WIND TUNNEL STUDY TO REDUCE WIND DAMAGE TO LOW-COST PLASTIC FILM CROP COVERS

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INTRODUCTION

The general trend in agriculture worldwide is towards more intensive growing systems. It is desirable to ensure that the climate for crops is controlled as best as economically possible, since it has such a dramatic influence on production and quality. Greenhouse research has now split into two distinct areas:

1. High tech : looking at extreme control at any price. This includes specific spectrum lighting, multi-faceted shade/light/heat control, etc.

2. Low tech : seeking to get maximum environmental control at minimum cost.

In area 2, the logical approach is plastic film as a cover, using a low cost wire framework for support. The main problem with this system is its susceptibility to wind damage. Some workers in this field have commented that the industry is at the starting gates of a major revolution in this type of structure: fuelled by a demand from growers, a steady development of films that are stronger and have better light characteristics for the plant, and engineering advancement in terms of understanding the mechanics of such structures.

A variety of research into wind loads on agricultural structures has been performed at the National Institute of Agricultural Engineering in England, including that of Hoxey, Richardson and Robertson. Also, design wind load information for multi-span canopies and multi-span buildings is presented in BRE Digest 284 and by Holmes (1987).

In New Zealand since about 1985, a number of cherry orchards near Blenheim have been covered by experimental multi-span free-standing plastic-film canopies during the brief summer period when the cherries ripen. The canopies aim to keep the rain off the trees, as the cherries swell and burst if they get wet. Because the crop is particularly valuable if it can be kept to a high quality, and because the cherries are so susceptible to damage, the cherry orchards are particularly benefited by covering them. However, the structures are very flimsy, and therefore they have repeatedly suffered considerable wind damage, even during only moderately windy conditions. Consequently the use of such cheap crop covers has been only partially successful, and has not been widely taken up by growers of other crops. Relatively little information exists on specific means to reduce wind loads on such structures, or to reduce damage by absorbing or redistributing the loads.

No one has so far managed to develop a durable broad-acre rain cover at the sort of price needed to make its use viable. The commercially available systems are currently similar to open-sided, lightweight greenhouses, using rigid steel frameworks. The cherry covers, which have been designed and built ad hoc by individual owners and growers to various different designs, typically cost around a third of the cost of a rigid frame structure. The erection of these cherry covers has prompted a variety of research, including investigations into construction detailing, experiences with different designs, and full-scale and wind tunnel tests. Central Laboratories' work has been reported by Carpenter (1990).

THE EXPERIENCES OF THE CHERRY COVER OWNERS

The existing cherry covers were designed and built by various growers using their own experience, with some design input from Ministry of Agriculture and Fisheries (MAF) consultants (Robinson and Kearney, 1986). There was relatively little input based on wind engineering research. Initially, a variety of different designs were tried, but over a period of several years, various common features in the designs have emerged. This is due to the perception that certain designs work better, and the permanent damage experienced by others. Some existing covers were not used during the recent 1990 season because of the damage they had suffered previously.

Several common features have emerged in the overall design of the structures.

1) The covers are built in structurally-independent parallel rows, which are steeply pitched (about 40°) to prevent ponding of rainwater.

2) There is a gap (about 300 mm wide) along the top of each ridge which is covered by a separate plastic film hat above the ridge. This has the effect of:

   a) providing a ridge vent to equalise the pressures.
   b) preventing rain from entering the gap.
   c) providing a sheltered space where the plastic covers can be furled up when they are not in use for most of the year.

3) Where practical, the rows are aligned parallel to the prevailing wind directions.

4) The plastic film sheets are tensioned either by attaching them to wires along all 4 edges, or by using commercially available lightweight truss frames.

There are still numerous variations in the construction details as various new techniques are tried and rejected.

Some comments which have been expressed by some growers (but not necessarily accepted by others) include:

- Shelter belts (e.g. poplars) all round the orchards provide valuable shelter.
- Shelter belts can cause increased wind effects due to increased turbulence and "dumping" of the wind onto the covers just downwind of the shelterbelt.
- The plastic film should be kept in tension, and not allowed to become slack.
- Local damage tends to spread and cause damage to the whole row if it is not immediately repaired.
- The most successful covers are those whose owners put a lot of effort into maintenance.
- The truss frames are an unnecessary extra expense, and cause damage to the plastic.
- It is essential that the cover be built so that it is just strong enough, and no stronger, otherwise it becomes uneconomic.
- Gaps between adjacent covered orchards should be avoided.
- Most damage occurs when the wind blows directly across the rows.
- Wind blowing along the rows produces waves along the rows, and causes damage at the downwind end.
- The use of bird netting stretched flat over the top of the cover reduces the wind loads.

CONCEPT FOR WIND TUNNEL STUDY

Central Laboratories was approached by MAF with a proposal to perform a wind tunnel study for a novel concept for a low-cost crop cover. This involved using a long flexible weight, consisting of a plastic tube filled with water, to hold down the plastic film and apply tension. This would be used in place of the conventional lower cables on each row, and would result in a cheaper structure. Also, the flexible weight would ride up and down under the forces of the wind gust loading, and so avoid the high impact loads which tear the plastic film. This concept has been briefly trialled at full-scale. It has the drawback that it applies a continuous tension on the plastic film, causing stretching. The wind tunnel study would also examine the influence of various design parameters, such as the use of shelter belts, the slope of the plastic film, porosity in the ridges and troughs, the "hats", etc.

PROCEDURE FOR THE WIND TUNNEL STUDY

The crop cover was modelled at a scale of 1:20. The nominal full-scale size consisted of 5 m high supporting poles, spaced 5 m apart, with 7 parallel rows. Therefore the model was 250 mm high and 1750 mm square, this being the largest size which would conveniently fit onto the turntable. Only one row was modelled out of flexible plastic film, the others being rigid. The plastic film was kitchen "Gladwrap", and the flexible weight was modelled by light-weight chains of various sizes.

The similarity requirements for aeroelastic modelling, from Kind (1982), included:

a) Froude number: $(\text{wind speed})_{\text{wind tunnel}} = (1/20)^{1/2}\,(\text{wind speed})_{\text{full-scale}}$

b) Mass ratio: $(\text{chain weight per unit length})_{\text{wind tunnel}} = (1/20)^{2}\,(\text{flexible weight per unit length})_{\text{full-scale}}$

The Froude number scaling required the tests to be done at unusually low wind speeds in the wind tunnel, typically around 2 m/s mean, which are lower than our normal minimum speed. Also the required turbulence scale was unusually large. These two problems were solved by installing a 1100 mm high solid wall in the wind tunnel, 16 m upwind of the centre of the turntable. The wind tunnel is 1220 mm high, and therefore it was almost completely blocked by the wall. The wall had the effect of considerably reducing the air flow rate in the tunnel, and producing a high intensity of low frequency turbulence (although it was still at a higher frequency than the optimum for the chosen scale). The turbulence intensity decreased rapidly with distance downstream, and the 16 m distance was chosen to produce a turbulence intensity of 25% at the top of the model - roughly equivalent to Terrain Category 2½. No attempt was made to model the velocity profile accurately, and therefore the profile in the wind tunnel was fairly uniform.

The test procedure initially consisted of observing the degree of flapping of the plastic for different chain weights and tunnel speeds. Subsequently, the chain was attached to a load cell at one end, and therefore the fluctuating tension on the end of the chain was measured. Fixing the chain end restricted its movement, and therefore produced somewhat different motion of the plastic film.

WIND TUNNEL TEST RESULTS

The first tests looked at the relationship between chain weight against wind speed required to produce a certain degree of flapping of the plastic (flapping speed). The tests were performed on the basic crop cover design, with 40° roof pitch. The conclusions included:

a) Chain weight is proportional to flapping speed squared. There was no indication of any dynamic amplification at a particular wind speed for the measured range of full-scale mean wind speeds (3 to 20 m/s).

b) At a full-scale mean wind speed of 11 m/s (expected to occur once per year), the full-scale flexible weight for onset of significant flapping (bouncing of the chain causing impact loads) was about 40 kg/m for wind direction 90° (wind blowing directly across the ridges). This is a much higher weight than the anticipated practical limit due to film and wire strength, etc, of around 10 kg/m.

c) Higher wind speeds than the "flapping speed" caused the plastic to lift above the height of the ridges, causing the whole section of plastic film to bow up, producing occasional very high suction loads.

It became clear that, unless the aerodynamic loads could be substantially reduced somehow, the flexible weight would need to be additionally restrained, which rather defeated the purpose of the concept. The subsequent tests looked at the effects of modifying the design of the crop cover, with the aim of optimising the design. The use of a simple flexible model caused the measurements to be relatively crude. The effective force coefficient for various designs (an approximate figure derived from the mean, rms and peak load cell measurements) has been calculated relative to that of the standard configuration (i.e. C_F for standard configuration = 1.0). The test results are presented in the following list.

The design of the standard configuration was as follows:

- 5 m high
- 5 m wide sections
- continuous plastic film cover (i.e. no ridge vents, porosity, etc).
- completely open on all sides
- open underneath (i.e. no simulated trees)
- 40° pitch ridges

The effect of wind direction on the measurements was typically relatively small for most configurations and has been omitted from the results. Not all of the original configurations have been included in the list.

		Relative effective C_F
B	Standard configuration	1.0
C	12 m upwind extension (rigid construction)	0.9
D	5 m high solid fence all around the cover	0.8
E	7.5 m high solid fence all around the cover, with 2.5 m high gap under (i.e. previous 5 m high fence raised by 2.5 m)	1.4
G	5 m high, 50% porous fence all around the cover	1.3
H	1.5 m high, 50% porous fences along the top of each ridge, and across the ridges	0.8

K	10 m high, 50% porous fence, 10 m upwind from the cover	0.9
L	Simulated trees under the cover	1.2
M	400 mm wide ridge vents, with 600 mm wide "hats" above	0.7
N	Ridge vents, without "hats"	0.7
O	Ridge "hats", without vents	0.9
P	Horizontal 50% porous screen laid flat over the top of the whole cover	0.9
Q	Sloped, 50% porous fence at the front and sides of the cover, and open at the downwind end	0.7
R	Test panel at upwind end of cover	3.0
S	Test panel at downwind end of cover	0.1
T	Chain tied down at 12 m intervals	0.1
U	600 mm wide trough vents	0.2
W	10° pitch ridges	0.7

COMMENTS ON RESULTS

These results contain some interesting indicators for some methods which may be used to reduce wind loads on the crop covers e.g. smaller pitch angles, vents in the covers, shelter belts, etc. Also it can be seen that poorly positioned fences may increase the wind loads. However, to some extent for these tests, the basic aerodynamic forces are mixed up with the effects of the particular mechanism which causes bowing up of the flexible model and the resultant high measured forces. Hence the configurations which disrupt this mechanism (e.g. S, T and U) have conspicuously lower measured wind loads. In other cases the effects of design changes seem surprisingly small. The results obtained to date are therefore not sufficiently detailed to be used to provide design data.

We have found that we need to simplify the measurements, and to obtain more detailed information on the effects of design changes on the basic wind pressures. Therefore, during 1991, we plan to perform a similar range of tests using a conventional, rigid, pressure-tapped model at a smaller scale. The conclusions concerning the use of the flexible weight to hold down the plastic film, are:

a) The weight required to prevent flapping of the plastic in typical wind conditions is excessive.

b) Flapping of the plastic, if relatively unrestrained, causes the plastic to bow up, and so produce substantially greater forces.

Consequently the flexible weight must also be mechanically restrained, and this would add to the cost and complexity of the structure. In consultation with MAF, we have concluded that the development of the flexible-weight concept therefore seems to be impractical, and our attention has turned to reducing the wind loads on a comparatively rigid design.

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