and radiation heat transfer, the study of which requires the combination of new dynamic experiments, intensive instrumentation and advanced mathematical modelling. The five objectives, along with management and dissemination activities, form the basis of six work packages. The experimental work is split into three work packages (WP 1-3) whilst the modelling work (WP4) work will run concurrently such that both approaches are mutually complementary. An engine systems level study (WP5) will conclude the research activity.

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ME40321 – PSP Workplan

Methodology

The programme of research will be implemented during the two phases outlined below. Details of the research methodologies adopted in each phase, their relation to the stated objectives and how these will allow the aim of the project to be achieved are given below.

Phase 1: Design and development of the dynamic spinal test facility (months 0-24)

The first phase of the project will concentrate on the design and implementation of the bespoke dynamic test facility capable of accommodating long spinal segments, comprising 3 to 5 vertebral bodies stabilised through the actuation of muscle forces. This will consist of a rigid frame on which a custom-designed parallel mechanism (hexapod) will be mounted. Information relating to the loads and displacements that the hexapod will have to impose on the specimen in order to simulate activities characteristic of daily living (design constraints) has been obtained from the literature (see for instance [3;6;7;34-36]) and is summarised in **Table 1**.

The maximum achievable testing frequency will be 2 Hz. Bending and axial rotation will be introduced at the cranial end of the specimen to ensure physiological fidelity. The frame, which will be built in house, will be characterised by an adjustable base to accommodate specimens of differing lengths. The frame will display rigid behaviour under the loads generated during the tests and summarised in **Table 1** (**Objective 1**). The hexapod used to actuate the specimens will be attached to the frame and controlled via a software interface developed in house within the

ME40321 – PSP Workplan

4. PROGRAMME AND METHODOLOGY

The project consists of four Work Packages; WP1 and WP3 cover mathematical modelling and multiscale scientific computation of composites, and will be carried out by Researcher CI, Dodwell. WP2 incorporates the experimental programme, to be undertaken by GKN with the support of a university experimental officer. Dodwell will also be closely involved with WP4, which covers stochastic modelling, uncertainty quantification and optimisation. However the fundamental work for WP4 will be undertaken by one PhD student at Bath and one at UF, under the supervision of Scheichl and Haftka (UF), respectively. Dodwell will then bring together the results from all the work packages for the ultimate goal of developing probabilistic tools for: (i) predicting failure of as-manufactured parts and (ii) optimisation of laminate designs **(Milestone 5)**. The workplan illustrates the scheduling of the various activities and events.

WP1 Manufacturing Process Modelling. The principal mechanism for defect formation is process-induced fibre deformation during the consolidation and cure of components. Thus, modelling should cover all scales of Fig. 1. However, we will initially concentrate effort only down to the level of ply layers since we believe that design principles can be efficiently established with such simplifications.

T1.1 *Multiscale models for manufacturing processes.* Within uncured laminates, viscous resin between layers allows them to slip, introducing highly nonlinear behaviour, primarily friction. Although they may appear disparate areas of research, many of the physical processes which govern the deformation of laminates in the uncured state are similar to buckling in layered geological structures (on different spatial and temporal scales). This project will draw on Bath's expertise in the modelling of geological systems [5] by primarily seeking to implement a homogenised two-dimensional description of layers of uncured laminates which retains nonlinear inter-layer interactions [17, 3]. We expect to gain further insight into these

ME40321 – Assignment 1

Communicating and consulting with your

supervisor (and assessor if suitable) are vital !

PSP Marking scheme

- Summary - 10%
- Introduction/background and literature review - 30%
- Aims and objectives - 10%
- Work plan - 30%
- Gantt chart or similar – 10%
- Quality of the presentation – 10%