1st International Conference on Sensing Technology
November 21-23, 2005 Palmerston North, New Zealand

Measurement of Vibration in an Aircraft Hopper during Topdressing

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Abstract

A top-dressing aeroplane was instrumented to determine vibration of the hopper during a typical top-dressing flight. The values are reported and reviewed in relation to their effect on possible bridging of the powder.

Keywords: Crop dusting, bridging, vibration, flowablility, lime, fertilizer.

1 Introduction and Literature

Fertiliser to the value of approximately $1 billion is spread in New Zealand annually and a significant proportion of it is spread from the air using topdressing aircraft. The topdressing industry was born fifty years ago by a few pioneering pilots who saw the opportunity to develop land inaccessible to wheeled vehicles. There are a number of advantages to using aerial topdressing aircraft in terms of access and speed of operation over large areas. However in recent years the industry has come under greater scrutiny because of a poor safety record and concerns regarding the evenness of spread as land use has continued to intensify. Murray et al [1] demonstrated the economic benefit of applying precision agriculture (P.A.), in the form that variable rate application technology (VRAT) could bring. A twenty per cent increase in production was calculated on a property using the model developed by Zhang et al[2] for hill country farms in New Zealand. A prerequisite to using P.A. is the need to achieve even, accurate and repeatable applications of fertiliser and lime. Yule et al [3] highlighted the variation in application rate due to various sources while spreading fertiliser from an aircraft.

This means that the material flowing from the hopper must do so in a continuous, even manner, without this, the benefits of precision agriculture will not be achieved.

Flowability of material from the aircraft's hopper is one of the major issues of concern to aerial topdressing operators. In addition to poor flow characteristics resulting in high levels of variability in the fertiliser or lime application, it can result in the hopper becoming completely bridged. This is extremely dangerous and in some cases it is thought to have had a contributing effect to air accidents. There is also a safety requirement that at least 80% of the load can be jettisoned from the aircraft within 5 seconds.[4]

Potential bridging of the material in the hopper makes this guarantee impossible. The material of most concern is agricultural lime.

In order to explore the problem, two small-scale studies were commissioned by Fert Research NZ. The first by Praat [5] aimed to find a more objective method of determining the flow properties before the lime is put in the aircraft. The second study, by Yeung [6] examined the use of shear testing in more detail. Table 1 [ibid] attempts to summarize factors that affect the flowability of lime. It can be concluded from these reports that standard methods such as shear tests are not reliable and the results are inconclusive in terms of predicting when a lime will bridge in the aircraft hopper. Yeung suggested further test methods and Praat suggested that a Variable Aperture Flow Test might have some merit. The test showed significant consolidation in lime samples and significant difference between those exhibiting good and poor flow characteristics. During the Variable Aperture Flow Test, the apparatus was shaken on a standard Endicott Sieve Shaker. The settings for the Endicott are not reported but it was observed that some samples slumped more than others and that those that slumped the most tended to have the worst flow characteristics.

This implies that the vibration of the aircraft might cause compaction which could be one of the factors in bridging.

The purpose of the work described in this paper was to establish the actual level of vibration in an aircraft hopper during topdressing and to form an opinion as to whether this was likely to be a factor in consolidation of the bed.

Table 1. Summary of factors affecting lime flowability.

Parent Material and processing	Carbonate content Particle size distribution Moisture Content Bulk density Particle shape
Storage Environment	Weather effects, temperature and air humidity fluctuations, diurnal variation, Loading and movement, Transport Contact with water
Loading	Loading dynamics and stress on material,
Within the aircraft hopper	Vibration in the aircraft hopper Hopper shape and flow characteristics Hopper opening and flow characteristics

2 Method

A one-dimensional accelerometer, ACC 101, sold by Omega USA was affixed to a circumferential flange at mid-height of the standard fibre glass hopper installed in a PAC Cresco top-dressing aeroplane. The PAC Cresco is a single engined turbo-prop. Six sets of tests were done with the axis of the accelerometer positioned vertically, laterally and longitudinally. Each test was duplicated. The measurements covered loading, taxiing, takeoff, flying to the sites, three top-dressing passses, flying back, landing and taxiing back to the load point.

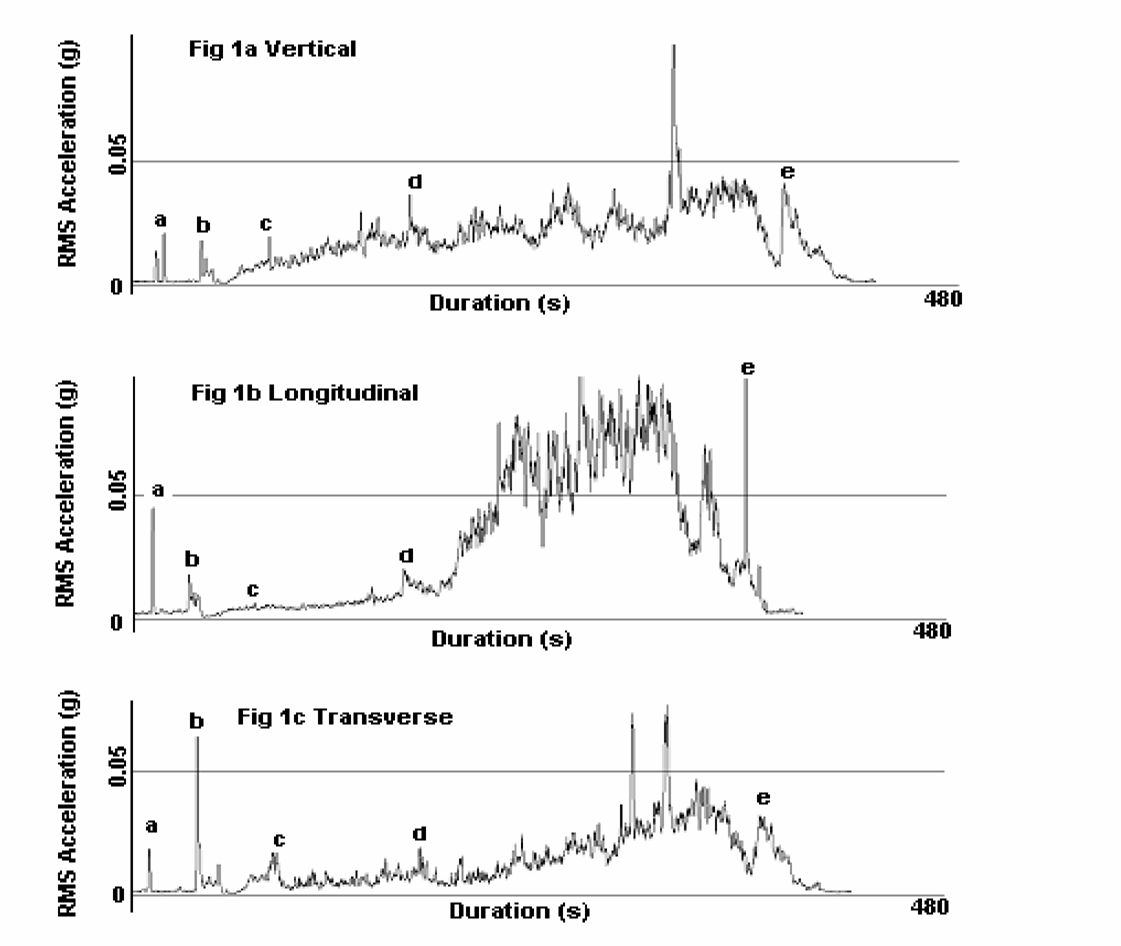
In addition, in order to assess the vibration levels of Praat et al, a standard Endicott sieve shaker was similarly instrumented and tests were run at 10%, 20% and 40% of full power.

3 Results

The readings for the Endicott tests were converted to average RMS values and expressed as a fraction of the earth’s gravitational attraction, g.

Table 2. Vibration of an Endicott Sieve Shaker

Setting %	**Longitudinal**	**Transverse**	**Vertical**
10	0.040 g	0.0263 g	0
20	0.057 g	0.0307 g	0
40	0.140 g	0.0824 g	0



For the aircraft tests a plot of RMS vibration versus time is plotted for each axis. These are shown in Figure 1

4 Discussion

Figures 1 a,b,c show the vibration history during three different flights. A separate set of data was collected in parallel with these three sets and all the features of these graphs are reflected in the other data, Therefore they must be recognized as valid events in the flight.

The first event, a, is the slamming of the aft cabin door after setting the laptop to collect data. b reflects the loading process where a loader poured the material into the hatch at the top of the hopper. Note that vibration is larger at the beginning than at the end because the weight of the hopper increases during the process. During the taxi and takeoff process up to point, c, the vertical vibration is larger than the transverse which is larger than the longitudinal. This is what one might expect as the aircraft travels down a grass runway. The longitudinal vibration is lowest because there is less pitch than yaw than bump.

The point c corresponds to the wheels leaving the ground. From c to d, the aircraft flew to the first field. Note that the longitudinal acceleration was very small because there tends to be little sudden change in aircraft attitude during steady flight. From d through e, the aircraft was spreading fertilizer and turning and banking between passes. The vertical changes can be seen in fig 1a.

At e the plane touched down, with a sharp attitude change, taxied to the end of the runway and turned.

Examination of the raw data showed no dominant frequency of vibration.

The following observations can be made;

A The vibration during flight with a full hopper is very small – typically 0.015 g vertically, 0.01 g transversely and longitudinally.

B The vibration increased as the weight of hopper and contents decreased. A representative figure for this maximum is 0.025g.
C As the hopper emptied, the longitudinal vibration became very large. This was because the accelerometer was orthogonal to the hopper wall and the unrestrained wall, above the fertilizer, vibrated. It is not judged that the load of fertilizer was vibrating like this.
D The spikes during the dusting portion of the flight are unexplained but were there for both flights for each axis. They may have their origin in the operation of the output valve, with sudden changes in material discharge and the momentum consequences of this or aerodynamic turbulence when the valve was open and the hopper empty.

An attempt to reconcile these figures with the data of Praat et al must be inconclusive because they do not report the settings of the Endicott. However, at the lowest practical setting of the shaker (10%), when the vibration seems very slight to the touch, the shaker vibration was twice the worst case of the hopper during flight.

5 Conclusion

The vibration of the hopper of a typical top-dressing aeroplane was measured during the full history of a top-dressing excursion and found to be very slight. It is obvious that a vibration of 0.025g is not capable of causing shear in a bed of fractured particles. Therefore, the vibration of the hopper is a most unlikely factor in consolidation of the bed with consequent decrease of flow properties. We speculate that the actual flow process as the hopper empties would cause orders of magnitude more shear and thus provide the possibility of consolidation where smaller particles move into the interstices between larger particles.

6 References

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