THE MECHANICS OF TRACTOR - IMPLEMENT PERFORMANCE

An Overview of Teaching and Learning

R. H. Macmillan*

Introduction

The agricultural tractor is a complex machine particularly when considered against the requirements for it to pull, drive and control implements and processing machines. This is particularly so in the context of the agricultural environment where, superficially at least, the conditions for good traction are opposite to those for good plant growth.

The various aspects of tractor performance associated with power generation, transmission (including traction on hard and soft surfaces) and implement control have each received significant attention from the research communities in mechanical and agricultural research and development centres.

However the formal process of professional agricultural engineering education is a relatively new activity and it is appropriate to ask how this might best be accomplished, particularly in the age of the digital computer and electronic publishing. Are our present curricula materials (text books, computer programs, web sites) and methods (laboratory and field research and testing) suitable for the 21st Century?

It is the view of the writer that the available material and concepts associated with tractor performance have not been brought together in a way that makes them readily available for use by engineering students and for engineers who have a background in engineering science at say the level of second year professional engineering courses.

It is doubtful if the expensive, one type fits all, hard bound text books of the past are really suitable for student use in the developed world. In any event we ought to move on and find ways of providing academic support for those who need help in curricula development in the developing world. Publishing on the World Wide Web (either free or with some small charge) seems to be a way which answers many of the problems, limitations and costs associated with traditional publishing.

* Senior Academic Associate, formerly Senior Lecturer in Agricultural Engineering, University of Melbourne
The context of this overview is the publication by the writer of a textbook, The Mechanics of Tractor - Implement Performance, Theory and Worked Examples A TEXT BOOK FOR STUDENTS AND ENGINEERS on the University of Melbourne Website. It is available free at: http://eprints.unimelb.edu.au/archive/00000204/

Existing books

When one looks at the existing (English language) text books on the agricultural tractor (and books covering aspects of its performance) they are seen to roughly fall into three categories:

(i) the descriptive books of the 'what it looks like and how it works' type which are designed for students in colleges of agriculture and for advisors and users who need to know how the tractor and the various machines are constructed and operate.

(ii) the 'engineering' type books which are rather more analytical and tend to cover the engineering principles of the various systems (engine, transmissions, wheels, implement hitching, etc) and the associated processes such as power transmission, traction, weight transfer and implement control, etc.

(iii) a small number of books dealing with the more general topic of 'off-road' locomotion and its application to earth moving and military machines.

The books in categories (i) and (iii) have a more limited purpose and address a different clientele. Those in category (ii) which are relevant to this review tend to cover not only the systems as used in the tractor but also attempt to cover the basic engineering science on which those systems are based.

Whether as a result of this or for some other reason, the influence of these particular systems on the 'performance' of the tractor as a whole is generally not considered in these books. For example the drawbar pull - travel speed characteristic for the tractor is not shown as being determined by the torque - speed characteristic of the engine. Without this background and a knowledge of the fuel consumption characteristic of the engine at part load, it will not be clear to the student why, for example, changing to a lower gear increases the fuel consumption.

Another aspect of existing text books, particularly in group (ii) above, is their failure to use graphical illustration of the variation in the performance which is inherent in the data. The parameters used to measure and specify tractor performance are related to and largely derived from each other. Thus one can trace the ideas of torque / force (pull), rotational speed / travel speed, engine power / drawbar power through the transmission / traction system (Baillie and Vasey, 1969)[1]

The student can therefore see that the more complex aspects of performance (for example, the condition for maximum drawbar power) is determined by the minimum sum of rolling resistance and slip losses which in turn are determined (for a given tractor on a given surface) by the essential practical choice of weight on the driving wheels. Such relationships, although inherent in the data, are lost, or at least not apparent, in a purely numerical tabulation of performance.

[1] Baillie, W.F. and Vasey, G.H. (1969), Graphical Representation of Tractor Performance. Journal of The Institution of Engineers, Australia 41(6) 83 – 92

In the past it was common for textbooks (particularly in category (ii) above) to attempt to treat all aspects and levels of the agricultural tractor in one volume. The increasing complication of various types, brands and systems makes this difficult and certainly unsatisfactory from a student point of view. A series of monographs on the principles of the various systems (where these differ from the principles of the standard mechanical / electrical engineering systems) would provide a base for understanding the research and development literature. This would follow the well understood approach of other engineering professions to machine analysis and design.

The present work

The present work is written for professional agricultural engineering courses or equivalent subjects for mechanical engineers. It could also form the basis for short courses for practising engineers. It assumes a 2nd year university level of engineering science.

It is limited to the functional performance of agricultural tractors – how, and how well, they perform the function for which they are designed - pulling loads. It is not about construction, operation or management but about performance and the factors that determine it. Because it treats the tractor in terms of the fundamentals of the subject, it is not limited to any type, size or make. No doubt this involves many assumptions that might be criticised. It however seems an appropriate initial approach for students and engineers who need a grounding in the principles of the basic machine analysis before the subtleties of the type, size and brand are introduced.

In preparing the present work the opportunity was taken to cast the material on the tractive performance in Chapters which illustrate the common methods of engineering analysis, viz:

* ideal (theoretical, simple mechanics)
* experimental (ideal [firm surface], measurement based)
* theoretical (soft surface) and comparison with experimental (soft surface)
* empirical (soft surface)

This has an important, if incidental, didactic purpose in showing and reinforcing the principles that are common to the analysis of many engineering machines and systems. Perhaps this notion may be taken for granted but it may also be lost to students if authors move from one analytical technique to another without any appropriate explanation.

Chapter 1 gives an outline of the subject, a justification for its study and an overview of the main systems in the power train of both the conventional and two wheeled tractor.

The analysis of performance starts in **Chapter 2** with the engine performance as a 'given' and extends this, via a simple mechanical analysis, to give the ideal performance of the tractor. The general non-dimensional measures of performance such as tractive coefficient, wheelslip and the various efficiencies are also introduced.

The results of tests that are performed by the testing stations following procedures such as those specified by the OECD are presented graphically and explained in **Chapter 3**. This approach is shown to confirm (within appropriate limits) the simple analysis presented in Chapter 2.

Chapters 4 and 5 treat both traction theory (after Bekker, Reece etc) and empirical analysis (after Wismer, Dwyer etc) in terms of the relevant parameters. The theoretical analysis shows how the performance of the tractor depends on the strength and deformation properties of the soil on which it is operating - that the tractor can only pull with a force equal to the reaction that the soil can generate - after the losses due to rolling resistance and wheelslip are allowed for. It is important that these insights, which may be obvious to the experienced engineer, form part of the students' understanding.

The empirical analysis of performance is a powerful tool which allows a rapid exploration of performance using computer modelling and graphical representation. By showing performance envelopes and the distribution of power flows it provides the student with further detailed insight into the effect of weight and soil condition on performance.

Both methods are required for students to understand the subject and to break into the extensive research literature that use these analyses.

Chapter 6 on chassis mechanics covers the fundamentals of the subject appropriate to tractor performance and includes material that has not previously been published, at least in a readily accessible form. Again the simple analysis and the worked examples provide insights into the subtle aspects of the weight 'transfer' process and the conditions for impending instability.

In **Chapter 7** all of the factors that determine tractor performance are brought together and their relevance to the selection of a tractor to match an implement and their efficient operation, in terms of performance, are illustrated.

Concluding remarks

It has been the writers experience that text books written for experienced engineers are frequently not suitable for student use. The latter often require an exploration of ideas, principles and generalisations that are obvious to the former but not to the latter. It is further desirable that these principles be explicitly tied into the more general body of engineering science.

What we need to do then is to make an investment, not only in research on the fundamentals of the technical material, but also in curricula materials that are suitable for student use - an investment which the writer believes the profession has not made, or not made available to date.

These educational ideas were well summed up by Reece (1964)[2] and illustrated in his research.

> *'To the writer however, the most important reason for the study of soil - vehicle mechanics is an educational one. The training of agricultural engineers at University level is a relatively new enterprise which aims at producing creative engineers in a shorter overall period than the old method of practical experience alone. In order to achieve this the University must concentrate on the teaching of principles and the scientific method applied to each particular field. The young engineer must then add to this some years of experience of the application of these principles and must support them with adequate background knowledge.*
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> *If the scientific approach is the aim of academic agricultural engineering, then it is plain that the principles of soil vehicle mechanics (and soil implement mechanics) must form an important part of the teaching. Unfortunately in this, as in other branches of agricultural engineering, the principles are obscure and can only be taught after considerable research on the part of the teacher. The research effort . . . is not aimed at the direct improvement of the farm tractor but rather at the elucidation of principles which can be taught to students who will use them in the development of better machines.'*

The writer would be pleased to engage in a discussion of this topic.

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[2] Reece, A.R. (1964), Theory and Practice of Off-the- Road Locomotion The Institution of Agricultural Engineers Annual Conference