Maths in Industry in Australia – Early Days

Graeme C Hocking

Mathematics and Statistics, Murdoch University, Perth, Australia

e-mail: G.Hocking@murdoch.edu.au

Organized via the Asia-Pacific Consortium of Mathematics for Industry [1]

1 Introduction

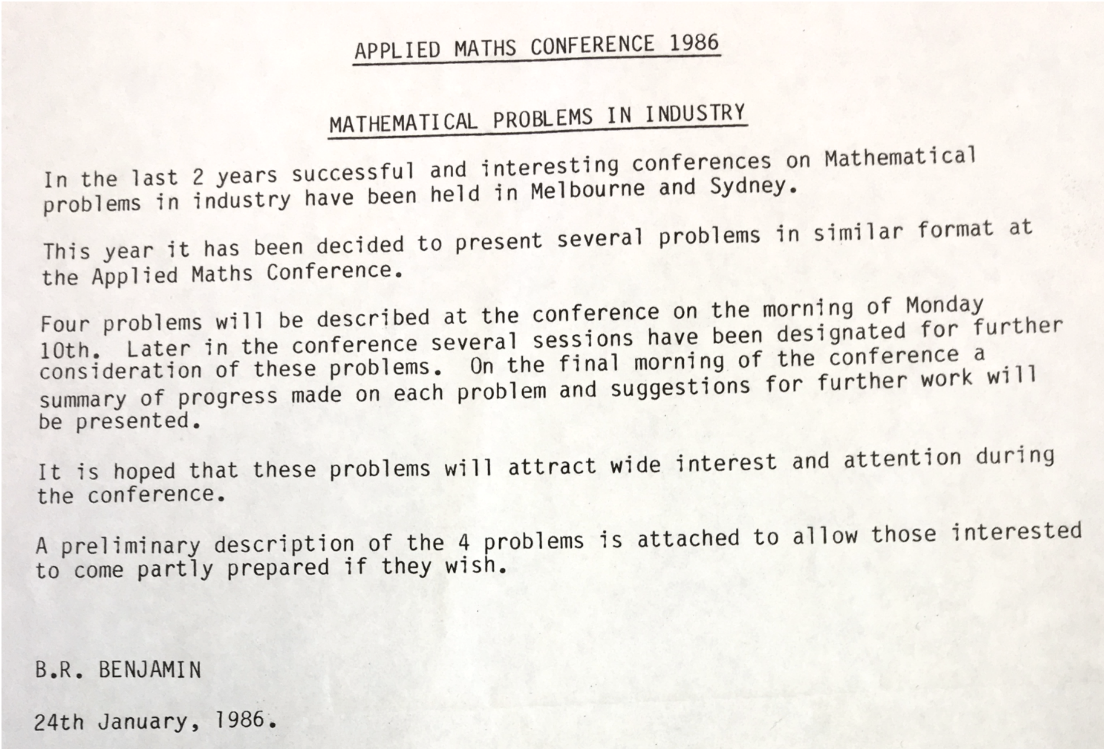
I will give a brief summary of my recollections of study groups in Australia. This is by no means definitive, and others may recall more or have better knowledge of this. After that I will outline some interesting problems, including both "successes" and "failures", on which I have worked over the years.

2 The Beginning - Early years and general comments

My earliest exposure to the concept of Mathematics-in-Industry was at the 1986 Division of Applied Mathematics (DAM) Conference (now the ANZIAM conference) at Wirrina, just south of Adelaide. In fact this was not my first contact with industrial applications of mathematics because I was aware of the work that had been done by the late Professor Ernie Tuck (1939–2009) from Adelaide University on jet-stripping of steel coatings [2]. This problem re-appeared later at two study groups in which I was involved and I have developed a particular affection for it (see later). In fact there had been a Mathematics-in-Industry Conference held at the Ormond College at the University of Melbourne, organized by Kerry Landman and John and Hilary Ockendon in 1984 and another at the University of NSW in December, 1985, organized by Noel Barton from CSIRO, but I was unaware of this at the time.

A clip from the abstract booklet for the 1986 conference is shown in Figure 1 that describes the concept to the participants of the conference. Figure 2 shows an extract from the timetable for the same conference, including evidence that I was actually there!

The problems at the conference are illustrated by another extract in Figure 3, showing brief introductions to the 4 problems considered; "Automatic Pattern recognition in distress communication channels", "Longitudinal surge in road tanker design", "Lot sizing in materials requirements planning system" and "Monitoring of gas injection in petroleum reservoirs".



APPLIED MATHS CONFERENCE 1986

MATHEMATICAL PROBLEMS IN INDUSTRY

In the last 2 years successful and interesting conferences on Mathematical problems in industry have been held in Melbourne and Sydney.

This year it has been decided to present several problems in similar format at the Applied Maths Conference.

Four problems will be described at the conference on the morning of Monday 10th. Later in the conference several sessions have been designated for further consideration of these problems. On the final morning of the conference a summary of progress made on each problem and suggestions for further work will be presented.

It is hoped that these problems will attract wide interest and attention during the conference.

A preliminary description of the 4 problems is attached to allow those interested to come partly prepared if they wish.

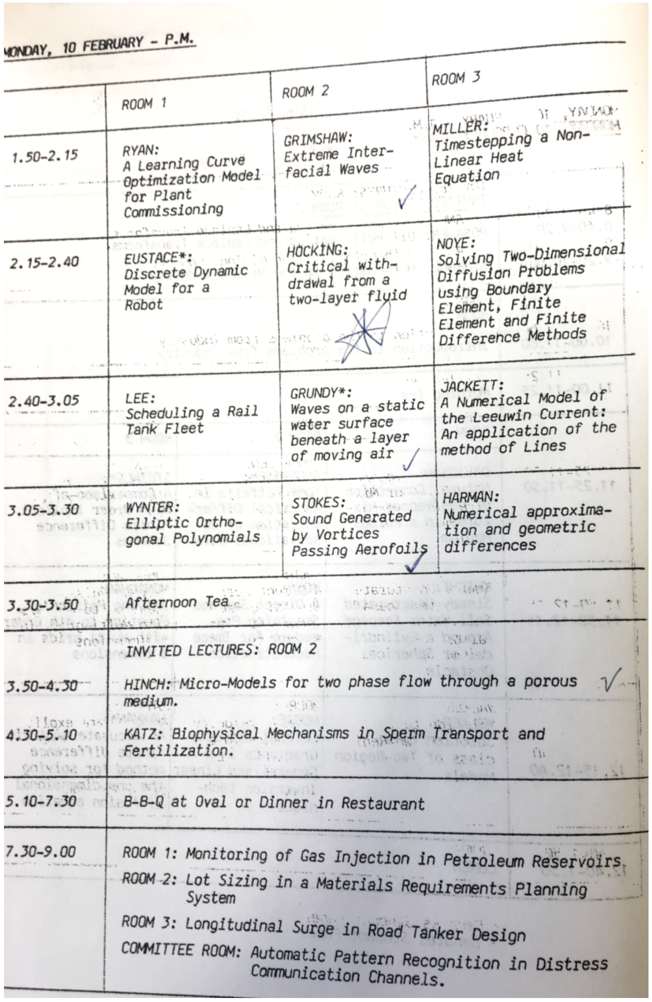
B.R. BENJAMIN

24th January, 1986.

Figure 1: Extract from the 1986 "Division of Applied Mathematics Conference" (now the ANZIAM Conference) book of abstracts showing comments on the "Mathematical Problems in Industry" work proposed.

Standalone study groups began around this time and since then have been run on a regular basis - usually a rolling 3-year cycle. The organizers and locations have been (see [3]);

- Kerry Landman, John and Hilary Ockendon, 1984, Ormond College, University of Melbourne,
- Noel Barton, 1985, University of NSW, Sydney
- Frank de Hoog, 1986, Monash University, Melbourne
- Noel Barton,
  - University of NSW, Sydney, 1988
  - Monash University, Melbourne, 1989
  - Bond University, Gold Coast, 1990
  - University of South Australia, Adelaide, 1991
  - Maquarie University, Sydney, 1992
  - University of Melbourne, Melbourne, 1993
- Kerry Landman,



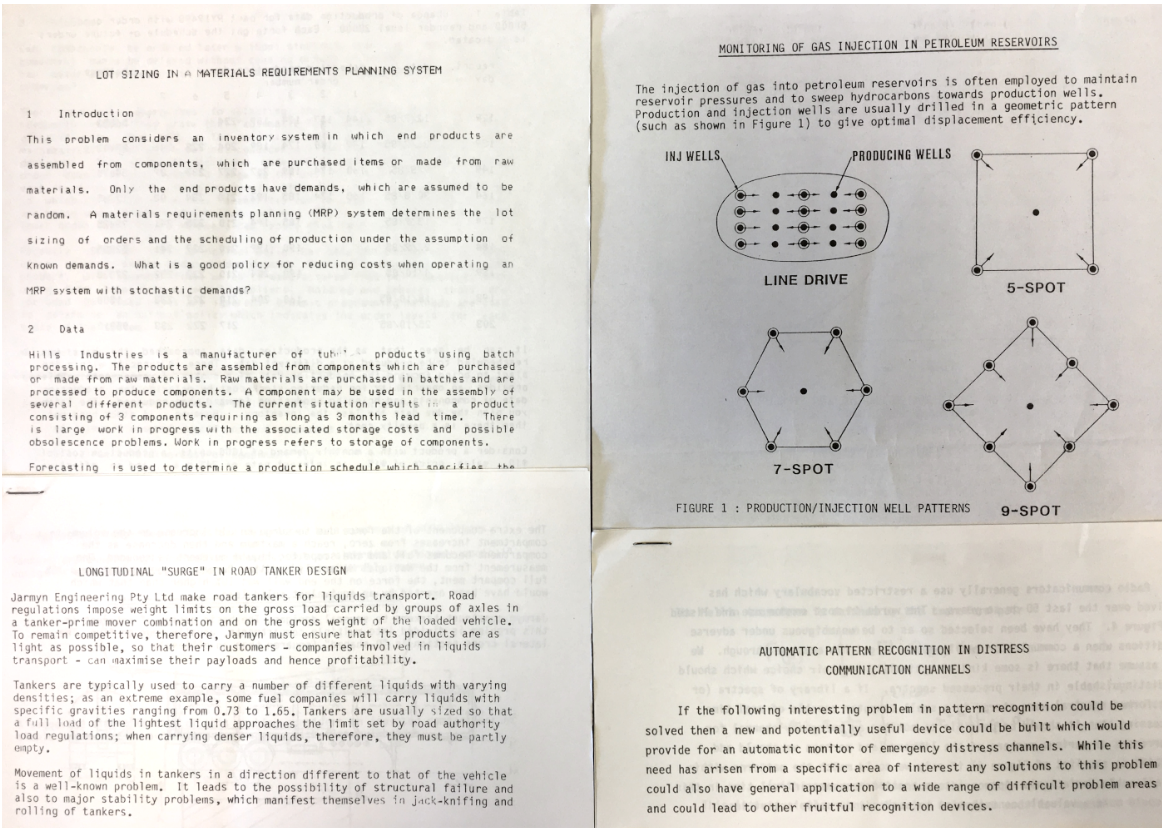
MONDAY, 10 FEBRUARY – P.M.

	ROOM 1	ROOM 2	ROOM 3
1.50–2.15	RYAN: A Learning Curve Optimization Model for Plant Commissioning	GRIMSHAW: Extreme Inter-facial Waves	MILLER: Timestepping a Non-Linear Heat Equation
2.15–2.40	EUSTACE*: Discrete Dynamic Model for a Robot	HOCKING: Critical with-drawal from a two-layer fluid	NOYE: Solving Two-Dimensional Diffusion Problems using Boundary Element, Finite Element and Finite Difference Methods
2.40–3.05	LEE: Scheduling a Rail Tank Fleet	GRUNDY*: Waves on a static water surface beneath a layer of moving air	JACKETT: A Numerical Model of the Leeuwin Current: An application of the method of Lines
3.05–3.30	WYNTER: Elliptic Ortho-gonal Polynomials	STOKES: Sound Generated by Vortices Passing Aerofoils	HARMAN: Numerical approxima-tion and geometric differences
3.30–3.50	Afternoon Tea		
	INVITED LECTURES: ROOM 2		
3.50–4.30	HINCH: Micro-Models for two phase flow through a porous medium.		
4.30–5.10	KATZ: Biophysical Mechanisms in Sperm Transport and Fertilization.		
5.10–7.30	B-B-Q at Oval or Dinner in Restaurant		
7.30–9.00	ROOM 1: Monitoring of Gas Injection in Petroleum Reservoirs ROOM 2: Lot Sizing in a Materials Requirements Planning System ROOM 3: Longitudinal Surge in Road Tanker Design COMMITTEE ROOM: Automatic Pattern Recognition in Distress Communication Channels.		

Figure 2: Extract from the Timetable of the 1986 Conference, showing the evening timetabling of the event

  - University of Newcastle, Newcastle, 1994
  - University of Melbourne, Melbourne, 1995-1997

- Sean McElwain, Queensland University of Technology, Brisbane, 1998-1999
- Phil Howlett, University of South Australia, Adelaide, 2000-2003
- Graeme Wake et al, Auckland and Massey Universitys, New Zealand, 2004-2006
- Tim Marchant, Maureen Edwards, Geoff Mercer, University of Wollongong, Wollongong, 2007-2009,
- John Shepherd, Royal Melbourne Institute of Technology, 2010-2012
- Troy Farrell et al, Queensland University of Technology, Brisbane, 2013-2015
- Peter Pudney, University of South Australia, Adelaide, 2016-2019



LOT SIZING IN A MATERIALS REQUIREMENTS PLANNING SYSTEM

1 Introduction

This problem considers an inventory system in which end products are assembled from components, which are purchased items or made from raw materials. Only the end products have demands, which are assumed to be random. A materials requirements planning (MRP) system determines the lot sizing of orders and the scheduling of production under the assumption of known demands. What is a good policy for reducing costs when operating an MRP system with stochastic demands?

2 Data

Hills Industries is a manufacturer of tub[illegible] products using batch processing. The products are assembled from components which are purchased or made from raw materials. Raw materials are purchased in batches and are processed to produce components. A component may be used in the assembly of several different products. The current situation results in a product consisting of 3 components requiring as long as 3 months lead time. There is large work in progress with the associated storage costs and possible obsolescence problems. Work in progress refers to storage of components.

Forecasting is used to determine a production schedule which specifies the

LONGITUDINAL "SURGE" IN ROAD TANKER DESIGN

Jarmyn Engineering Pty Ltd make road tankers for liquids transport. Road regulations impose weight limits on the gross load carried by groups of axles in a tanker-prime mover combination and on the gross weight of the loaded vehicle. To remain competitive, therefore, Jarmyn must ensure that its products are as light as possible, so that their customers - companies involved in liquids transport - can maximise their payloads and hence profitability.

Tankers are typically used to carry a number of different liquids with varying densities; as an extreme example, some fuel companies will carry liquids with specific gravities ranging from 0.73 to 1.65. Tankers are usually sized so that a full load of the lightest liquid approaches the limit set by road authority load regulations; when carrying denser liquids, therefore, they must be partly empty.

Movement of liquids in tankers in a direction different to that of the vehicle is a well-known problem. It leads to the possibility of structural failure and also to major stability problems, which manifest themselves in jack-knifing and rolling of tankers.

MONITORING OF GAS INJECTION IN PETROLEUM RESERVOIRS

The injection of gas into petroleum reservoirs is often employed to maintain reservoir pressures and to sweep hydrocarbons towards production wells. Production and injection wells are usually drilled in a geometric pattern (such as shown in Figure 1) to give optimal displacement efficiency.

INJ WELLS
PRODUCING WELLS
LINE DRIVE
5-SPOT
7-SPOT
9-SPOT

FIGURE 1 : PRODUCTION/INJECTION WELL PATTERNS

AUTOMATIC PATTERN RECOGNITION IN DISTRESS COMMUNICATION CHANNELS

If the following interesting problem in pattern recognition could be solved then a new and potentially useful device could be built which would provide for an automatic monitor of emergency distress channels. While this need has arisen from a specific area of interest any solutions to this problem could also have general application to a wide range of difficult problem areas and could lead to other fruitful recognition devices.

Figure 3: Problems discussed at the DAM conference in 1986

- Natalie Thamwattana, University of Newcastle, Newcastle, 2020-

The first Australian Study group that I attended was in 1991 at the University of South Australia. In 1998, at the Queensland University of Technology, I was very fortunate to be asked to moderate a problem, and I can recall working on the "Design of an ultrasonic nebulizer" [4]. This event completely changed the direction of my research career and for that I am very grateful.

Over the years there has been a diverse range of interesting problems at the Australian Study Groups. Those in which I have been involved include;

- Optimisation of an ultrasonic nebulizer [4]
- Cavity formation and entrainment in deep submerged waterjets [5]
- Analysis of Train Wheel Noise [6]
- Implementing Lanier's patents for stable, safe economical ultra-short wing vacu- and para-planes [7]
- Tsunami risk modelling for Australia: understanding impact of data [8]
- Coating deformations in the continuous hot dipped gavanizing process [9]
- Math models for uptake of agrichemicals through plant leaves [10]

- Flow of non-Newtonian fluids in open channels [11]
- Pressure drop in pipelines due to pump trip event [12]
- Modelling microbial pollutant loads associated with surface water run-off in water supply catchments [13]

2.1 Brief Aside – South African Study Groups

Over the last 15 years, starting in 2004, Professor David Mason, (assisted by Ashleigh Hutchinson and others) from the University of Witswatersrand, Johannesburg, South Africa has run annual study groups [14]. They have generally alternated between University of Wits in Johannesburg and the African Institute for Mathematical Sciences (AIMS) in Cape Town. The groups have a strong African flavour, from mining to environmental to commercial. More than any other that I have attended, they have a very strong training component for African students, with many more students than research academics. Problems including mine collapse, Johannesburg bus system, user agent strings in cell phones, car parking optimisation, water seepage in mines, automatic pattern recognition, exploding lakes, rogue waves, extreme swimming water fins, curve on a football at altitude and a number of problems from the important sugar industry [14]. I recommend it as an interesting exercise in a different environment.

2.2 Does a study group ever fail?

In my first few study groups I worried about whether we would "solve" the problems. However, I realized fairly quickly that the purpose was not always to get a complete solution. At the very least, most study groups provide the industry partner with a different perspective. I've only ever seen ONE industry partner complain openly, and that was without any sensible basis (the group proved that their current practice was almost optimal and that they could not do it any better - they wanted an improved process). Gains range from complete solution of the problem (often in Operations Research or Optimisation) to a significant improvement in processes, to a better understanding or a new way forward. Academics gain a lot by exposure to new and interesting problems, along with different techniques, thus enhancing both their research and teaching capabilities.

However, sometimes WE may feel we could have done more, or perhaps just get an interesting problem for further work. Here are a couple from Australia/New Zealand study groups.

2.2.1 Most interesting "failures"

Breakage of metal "swimmers" [15]. Metal is wound around small metal knobs of various sizes, called "swimmers", to create piping. The process occurs at high speed and every now and then the "swimmers" fail. This occurence can be quite expensive and there was no observed reason for the failure. The company had almost no data and until "recently" (1991) the engineers had been discouraged from collecting data. There was no information on when the swimmers failed, or whether particular sizes failed more often or sooner. Very little progress was made on the problem and the only suggestion available was to collect more data and then come back (they never did).

Optimisation of an Ultrasonic Nebulizer [4]. A nebulizer is a medical device to deliver atomized drug. The industry person had designed an extremely efficient, small, tubular device in which the drug was atomized using vibrations of an ultrasonic crystal. The problem was that the atomized particles were too large to inhale effectively. It turned out that the particle size is proportional to the frequency of oscillation, a property of the crystal. At that time (1998), such crystals were not available, so the solution was really to just wait. However, this problem is REALLY interesting because of the atomization process, in which a small jet of liquid appears out of nowhere as the crystal is activated. The problem led to subsequent work and is still on my to-do list for future work. This is the best kind of failure!

3 Longest running problem? - Jet-stripping

I will spend the remainder of this session discussing one of the longest running, and also my favourite study group problem. It pre-dates the Australian Study Groups and I first met it during my honours year at Adelaide University. Professor Ernie Tuck was contacted by Port Kembla steel works (now Bluescope steel) to assist in the prediction of coating thickness during the continuous coating process. The environment in the factory made the conditions too hot to inspect in person. This problem returned to MISG in Australia [9] and also in Ireland (Dublin) [16]. This is one of my favourite examples of modelling fluids and I use it in teaching as an example of a real problem and also as an example of uni-directional flow.

In this problem, sheets of metal are passed through a molten bath of alloy that coats the sheeting. Air jets strip off the surplus coating giving a layer of prescribed thickness, see Figure 4. Higher pressure of the jet leads to a thinner coat whereas if the sheet moves at a slower speed then the coating will be thicker.

The study groups were asked to consider problems involving defects in the coating as the manufacturer tried to extend the range of values at which the process could proceed to create thinner coatings and more product in less time.

3.1 Uni-directional flow - Exact Solution for gravitational flow.

I don't have time in this talk to discuss the full problem but since this is a beautiful example of mathematical modelling I will outline the process that provides the solution for the case in which there is no air jet, i.e. gravity stripping. Full details of the problem with the air jet included can be found in the work by Tuck [2].

We assume that the fluid is viscous and incompressible and that the sheet of metal is broad and flat and so can be considered as two dimensional. Near the bath the flow is very messy, and at some time after it has left the bath the coating is beginning to solidify. There is a region in between where the flow can be considered as being steady. The main assumption in obtaining a solution is that the flow is unidirectional. Therefore we begin with

$$u_x + v_y + w_z = 0, \qquad \text{the Continuity equation,} \tag{1}$$

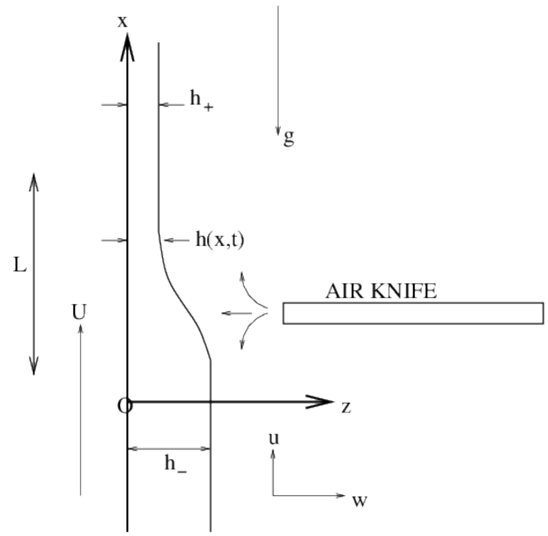


Figure 4: The sheet passes through molten zinc alloy at around 2 m/s and the air jet at is about 2 mm across and travels at around 200 m/s. The knife strips the coating to the desired thickness.

where (u, v, w) are the velocity components in the (x, y, z) directions respectively. The sheet is travelling upward in the x-direction, with gravity oriented downward. The z-direction is oriented perpendicular to the sheet. Under the uni-directional flow assumption we can then say $v = w = 0$, leaving $u_x = 0 \Rightarrow u = u(z)$ only.

The Navier-Stokes equations, with the assumption that now $u(z)$ only,

$$\frac{D\mathbf{q}}{Dt} = -\frac{1}{\rho}\nabla p - g\mathbf{i} + \nu\nabla^2\mathbf{q} \tag{2}$$

lead to $p'(y) = p'(z) = 0$, and pressure p is a function of x only so that

$$0 = -\frac{1}{\rho}\frac{\partial p}{\partial x} - g + \nu u_{zz}. \tag{3}$$

Finally, we need to set up some boundary conditions, noting that the liquid metal sticks to the sheet, stress components on the surface are zero on the outer edge and the pressure along the free surface is constant, $p'(x) = 0$. Therefore, the full problem becomes

$$\begin{aligned} \frac{d^2u}{dx^2} &= g/\nu \\ u = U, &\;\; z = 0, \\ u_z = 0, &\;\; z = h, \end{aligned}$$

where $z = h$ is the outer surface of the coating. Integrating twice gives a full solution for the velocity profile within the coating of

$$u(z) = U + \frac{g}{2\nu}z(z - 2h).$$

This velocity profile is valid for any h, but we don't know the value of h. It must be determined by the flow out of the bath and it is at this point that some modelling intuition is required. The appropriate condition turns out to be the maximum flux criteria. This says that if too much fluid is pulled upward it will fall off, whereas if not enough is pulled upward then more will attach itself. The flux Q is

$$Q = \int_0^h u(z)dz \ = -\frac{g}{3\nu}h^3 + Uh$$

and to maximise Q, $\frac{dQ}{dh} = 0$

$$\Rightarrow -\frac{g}{\nu}h^2 + U = 0 \Rightarrow h^* = \sqrt{\frac{U\nu}{g}}.$$

This results in the speed on the free boundary being $u(h^*) = U/2$ and so the maximum flux is given by $Q_{max} = \frac{2}{3}U^{2/3}(\nu/g)^{1/2}$. The dependence of coating thickness on speed, viscosity and gravity is now given clearly, and has subsequently been verified in factory conditions. The coating thickness obtained under gravitational flow are generally too large for commercial coatings, and hence the air jet must be employed to produce the required product.

Further work on the effect of the air jet can be found in Tuck [2] and on the stability of the coating in Hocking et. al. [16, 17]. This is an elegant example of mathematics-in-industry and provides an excellent problem for teaching real mathematics and motivating students at the same time as giving a solution to a real problem.

4 Final Comments

Study Groups in Australia and NZ have been generally successful and have grown in popularity over the last 35 years. Support from academics definitely depends on the nature of the problems, while industry has had some spectacular successes in participation. A number of industries continue to return. The next MISG in Australia will be at the University of Newcastle, NSW in late January 2020.

I would like to sincerely thank the organizers of this session, Kenji Kajiwara, Yasuhide Fukumoto, Osamu Saeki and Masato Wakayama for their invitation to participate.

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