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# **FLOW OF PARTICULATE MATERIAL FROM A TOPDRESSING AIRCRAFT**

A thesis presented in partial fulfilment of the requirements of the degree of Doctor of  
Philosophy in Agricultural Engineering  
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# Abstract

Fixed wing agricultural aircraft apply approximately 40% of the fertiliser used in New Zealand, the majority of which is applied in hill country. The amount varies from approximately 600,000 tonnes to 1.2 million tonnes per annum.

About 100 fixed wing aircraft of various types are engaged in agricultural operations throughout the country and the safety record has been of considerable concern; the Civil Aviation Authority (CAA) of New Zealand report that there are 12 serious accidents per 100,000 flying hours which result in 4 deaths, almost 2 annually.

Agricultural aviation stakeholders, including, the Department of Labour, Civil Aviation Authority, New Zealand Agricultural Aviation Association (NZAAA) and Federated Farmers are trying to reduce the number of incidents in the sector by establishing guidelines for airstrips, fertiliser storage facilities, their use and application from them.

A large proportion of incidents have, as contributing factors, poor flowing product which cannot be jettisoned in time to avert an accident, collisions with obstructions near the airstrip (20% of all accidents are aircraft hitting fences in proximity to the airstrip) and damage to aircraft due to an inappropriate surface, such as rutting.

The New Zealand topdressing industry handles many products of which only a few are homogenous e.g. Urea and fresh Di-ammonium phosphate. The majority of spreading being undertaken involves products with large variations in particle size

and moisture content producing particles from fine dust to concretions. These characteristics make it very difficult to achieve continuous flow and even spreading from an aircraft. There have been a disproportionate number of accidents and near misses in the New Zealand topdressing industry that have occurred whilst spreading agricultural limestone (lime). Lime has been identified as being particularly problematic and is being used as a focus for this study. Superphosphate, which is used as a flow standard in New Zealand Civil Aviation Authority rules, is used as a comparison in powder flow engineering experiments.

This thesis is a prescribed project concerned with solving specific problems for industry mainly funded by the Fertiliser Manufacturers' Research Association.

**Specific objectives/aims of the project:**

1. Quantify the flow characteristic of products being spread and identify risks within the system, identifying risk materials and risk situations.
2. Develop a better understanding of material variability in terms of characterising the different deposits used around New Zealand and relating these differences to flow properties.
3. Develop a better understanding of the mechanisms creating the variability in flow properties that relate to production processes, transport and storage and finally loading and spreading with topdressing aircraft of the different limes used in New Zealand.
4. Quantify system performance in terms of economic and environmental impacts.

5. Identify suitable test methodologies that can be used within the industry to determine whether a product is fit for spreading and its flow characteristics. These would be dispatch tests at the lime quarry or fertiliser plant and a flowability test as the material is loaded onto the aircraft.
6. Identify design criteria that determine the performance of aircraft in relation to safety, flow control and spreading performance. Work with the interested parties to improve work quality and safety associated with agricultural aviation systems.

Flow properties have been quantified using a shear testing regime and engineering design parameters established for mass flow have been calculated from interpreting the powder flow functions. However, as the material from each quarry has variations in particle size distributions caused by factors such as the moisture of the parent limestone, age of the crushing hammers and time being crushed; the results are only an instantaneous solution. All commonly used products except lime are free flowing and shear testing was undertaken on superphosphate samples as a comparison. All the limes tend to be on the cohesive – easy flow boundary.

Limes from throughout New Zealand have been classified by mineralogy, have been analysed by thermal decomposition and have had impurities identified through X-ray diffraction. Although there were differences in the particle size distributions and loose and tapped bulk densities between the limes, helium pycnometry testing showed the limes to have similar particle densities.

In order to achieve free flow conditions with these products they require modification.

The simplest modification that proved effective was the removal of fine particles.

This had the effect of reducing the particle size distribution which is important in reducing the packing density and cohesive strength. This was also achieved by only having particles within a narrow particle size range, by removing the fine particles the cohesive strength was reduced and the materials were free flowing.

Although this can be done there is clearly a cost involved, the industry is already struggling with reduced demand and any increase in cost is likely to be unwelcome even though it could help to save pilots' lives and improve the quality of spread achieved.

This thesis considers three aspects of topdressing costs in order to estimate the actual costs of spreading fertiliser and lime. The questions posed are; what are the actual costs of operating the two main models of aircraft flown in New Zealand? What size of aircraft fleet is required to fulfil the spreading requirements? What are the on-farm infrastructure costs that also need to be considered in order to calculate the true costs of servicing the application of fertiliser to our hill country sector?

Topdressing services mainly the sheep and beef sectors which contribute 22.5% of New Zealand's agricultural output. Farm income in this sector is nearly \$4 billion. Application of fertiliser is important to sector productivity and the possible collapse of the topdressing industry would have far reaching consequences for these farming sectors and New Zealand's export earnings.

The model finds that there is no financial return on capital invested in the industry. Therefore, the best returns are found by applying fertiliser from old aircraft with aged

support vehicles all with little capital value. This is clearly unsustainable as even old aircraft require large injections of capital periodically to maintain airworthiness.

As fertiliser prices have increased, application rates have fallen, which increases application cost per tonne applied. The agreed fixed price charging model is traditionally based on an application charge per tonne. It is likely that farmers perceive increased application charges per tonne as a price increase, whereas it is only compensating the applicator for the additional time of sowing at a lower rate.

It is clear that although farmers buy fertiliser on a cost per tonne basis this is not the activity based cost driver for the aerial applicator. Converting the cost per hour aircraft cost driver, to a cost per tonne for charging farmers; is confusing as application charges alter by rate and product. The industry needs to alter its charging mechanism to a cost per aircraft flying hour activity based charging regime.

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# Preface

This thesis is submitted to the University of Massey in partial fulfilment for the degree of Doctor of Philosophy in Agricultural Engineering. The material submitted in this thesis was carried out by the candidate during the years 2007 – 2010 under the supervision of Associate Professor I.J. Yule. All the work was carried out in the School of Engineering and Advanced Technology and the Institute of Natural Resources at Massey University, Palmerston North.

The candidate submits that the thesis has been composed by him and that the work described herein is his own unless otherwise stated in the text.

Nine supporting journal and conference papers which are based on the work presented have been published or submitted to international journals and conferences:

## *Journal Publications*

Grafton, MCE, Yule IJ, Lockhart, JC, 2010, An Economic Analysis of Aerial Topdressing in New Zealand, New Zealand Journal of Agricultural Research (Under Review)

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## NOMENCLATURE

$\tau$	=	Shear stress (Pa)
$\sigma$	=	Normal stress (Pa)
$P_b$	=	Bulk density ( $\text{kgm}^{-3}$ )
B	=	Angle between cohesive arch and hopper wall
g	=	Acceleration due to gravity ( $\text{ms}^{-2}$ )
$A_1$	=	Depth of arch supported by unconfined yield stress (m)
UYS	=	Unconfined yield stress (Pa)
MCS	=	Maximum consolidated stress (Pa)
$\beta$	=	Length of narrowest sides of a rectangular orifice (m)
L	=	Length of longest sides of a rectangular orifice (m)
$r$	=	Radius of circular orifice (m)
I	=	Intensity of reflected X-rays
IYL	=	Incipient yield locus
WYL	=	Wall yield locus
$\sigma_1$	=	Maximum consolidation stress (Pa)
$\sigma_1$	=	Critical applied stress (Pa)
$\sigma_c$	=	Unconfined yield stress (Pa)
CAS	=	Critical applied stress (Pa)
$\alpha$	=	Hopper half wall angle

$H(\alpha)$	=	Hopper half angle divided by $60^\circ$
$\delta$	=	Angle of internal friction
$\delta_e$	=	Effective angle of internal friction
$\phi$	=	Angle of wall friction
$G(\phi_t)$	=	Jenike function for funnel flow is $4.3 \tan \phi$
$y$	=	Bulk density multiplied by acceleration due to gravity ( $\text{kgm}^{-2}\text{s}^{-2}$ )
$P$	=	Pressure (Pa)
$ff$	=	flow factor
$T$	=	Tensile strength (Pa)
$V$	=	Volume ( $\text{m}^3$ )
$K$	=	Beverloo constant for mass flow rate
$M$	=	Mass flow rate ( $\text{kgm}^{-3}$ )
$k$	=	Beverloo constant multiplier for mean particle size and shape
$d$	=	Mean particle size diameter (m)
$h$	=	Head or height of bulk solid in a silo (m)
$B$	=	Angle between cohesive arch and hopper wall
$g$	=	Acceleration due to gravity ( $\text{ms}^{-2}$ )
$A_1$	=	Depth of arch supported by unconfined yield stress (m)
$UYS$	=	Unconfined yield stress (Pa)
$MCS$	=	Maximum consolidated stress (Pa)
$D$	=	Diameter of circular opening and diagonal opening of a square orifice (m)