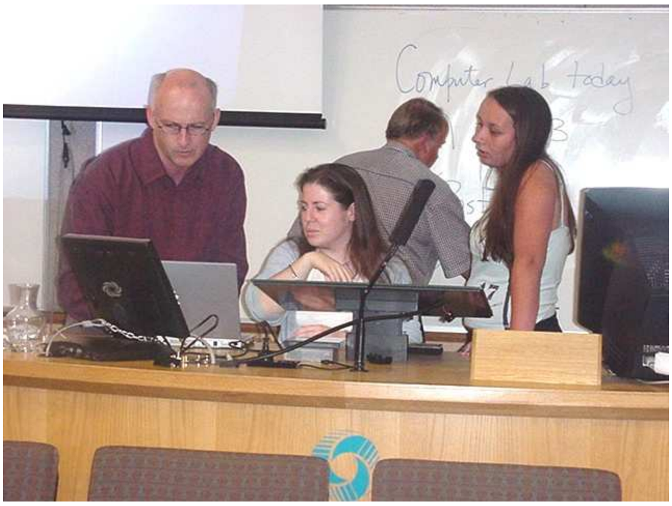
Mathematics-in-Industry Study Group 2005

Problem reports: Equation-Free Summaries



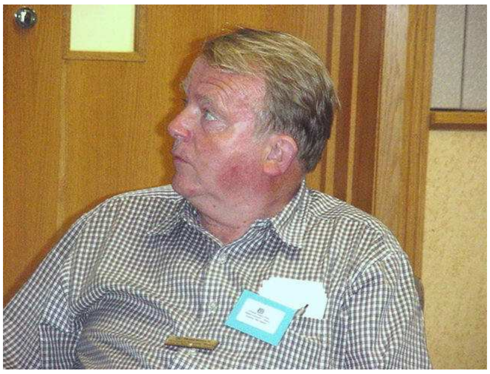
Massey University

CMI

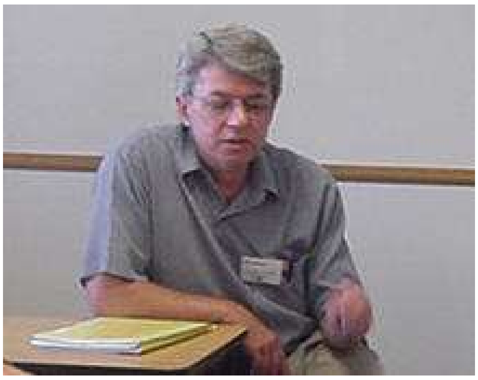
Centre for Mathematics in Industry

Director of CMI: Professor Robert McKibbin

Director of MISG2005: Professor Graeme Wake



Graeme Wake



Robert McKibbin

INTRODUCTION

The second of the ANZIAM Mathematics-in-Industry Study Groups to be held in New Zealand (MISG2005) took place at Massey University at Auckland, 24-28 January 2005. Hosted by the Centre for Mathematics in Industry, based there it was directed by Professor Graeme Wake, Adjunct Professor of Industrial Mathematics. Administrative support was provided by the Institute of Information and Mathematical Sciences (headed by Professor Robert McKibbin) and MISG2005 Administrator was Nikki Luke.

Seven problems were presented, six from New Zealand and one from Australia. Industry based in Australia seems very reluctant to bring their problems off-shore, in spite of considerable effort being made to lure them to a New Zealand-based MISG. With a strong following from New Zealand it points to a need for a MISG-type of activity in both countries with synergy maintained between them.

The Centre for Mathematics in Industry was formed to provide a national base for MISG and has also built links with emerging similar activities, in South Korea and Thailand in 2004. This year's MISG was fortunate in attracting Professor Sam Howison, Director of the Oxford Centre for Industrial and Applied Mathematics in the United Kingdom as an overview facilitator. The Deputy Prime Minister for New Zealand, the Honourable Dr Michael Cullen provided a keynote opening address providing welcome but controversial publicity for MISG2005. Student workshops were held and addressed by Dr Howison, Mr Paul Milliken (an entrepreneurial consultant) and MISG2005 Director Professor Graeme Wake. We were fortunate in obtaining a significant grant from Technology New Zealand under their "Smart Start" programme, which is gratefully acknowledged. Last but not least we acknowledge the immense work provided by the problem moderating team – mentioned below, which this year included a postgraduate student in each case. Their contributions – often beyond the call of duty – is warmly acknowledged. Without this input MISGs just would not happen.

Graeme Wake

Problem reports: Equation-Free Summaries

Seven industrial problems were presented and considered:

These are described in the following pages along with the outcomes from the group meetings. A full technical report will be published by the CMI as "Proceedings of MISG2005" in due course. In most cases ongoing work is in progress.

PREDICTING OFF-SITE DEPOSITION OF SPRAY DRIFT FROM HORTICULTURAL SPRAYING THROUGH POROUS BARRIERS ON SOIL AND PLANT SURFACES

Lincoln Ventures Ltd/Plant Protection Chemistry of NZ

Industry Representatives:
John-Paul Praat, Lincoln Ventures Ltd., Hamilton, New Zealand
Alison Forster, Plant Protection Chemistry NZ Ltd, Rotorua New Zealand
Jerzy Zabkiewicz, Plant Protection Chemistry NZ Ltd, New Zealand

Project Moderators:
Tony Roberts, University of Southern Queensland, Toowoomba, Qld, Australia
Geoff Mercer, University of New South Wales, Canberra, ACT, Australia
Sean Oughton, University of Waikato, Hamilton, New Zealand

Student Moderator:
Sharleen Harper, Massey University, Albany, New Zealand

New Zealand is a recognised leader in horticultural practices which include the use of boundary shelterbelts around orchards. These shelterbelts were primarily established to provide protection to the crop but are also an effective means of ameliorating agrichemical spray drift that may arise from the crop production area. Shelterbelt structure ranges from large trees (ranging from broad leaf to needle in structure) to hedgerows and artificial netting. The efficiency of the shelterbelt in capturing spray drift is known to depend on factors such as spray drift droplet size, wind velocity and the vegetation structure. However more specific information and models are required to define the capture efficiency to form part of a comprehensive spray drift management system.

The task set the MISG team was to develop and investigate a mathematical model of shelterbelt efficiency. Factors such as wind profiles through and above the shelterbelts, release height of the spray drift, capture efficiency of different droplet sizes and evaporation rates all need to be considered. The object is to either produce a better working model or to clearly define the deficiencies in the existing models. Any model that is developed would need to be usable at the farm level. That is, any inputs to the model need to be easily measured or estimated quantities such as free stream wind velocity, optical porosity of the shelterbelt and typical vegetation element size of the shelterbelt. In practice barriers effective at trapping spray drift must have some airflow through them, solid barriers will direct airflow with spray droplets upward and over the barrier.

The team began by dividing the task into three main areas. Firstly, we determined the mean flow through and over the shelterbelt and surrounding crop. Secondly, the spray drift droplet size distribution and the effects of evaporation and settling was calculated. Thirdly, we modelled the capture efficiency within the shelterbelt as a function of the characteristics of the shelterbelt and the wind field.

The wind through and over the shelterbelt and crop is strongly turbulent. Accurately determining the wind profile was beyond the scope of the project and unnecessarily complicated given the generic nature of the desired outcomes. A general guideline for the typical flow fields is desired, not an investigation of specific cases. A simplified turbulence model was used where the eddy viscosity increases linearly with height and then the model solved to get the mean flow. Remember that turbulent flow is intermittent and thus, although we only considered the mean flow, there will be significant departures from the mean that will occur from time to time in unpredictable gusts of wind. Such intermittency may not always be ignorable. The shelterbelt and crop was modelled with a quadratic drag law term that is applicable for the flow speeds considered in this scenario.

Remarkably, the geometry of the air flow through the shelterbelt was found to be largely independent of the wind speed. The reason for this is that the turbulence scales with the velocity and so the eddy diffusivity scales with the inertial effects. Similarly, the quadratic drag also scales with the inertia. Consequently the same pattern of air flow appears for all wind speeds. This was a very useful finding as it means that for the later work on the capture efficiency only changes in the magnitude of the mean flow need to be considered and not changes in the flow field due to different strength winds.

By considering the Stokes settling velocity of droplets (a balance between the gravitational effects and the buoyancy and drag) in the spray drift it was found that droplets larger than about 200μm are not present in the spray drift. For a typical spray scenario droplets of this size or larger have settled out onto the target crop and do not reach the shelterbelt nor the flow over the shelterbelt. Also we showed that the larger droplets are very effectively captured by the shelterbelt so they are not an important part of the spray drift calculations.

Evaporation of the droplets is relevant for the relatively small droplets less than about 50μm as they will significantly change their volume and hence radius in the time taken to reach the shelterbelt. For these droplets the distance of release from the shelterbelt, velocity of release and wind velocity are important factors. For larger droplets the time scales of evaporation are more relevant to the spray drift that goes over the shelterbelt and is deposited far downstream a significant time later. In the time these droplets spend near the target crop their radius does not change significantly to warrant modelling.

An existing model of the capture of droplets in the shelterbelt was analysed for the range of parameters of interest here and found to be a suitable predictor of shelterbelt efficiency. To model the capture efficiency within the shelterbelt certain assumptions about the flow had to be made. These include that the flow through the shelterbelt is horizontal, the wind is perpendicular to the shelterbelt, there is no vertical variation in the flow field or the incoming droplet concentration. The earlier flow calculations suggest that these are reasonable assumptions to make over the parameter range considered in this project.

By considering the inertia of droplets in the mean air flow we determine their capture efficiency onto individual vegetation elements. As fluid flows around each shelterbelt vegetation element the small droplets are swept along with the flow while larger particles with more inertia will deviate from the flow and possibly impact on the vegetation and be captured. Hence larger droplets have a higher capture efficiency. Small vegetation elements have a better capture efficiency since the flow around them is deflected less than that for large elements so the droplets have a higher probability of hitting the element and being captured.

The total capture efficiency of a shelterbelt is then determined as a function of the bleed velocity (the velocity through the shelterbelt), the optical porosity of the shelterbelt, and the vegetation characteristics. The optical porosity is a useful variable as it is relatively easy to measure in the field. It was then possible to calculate the bleed velocity as a function of the optical porosity and the mean wind velocity to obtain a formula for the capture efficiency of the shelterbelt. We found that there is a trade off in the efficiency of the shelterbelt with respect to the optical porosity. A dense shelterbelt (low optical porosity) has a low bleed velocity but a high capture efficiency hence very little of the flow, and hence the spray drift, enters the shelterbelt but what does is efficiently captured. Whereas a sparse shelterbelt (high optical porosity) has a high bleed velocity but a low capture efficiency. The maximum efficiency is found to be for shelterbelts with optical porosity between 10% and 30% and with fine vegetation elements (needles rather than broadleaf). Under these situations up to 50% of the spray drift is captured by the shelterbelt. Of the spray drift that is not captured the majority of it is very small droplets that are carried over the shelterbelt.

Streamlining of the vegetation elements in the wind was found to decrease the efficiency of the shelterbelt with a larger effect on the lighter vegetation elements that are easier to deflect in a wind.

One of the original assumptions was that the wind was perpendicular to the shelterbelt. For wind at an angle we find that the flow through the shelterbelt was still largely perpendicular to the shelterbelt with a suitably reduced velocity and hence all of the previous analysis still holds in this situation.

In conclusion the MISG team have verified that an existing model was suitable for use in determining the efficiency of a shelterbelt at collecting spray drift. The model is relatively simple to program and uses as inputs easily obtainable variables such as the free stream wind velocity, the optical porosity of the shelterbelt and the structure of the shelterbelt. With allowances for settling and evaporation the model was found to be valid over the range of inputs typically found for droplet distribution, wind velocity and vegetation element size. Numerical simulations of the flow field over and through the shelterbelt have justified some of the assumption used in the model and given insight into the flow characteristics that are important to consider. Although these models are never perfect representations of the real world, we believe they are suitably robust for inclusion in a larger spray drift management system. Although care must be taken to ensure that some of the original assumptions are not overly breached.

Further work on determining the optimal shelterbelt is also possible. This has implications to the design of artificial shelterbelts where the highest possible spray drift capture is desired.

DEVELOPMENT OF EMPIRICAL RELATIONSHIPS FOR METALLURGICAL DESIGN OF HOT-ROLLED STEEL PRODUCTS

New Zealand Steel Ltd, Glenbrook

Industry Representatives:
Philip Bagshaw, New Zealand Steel, Auckland, New Zealand
Ben Garside, New Zealand Steel, Auckland, New Zealand

Project Moderators:
Tim Marchant, University of Wollongong, New South Wales, Australia
Steve Taylor, University of Auckland, Auckland, New Zealand

Student Moderator:
Alysha Nickerson, Victoria University of Wellington, New Zealand

New Zealand Steel Ltd asked the Study Group to develop empirical relationships for their hot-rolled coil and plate products. These empirical formulae are intended to describe the relationship between various mechanical properties of the coil and plate products and input parameters such as processing temperatures at various stages of the operation and steel chemistry.

Once rolled these coils and plates are subjected to various tests of mechanical properties, which must have a certain minimum value for the product to pass. Only 0.2% of all coils fail but this is costly as the coils are worth about twelve thousand U.S. dollars each.

Such empirical relationships will allow the company to predict the mechanical properties of products when changes are made to the chemistry or process parameters and thus it could prove to be a useful tool to minimise the coil and plate failure rate or for the development of new products.

NZ Steel Ltd provided the Study Group with a large collection of data relating mechanical properties to the various input parameters of the hot-rolling process, which was analysed using multiple linear regression. A key measure of the analysis is the value of R^2, which should be as close to unity as possible. This is a measure of how well a variation of the input variables explains a variation in the mechanical properties.

Analyses were performed which showed that the mechanical properties do indeed depend linearly on the hot-rolling variables. Separate models were developed for each of the metallurgical properties. The model for Ultimate Tensile Strength (UTS) had the largest R^2 value of 0.94, Yield Strength (YS) was next with a value of 0.78, and Elongation had a value of 0.57.

A particular hot-rolled coil product (HA250, with a 2mm gauge) was analysed in detail. The experimental data, collected for 150 different coils, showed that the mean YS was only one standard deviation away from the YS minimum test requirement whilst the other mechanical properties were many standard deviations above their test requirement minimum values. Hence any failures of this coil product is likely to be the result of a YS test failure.

The multiple linear regression model was used to determine how much the YS could be increased by varying the steel chemistry and processing temperatures within the allowed ranges. It was found that the mean YS could be increased to about two standard deviations above the test minimum, an outcome which would dramatically reduce test failures for this product.

Of course, in reality, the optimisation problem is more complicated than this as more than one steel product uses the same chemical grade of steel. Hence optimisation of the relevant mechanical properties over a whole class of steel products needs to be done.

OPTIMISING THE RELATIONSHIP OF ELECTRICITY SPOT PRICE TO REAL-TIME INPUT DATA

Transpower Ltd, Wellington

Industry Contacts:
Conrad Edwards, Transpower Ltd, Wellington, New Zealand
Shantha Ranatunga, Transpower Ltd, Wellington, New Zealand
David Wright, Transpower Ltd, Wellington, New Zealand

Project Moderators:
Bill Whiten, University of Queensland, Brisbane, Australia
Kaye Marion, RMIT University, Victoria, Australia

Student Moderator:
Ratneesh Suri, Massey University, Auckland, New Zealand

Electrical power is paid for at a marginal price calculated by an optimisation to minimise the total cost of generation based on bids made by the power generation companies and consumer requirements. Generation companies are paid on the marginal rate (the level of the highest bid accepted) determined at their location. Similarly bulk power consumers are charged on the marginal price of supply at their location, which includes costs related to delivery to the user's location.

There are well known laws that determine the amount of power delivered along transmission lines. In the case where power lines form a loop, when a power limit is reached on one of the lines, it is necessary to bring into use more expensive generators to allow an increase in power consumption. This creates a step change in the marginal rates charged to consumers. Further it becomes more difficult to deliver power to one end of the limiting line, which is reflected in increased rates at that end. This sudden change in prices is known as a spring washer, with prices increasing on one side of the limiting line, and decreasing on the other side. This contrasts with the usual conditions where consumer costs are constant (when line costs are negligible). Under some circumstances the change in power costs can become extreme.

Transpower wanted to determine when large spring washers could occur, and also determine when the spring washer is sensitive to the physical parameters of the network.

A simplified version of the network equations were used by the MISG. These were supplied and explained by Transpower and are believed to retain the essential features of the full description.

It was found that when a simple spring washer condition exists, the costs of supply can be plotted as a straight line when the x-axis is the cumulative of the inverse transmission line admittances around the loop. Without a spring washer this line is a constant. This plot allowed an improved understanding of the nature of the spring washer. The position of the line is set, in the simple case, by two power generators. The difference between the marginal power costs at the two generators and the admittance of the line between them, determine the slope of the line, and hence the size of the step change in prices when the spring washer comes into existence. The distance from the generators determines the magnification of the prices, with the effect being similar to a lever.

Where one spring washer is supplying power to a second, an amplification can occur, similar to connected levers, and this is likely to account for the very large power charges seen occasionally.

The switch to operation as a spring washer is a step change, that occurs when a limit to the transmission lines is reached and the use of a more expensive generator becomes necessary. The exact position of this step charge in marginal rates is sensitive to all the parameters in the calculation of dispatch and pricing. The closeness of the current conditions to a large spring washer effect was considered more important than the sensitivity at the switch point.

An investigation of the linear programming equations was carried out to determine if the calculated prices will be sensitive to changes in parameter values. The conditioning number of a matrix depending on the admittance matrix was found indicate the sensitivity near the linear programming solution.

The MISG group proposed two methods to determine the closeness of a possible spring washer. The first is an investigation of near optimal vertices in the linear programming optimisation. The sensitivity figures from the linear programming optimisation can be used as the basis for this calculation. The number of vertices near to the optimum and the proportion of these investigated, will determine the reliability of this method.

The second method is simpler. Perturbations are made to the inputs, such as the demand figures, to the optimisation and the variation in the outputs recorded. The size of the perturbations can be made proportional to the amount of variation seen in the historical values of each variable. To ensure that calculations made are repeatable (necessary for auditing) pseudo random numbers from a generator with known starting conditions could be used, or alternatively quasi random numbers could be used. As part of recording the result of the perturbations, a record of the lines that reach limiting conditions can be kept.

A suggestion yet to be fully evaluated came late in the MISG. It was noted that the severity of the spring washer effect could be reduced by increasing the prices at certain generators. An optimisation that leaves the dispatch of power the same but increases the prices at certain generators to reduce the lever effect of the spring washer was proposed.

The actual power dispatch and pricing is a large and complex calculation, and thus the MISG suggestions need to be tested on small optimisations before being applied to the full dispatch and pricing calculations.

FACTORS ASSOCIATED WITH TRENDS IN BARE GROUND IN HIGH COUNTRY

Environment Canterbury, Christchurch

Industry Contacts:
Jeromy Cuff, Environment Canterbury, Timaru, New Zealand

Project Moderators:
Heather North, Landcare Research, Lincoln, New Zealand
Ken Russell, University of Wollongong, New South Wales, Australia
Rodney Weber, University of New South Wales, Sydney, Australia

Student Moderator:
Joanne Mann, Massey University, Auckland, New Zealand

Environment Canterbury Problem overview and dataset

Environment Canterbury has responsibility for promoting sustainable management of the region's natural resources. Soil erosion in the Canterbury high country has been a long-term concern, and was the subject of the problem brought to MISG. Pre-European and early European burning and grazing not only induced large tracts of tussock grassland in areas that were previously wooded, but also exposed areas of soil to further erosion by wind, rain and frost. In the 1960s to 1980s the government encouraged de-stocking on some properties, with the aim of restoring vegetative cover. In the late 1970s, a monitoring programme was set up in parts of the Canterbury high country to track the effects of lowered grazing levels.

The problem posed at MISG was to analyse the monitoring programme dataset to determine the factors associated with improvement or degradation in vegetative cover. A model resulting from this analysis would assist Environment Canterbury in recommending appropriate management strategies for different land types. Percent bare ground has been monitored at approximately 140 sites throughout the high country, at intervals of one to seven years. Record length varies from 12 to 27 years. Site characteristics specified in the dataset include soil type, topographic position and general management history. Initial analysis at Environment Canterbury suggested that soil fertility and altitude were important factors in recovery of vegetation, but that removal of the already low level of grazing had little effect.

Progress at MISG

The response variable to be studied and subsequently managed is the change in percent bare ground over time[1]. While the absolute amount of bare ground at the start of the monitoring period is informative for studying the processes by which the land first became bare, it is the change that is informative for studying the processes of subsequent revegetation (or failure of revegetation).

The group's initial data exploration included regression tree analysis. This first selects the independent variable that explains most variation in the response variable, and then clusters the values of this independent variable. The analysis produced clusters of soil series[2], where two clusters were associated with reduction in bare ground, one with increase, and two with stability (starting from extensive and

[1] Calculated as the slope coefficient of a linear regression of percent bare ground against time.
[2] Soil series are categories of soil classification.

minimal bare ground, respectively). Thus the group identified early that soil type is important (soil cluster alone explained 55% of the variation in bare ground change). Interpretation remained difficult, however, as soil series is strongly confounded with topographic position and land use. So it was unclear whether bare ground change was being affected by the inherent chemistry and physical properties of the soil, by the climate and topography in which that soil tends to occur, or by the land use management practices common on that soil type.

In addition, the group recognised that:

- Not all soil series are represented in the dataset, so a model based on these names would not be sufficiently general to be applied throughout the Canterbury high country.
- The model needed to answer questions about what land management practices are appropriate in what areas, and thus the effects of land management needed to be untangled from the effects of landform, soils and climate.

Therefore efforts were focused in two areas. One was to characterise the soil series in terms of their chemistry, topographic position and climatic zone. The other was to isolate the effects of individual management practices, specifically those of fertiliser application and oversowing, stocking intensity and rabbit control.

The four soil clusters where bare ground was decreasing or remaining stable were well characterised by soil nutrient status and general plant growing conditions. But the fifth cluster, where bare ground was increasing, was not. The data available did not explain why growing conditions were so poor in these areas, despite their being reasonably flat and at lower altitude. Across all the clusters, soil chemistry data was available for 74 of the 143 sites.

Each management factor was studied separately. For each, records were selected from the database where both levels of the factor were present in the same environment, e.g., sites with and without fertiliser application in a similar geographic area and on the same soil type. Five data blocks (regions/soil types) were available for fertiliser analysis and two for grazing analysis. Two-way analysis of variance (ANOVA) showed that fertilising/oversowing was effective in increasing vegetative cover on all soil types, though the magnitude of that change was greater at low altitude than at high. No difference in revegetation rate could be detected between low intensity grazing (less than one stock unit/ha) and no grazing. No comparison was available between “high” intensity grazing (1–4 stock unit/ha) and no grazing.

The effects of rabbit management had to be investigated in a different way, as this treatment is applied over broad areas, meaning no side-by-side comparison of treatment versus no treatment is available. In a simple comparison of mean change in bare ground, revegetation proceeded more quickly when rabbits were controlled on sites that were also fertilised. However, of the non-fertilised sites, degradation of vegetation cover appeared to be faster on sites where rabbits were controlled. It was thought that this was due to another (undefined) factor on those particular soils where rabbit control (but not fertiliser application) had taken place. No definite conclusion could be reached on the effects of rabbit control though it did appear to help on some sites.

A final model was developed which depended on fertiliser application, percent bare ground at the start of the monitoring period, annual average temperature (strongly correlated with altitude) and winter rain (probably supplying moisture for the spring growth flush). Several interactions of variables were also significant. This model explained 63% of the variation in bare ground change, compared with an earlier model that contained the soil series names plus other factors, which explained 77%

of the variation. However, the final model was generic (not dependent on soil names). In addition, the group is aware that soil chemistry and physical properties are important, but this information was not available for all sites so it was not included in the model.

Conclusions and future work

- A general model was developed for change in percent bare ground, where the significant factors include fertiliser application, starting percent bare ground, annual average temperature and winter rainfall.
- Soil chemistry and physical properties also appear to be important. Further data gathering and analysis is needed to include these in the model.
- Fertiliser application and oversowing has a strong positive effect on revegetation on all soils tested, with the effect strongest at low altitude.
- Little effect on revegetation was observed from de-stocking (from low intensity grazing to none).
- The effects of rabbit control were difficult to interpret, though there seemed to be some extra positive effect on the better soils that were also fertilised.

IMPLEMENTING LANIER'S PATENTS FOR STABLE, SAFE AND ECONOMICAL ULTRA-SHORT WING VACU- AND PARA-PLANES

Backyard Technology, Queensland

Industry representatives:
Pat Howden, Backyard Technology, Queensland, Australia

Project Moderators:
Graeme Hocking, Murdoch University, Perth, Western Australia
Yvonne Stokes, University of Adelaide, Adelaide, Australia
Winston Sweatman, Massey University, Auckland, New Zealand

Backyard Technology are interested in aspects of aircraft design described by Edward H Lanier in a series of six patents obtained from 1930 to 1933. Lanier's overall aim was to provide an exceptionally stable aeroplane that would both fly normally and recover from undesirable attitudes without pilot aid. Backyard Technology were specifically interested in Lanier's idea of creating a vacuum cavity in the wing by replacing a section of the upper skin of the wing with a series of angled slats, believing that this wing design would give superior lift and stability compared to typical wing designs.

The MISG group approached this problem with a background reading of Lanier's patents, calculations and study based on the basic theory of aerodynamics, and numerical simulations using the package Fastflo. The complexity of the situation and lack of experimental data made mathematical modelling rather difficult. To the limited extent to which modelling was possible there was no indication that modern aeroplane design had overlooked a major feature which would improve flight characteristics. Lanier's designs from the 1930s are now over seventy years old and are perhaps more readily related to the pioneering aircraft of the early 1900's than those of the present day.

Details obtained of aircraft studies based on Lanier's patents from the 1930's were very limited. A few non-technical articles appeared in contemporary popular science magazines. We were unable to find any reference or citation of the designs in the scientific literature. The main sources of information which we had available were Lanier's six US patents themselves.

Lanier's six patents are each for an entire aircraft design and include commentary on matters such as the windows and landing gear. The aspect of the design of interest is the presence of cavities or slats on the upper surface of the wing and fuselage. In the early patents these were claimed to improve stability; later patents claimed enhanced lift as well. Lanier in part attempted to explain added lift by claiming that a partial vacuum is set up in the aeroplane's wings and body which could lead to increased buoyancy. He also appears to anticipate an additional lift effect by exposing the inside top surface of the lower shell of the wing. Being patents the descriptions are on the whole general without detailed measurements.

During our study, buoyancy calculations indicated that the effect of reducing air density within the wings would have an almost negligible effect, perhaps lightening the aeroplane by a few hundred grams. The other arguments provided by Lanier for additional lift similarly appear unconvincing.

The numerical simulations using Fastflo were performed at different angles of attack for a two-dimensional fluid flow over an aerofoil shape that superficially resembled the "Clarke Y wing" profile. To complement flow over the basic shape, the flow was also considered around a similar shape with a cut away cavity and slats to resemble the Lanier design. There was very little apparent difference in lift between the experiments although the Lanier design had a noticeably increased drag in particular for low angles of attack. (For higher angles separation at the blunt nose of the wing meant that the presence of a cavity had less effect on the drag.)

To illustrate the general features of a flow across a slot cavity further numerical simulations were conducted. As a result of the flow a vortex is created in the slot. The vortex flow and pressure in the slot varied with the angle, width and depth of the slot. In general the pressure was higher in the slot than in the flow immediately above it but the geometry could be adjusted to give regions of lower pressure.

In general, wing profile designs must balance lift with drag. Fatter wings tend to have higher lifts for a given speed, however, they also tend to have increased drag making it more difficult to attain speed. In addition, fatter wings at higher speed are more likely to induce separation of the flow and hence stall (loss of lift). At the time of Lanier's patents wings tended to be narrow in profile. However, one of his patents includes an illustration of a conventional wing together with the slatted wing of the patent design. The slatted wing is much fatter in profile than the conventional wing in the picture and if in practice this were the case then that could provide an explanation of increased lift for the Lanier aeroplane.

The investigation of Lanier's designs could be extended. Probably the most natural approach would be to experimentally compare aerofoils using wind tunnel experiments. Improved numerical experiments might also help illuminate the problem. Further historical research might find out more from the 1930's to add to the largely anecdotal information available. The possible stability features at low speed appear the most promising aspect. It could be interesting to see how the Lanier design compared with contemporary aircraft of the 1930's. However, it appears unlikely that any such study would have an impact on modern aircraft design.

MODELLING THE PHYSICS OF HIGH SPEED PRODUCT-WEIGHING

Compac Sorting Equipment Ltd, Auckland

Industry Contacts:
Gavin Reeve, Compac Sorting Equipment, Auckland, New Zealand
Nigel Beach, Compac Sorting Equipment, Auckland, New Zealand

Project Moderators:
Mark McGuinness, Victoria University of Wellington & Korean Advanced Institute of Science & Technology (KAIST)
David Jenkins, CSIRO, WA, Australia

Student Moderator:
Mr Galkadowite Senaratne (Sena), Massey University, Auckland, New Zealand

Compac Sorting Equipment Auckland (Compac) manufactures and exports high-speed, accurate sorting systems for fruit and vegetables. Their sizers operate at between 10-15 pieces of fruit per second per lane. They weigh each piece of fruit individually, using a pair of cantilever loadcells, in less than 1/10 of a second. Compac wanted a mathematical model of the weighing process, that will help them to accurately weigh heavier fruit (more than 250g) at higher speeds (in less than a tenth of a second). They also asked for help with easing back on the size and stability of the weighing assembly, which would reduce the physical size and manufacturing cost of the overall system.

The signal from each loadcell is amplified and low-pass filtered. The tail end of the signal is averaged, to obtain a mass that is required to be accurate to less than 1g.

The MISG group studied the frequency components present in the output of loadcells, for various sized fruit running at various speeds. Apart from a high frequency which is of no concern to Compac, we typically observed two lower frequencies, which reduce as fruit mass increases, causing difficulties with oscillations getting past the analogue filter. An option is to reduce the cutoff frequency of the lowpass filter. However, this might not help at higher operating speeds, as there may not be enough time for the filtered signal to level off.

We developed models for simple harmonic motion in the vertical direction, as well as a side to side rocking motion between the two loadcells. Our modelling suggests that the reduction in the low frequency is generally to be expected as mass increases.

The key parameters are mass (and its distribution), effective spring constant, and effective damping. An option is to stiffen and reduce the effective mass of the loadcells, thereby increasing oscillation frequency and damping. However, stiffer loadcells require greater amplification of the signal from the loadcell and are more vulnerable to drift, thus potentially reducing the overall accuracy of weighing.

A possible strategy is to use the understandings from the modelling, rather than just filtering out the oscillations. We showed that it is feasible to infer key parameter values from the oscillation frequency, damping rate and oscillation amplitude. A joint approach, digitally combining this information with filtered output, might be faster and more accurate than the present setup. In order to do this, a model that takes into account the structure of the loadcells and attached plates has been proposed. This model is more complex than a damped oscillator and involves a few time-dependent frequencies but is a promising direction for continued work.

People at MISG who contributed to this project included Ian Howells, Pol Haji, Paul Milliken, Kiwan Jeon, Sungmin Cho, Hyeon Je Cho, Boyun Seo, Namgil Lee, Alona Ben-Tal, Tony Gibb, John Cogill, Mike Plank, Frank de Hoog, Shixiao Wang, Sam Howison, and Carlo Laing.

Special thanks go to Gavin Reeve from Compac for his time, patience and expert help.

DETERMINING TEMPERATURE CONTROL OF WASH WATER IN A LAUNDRY ENVIRONMENT

Fisher & Paykel, Auckland

Industry Contacts:
Steven Mansell, Fisher and Paykel, Auckland, New Zealand
Ian McGill, Fisher and Paykel, Auckland, New Zealand

Project Moderators:
Clive Marsh, Canesis, Canterbury, New Zealand
Andy Wilkins, Queensland University of Technology, Queensland, Australia

Student Moderator:
Jane Thredgold, University of South Australia, Adelaide, Australia

Fisher and Paykel (F&P) are developing a new model of washing machine. One of its key features will be that it uses less water. It is important to regulate the operating temperature of washing machines since if they operate hotter than the user-selected temperature there is a risk of damage to clothes and if they operate below the user-selected temperature there is a risk of incompletely dissolved detergent being sprayed onto clothes, which is also undesirable. F&P seek to improve their temperature regulation strategies from the current state-of-the-art. Further, since the new machine will have a smaller mass of water relative to clothes load, the impact of abnormal clothes loads and of start-up disturbances in water supply temperatures (e.g. cold slugs in hot water supply) on the bulk temperature is greater. Thus a thorough review of temperature regulation strategies is well motivated.

Temperature regulation is achieved through feedback of signals from temperature sensor(s) and manipulation of the inlet valves for hot and cold water. The temperature should be regulated throughout the fill cycle since significant deviations from the set point at any time during the fill have negative consequences. Generally, once the fill cycle is complete, the temperature will not fall significantly unless further load is placed on the system (wet, cold clothes added after 'fill' is complete). There is no simple way to ameliorate the effects of such disturbances without using additional water which is undesirable. The merits of the actions that can be taken after the end of the fill cycle were only briefly considered and are effectively outside the scope of this project. It should be noted that an 'exception case' is when the clothes are virtually saturated and cold at the start, in this case the mass of water added may not be sufficient to regulate the temperature.

Specifically, F&P want a better understanding of the impact of disturbances such as abnormal clothes loads and of start-up disturbances in water supply temperatures on the bulk temperature, this is provided by the model produced. Further, they need to design the most effective control strategy. This includes selecting the best placement of the temperature sensor and a benefit analysis of the use of multiple temperature sensors.

The machine is connected to hot and cold water supply lines with throttling valves. These valves are on/off type and when on have a throttle which gives flowrates which are effectively independent of supply pressure as long as it is above a threshold of ~ 1 bar. The supplies mix in a small mixing chamber then enter the sump. The detergent is placed in the sump. From the sump the water is pumped through a recirculation line and is sprayed onto the clothes which reside in the rotating bowl above the sump. Water which is not absorbed by the clothes drips back into the sump.

It was established that the sump temperature is the ‘process variable’, i.e. the thing that needs to be regulated as this represents the temperature at which water is sprayed onto the clothes and this is where detergent is entrained and needs to be dissolved in the water. A mass and energy balance analysis was developed which relates sump temperature to energy from water supplies, clothes loads and energy losses. It was determined that energy losses to ambient are negligible (as long as the lid is not opened for long periods of time) and that the heat load of the clothes is dominated by how much cold water is input with the clothes. The steady state balance is mathematically represented as a set of algebraic equations which can easily be analysed by spreadsheet. This describes the envelope of water supply temperatures and load characteristics which can be tolerated whilst attaining the target sump temperature. The dynamic balance describes the time history of sump temperatures and is mathematically described by a set of differential equations. Simulation software was developed for these equations in the software packages Mathematica and MATLAB. The dynamical model can be used to determine if the system dynamics permit the control strategy to reject the impact of disturbances sufficiently quickly to avoid significant temperature deviations from the target value.

The dynamical model included a model of water and heat flow to and from the clothes. This model considered the clothes to be layered. Upon application of the recirculation water, the top layer becomes completely saturated and only then does it start releasing water to the next layer down and to the sump through its sides (via the perforations in the drum). In this model, therefore, the upper portion of the clothes becomes completely saturated while the lower portion remains untouched, and the constant application of the recirculation water causes the junction between the two phases to constantly move downwards. The top layers will also be close to the temperature of the recirculation water, with the temperature decreasing for deeper layers, while the lower, untouched layers will be at their initial temperature. This model predicts that the drip rate will be small initially, as the upper layers absorb most of the recirculating water. This rate will increase with time as more and more of the clothes start dripping from their sides through the perforated drum to the sump. The model also predicts that the temperature of the drip water stays roughly constant during the fill. The control implications of this model are that, during the early and middle stages of the fill, it is likely that the impact on the sump temperature of the cool drip-down flow can be controlled by manipulation of the hot feed. However, towards the end of the fill when the drip-down flowrate is higher and still cool, it may not be possible to completely control the sump temperature since the feed flowrate will be low relative to the drip-down flowrate. In particular, during the final stages of the fill when there is oscillation between sump full, feed disabled and sump not full, feed enabled modes it may be difficult to control the sump temperature. So, for wet, cold clothes loads a critical issue requiring further model validation effort, is whether the drip-down flow is still cool, i.e. how early in the fill any cold water in the clothes can be displaced down to the sump where its impact will be measured and controlling measures taken.

A simple control strategy was suggested which uses feedback from a sump temperature sensor was presented. The dynamic model and analysis thereof via the MATLAB code will determine if this strategy is sufficient. Preliminary simulations using this code suggest that in most situations the sump temperature can be controlled to within F&P's specifications (± 2 degC).

Enhancements suggested to this include, additional measurement and feedback (in a cascade strategy) of the temperature in the supply mixing chamber to assist rejection of supply side disturbances, on-line identification of supply temperatures, load identification using information from the load cell and use of system memory to tune the machine to a particular installation and assist with diagnostics.

The filling algorithm was also reviewed and found to be effective and should result in the clothes being saturated at the end of the fill with an appropriate level of water in the sump. The temperature control strategy will determine the relative opening times of the hot and cold valves but the greater the overall openings, the shorter the 'fill'. However, fast filling will make phase lags incurred due to sensor and actuation dynamics more significant and will impact negatively on the timely rejection of disturbances, the significance of these impacts can be determined from analysis of the dynamic model.

CONCLUDING REMARKS

MISG2005 was sponsored by the list on the next page. They, along with the organisations presenting problems, provided the financial support which made it all possible. This is gratefully acknowledged by all of us in CMI. The Director's prize for the best remark "Overheard in passing" was awarded to Ron Thatcher and Ken Russell who were heard to say…

"Have we seen the plot yet?" Ron Thatcher

"No we have lost the plot." Ken Russell

The ANZIAM organisation has asked us to do MISG2006 which will be in the same style and location as MISG2005. The dates for this are: -

30 January – 3 February 2006
at Massey University, Auckland.

Graeme Wake, Director, May 2005

email: g.c.wake@massey.ac.nz

SPONSORS

ANZIAM
Financial Sponsor

Massey University
Host of MISG2005

CSIRO
Financial Sponsor

NZMS
Financial Sponsor

Technology NZ
Financial Sponsor

Industrial Research
Financial Sponsor

Albany Executive Motor Inn
Financial Sponsor

Backyard Technology
Problem Sponsor

Compac Sorting Equipment
Problem Sponsor

Environment Canterbury
Problem Sponsor

Fisher & Paykel
Problem Sponsor

Lincoln Ventures
Problem Sponsor

New Zealand Steel
Problem Sponsor

Transpower
Problem Sponsor