The evolution of a versatile wind-tunnel facility

Tony Bowen
Department of Mechanical Engineering
University of Canterbury

Abstract
A proposal to develop an existing boundary-layer wind tunnel into a versatile, general purpose facility while retaining the existing boundary-layer test section is reported. An additional blockage-tolerant working section and a closed circuit layout are features of the proposal. Although the proposed replacement of the fan unit is an expensive option, it will provide significantly better performances for both test sections.

The original tunnel
The tunnel was designed and constructed by Stevenson and Raine (1976) with a 1.2m square by 12.2m long boundary-layer working section for specific work on modelling the wind flow over fences. The open-circuit facility (see Fig 1a) is situated in the Mechanical Engineering Department Laboratories of the University of Canterbury. The structure comprises a combination of timber for convenience and the dampening of noise emissions, together with some structural steel components. A mezzanine floor which is used to provide access to the working section of the other aeronautical wind tunnel in the laboratory, also supports the second low-noise 0.76m square by 2.44m long tunnel working section for acoustic-flow studies. The tunnel is powered by a Woods 1.2m dia. x 50kW two stage, contra-rotating fan unit with pneumatic blade-pitch control which was initially situated on the ground floor near the tunnel entry. In this configuration (Fig1a), a maximum flow rate of $27m^3/s$ provided a mean speed in the boundary-layer working section of 18.6m/s and 38.7m/s in the low-noise section near the outlet.

Present open-circuit Layout
It soon became apparent that most of the projects were related to wind modelling and only utilised the boundary-layer working section. The initial configuration with the upstream fan unit did not provide the best quality airstream in the working section, although the low-noise section benefited from the more remote position of the fans. In order to achieve a more uniform and efficient entry into the boundary-layer working section, the fan unit was moved to the mezzanine floor downstream of the boundary-layer working section and was replaced with a contraction and honeycomb settling chamber near the inlet (Stevenson and Raine 1976).

In this successful configuration which is shown in Fig1b, the boundary-layer wind tunnel has provided a useful facility for many wind-related projects spanning over more than 20 years. The noise related projects continued to be few and far between but the relatively high-speed working section near the outlet on the mezzanine floor proved to be a very useful facility for a wide range of final-year undergraduate projects. The contraction could also be removed to provide a low-speed free-air jet from the diffuser. It also allowed models from several projects to be installed at any one time during busy periods.

Operating deficiencies
The current lay-out of the boundary-layer wind tunnel (Fig1b) causes a number of nuisance-level problems. The open-plan laboratory building which was built in the early 1960's, was intended to allow access for an overhead crane over most of the laboratory floor space. However, the concept aggravates several chronic nuisance-level problems associated with both wind tunnels. In particular, the lack of a ceiling over the Industrial Aerodynamics Laboratory

which houses both wind tunnels, allows the free transmission of noise and dust from one laboratory to another. The more significant operating problems are outlined below.

a) The noise levels close to the operating boundary-layer tunnel are 73dB(A) on the ground floor and 71.5 dB(A) in the adjoining workshop. The noise levels from the aeronautical tunnel are also of a similar unpleasant level and has in that case resulted in inconvenient speed restrictions placed on the tunnel during normal working hours. In order to allow the aeronautical tunnel to continue to operate normally without restrictions and to reduce the noise nuisance from the boundary-layer tunnel, the Department has decided to proceed with the installation of a light-weight roof of foam-sandwich construction over the whole laboratory. The ceiling height will be 5.5m above the ground floor and 3.2m above the mezzanine floor. It is expected that noise levels within the laboratory from the boundary-layer tunnel will be lower with the closed-circuit tunnel layout.

b) There has been a chronic problem due to the frequent and rapid contamination of the hot-wires used in the tunnel. The cause was identified to be the regular emission of welding smoke from the workshop which is inhaled by the tunnel. As a temporary measure, a 5µm and 1µm double-layer cloth filter (Vilair medium MPSB/150) has been fitted across the tunnel inlet. It is quite shocking to see the amount of dirt collected by this filter over several months. Although the filter has solved this problem, the resulting pressure loss is excessive with the performance of the tunnel down significantly from the 18.6m/s obtained previously with an unobstructed inlet to a maximum speed of a little over 13m/s. Installation of the ceiling would also solve the problem of wire contamination.

c) The current fans which are fitted with pneumatic blade-pitch control, provide a very coarse flow-speed control which has a large amount of hysteresis. This defect would make the proposed use of a computer speed control almost impossible. Balancing the power demand between both fan motors by means of blade pitch angle adjustments has also proved to be an almost impossible task.

d) The high exit loss of the open-circuit layout has helped to keep the operating efficiency of the tunnel at an unnecessarily low level. It also causes violent air temperature fluctuations due to the disturbance of stratified air in the building by the tunnel exit jet. This problem will largely be removed by the new ceiling. However, the relatively small air space of the confined laboratory surrounding both tunnels would render the laboratory very unpleasant from the return air currents generated by the open-circuit tunnel when in operation. Both problems would be eliminated with a recirculating tunnel configuration.

Proposed closed circuit design

In addition to the objective of eliminating the above nuisance problems, there is a need for a larger working section to cope with larger models of buildings and complex terrain together with a growing popular interest in the effects of wind on sports such as windsurfing, skiing, cycling and pedestrians. A closed circuit configuration with an additional blockage-tolerant working section on the mezzanine floor such as the one assessed by Lamb (1993) in Fig 1c is currently being investigated to meet these demands.

An obvious option is to use the current twin fans in parallel, rather than series layout currently used, to suit better the circuit system losses. However, the predicted maximum test speed of about 15m/s in the new blockage-tolerant section is marginal for the generation of accurate pressure and force measurements. The preferred but more expensive option is to replace the existing fan unit with a single 110kW 1.9m dia. Woods fan with an AC motor speed control. An estimate of the cost for the supply of these items is NZ$46,000. Preliminary calculations show that maximum flow speeds in the lower boundary-layer working section of about 50m/s and 26m/s in the blockage tolerant section would be possible with the larger fan unit depending on size of the installed models. The replacement fan would therefore more than double the flow rate through both working sections, improve the accuracy of test measurements and allow for precision computer control of the flow speed. The larger diameter of the fan casing would also reduce the necessary area ratio of the diffuser leading up to the new settling chamber and blockage-tolerant working section.

Initial calculations by Rohan (1995) show that the temperature rise due to the 50kW fan unit will be at a rate of 0.8°C per hour with an equilibrium temperature around 23°C above ambient. This will of course rise proportionally if the larger fan unit is employed. One promising and economic solution is to exchange the hot air in the tunnel continuously with cool air from within the building. Such an opportunity exists if a bleed system is used to carry away the boundary layers on the duct walls just upstream of the lower boundary-layer working section. Cool air could then be reintroduced without effort at a position in the tunnel which is normally running at just below atmospheric, upstream of the fan unit.

New test section

A major element of the proposed closed-circuit layout is the addition of the blockage-tolerant working section on the mezzanine floor while preserving the existing boundary-layer section on the ground floor. The design of the new working section would be based on the concepts reported by Parkinson (1984, 86 and 1990) and the experience from recent designs such as Waudby-Smith and Rainbird (1985).

The 5.5m long slotted-wall working section would be housed within a plenum chamber so that the air that is forced out into the plenum at the upstream end of the test section is re-introduced to the main flow down-stream of the model. The slotted section is to be about 1.9m high to accommodate sports such as cycling and skiing but still provide clearance under the crane for the plenum. It is proposed to be enable the whole test section and plenum to be moved sideways to make way for several sizes of free-jet nozzle inserts that might be fitted to the outlet of the settling chamber. In this way, the section could be transformed into an open-jet test configuration. The width of the section is consequently confined to about 1.5m by the limited floor space on the mezzanine floor.

The objective is to complete the detailed design by March 1999. The continued contribution to this project from Graeme Harris, Technical Officer, is gratefully acknowledged.

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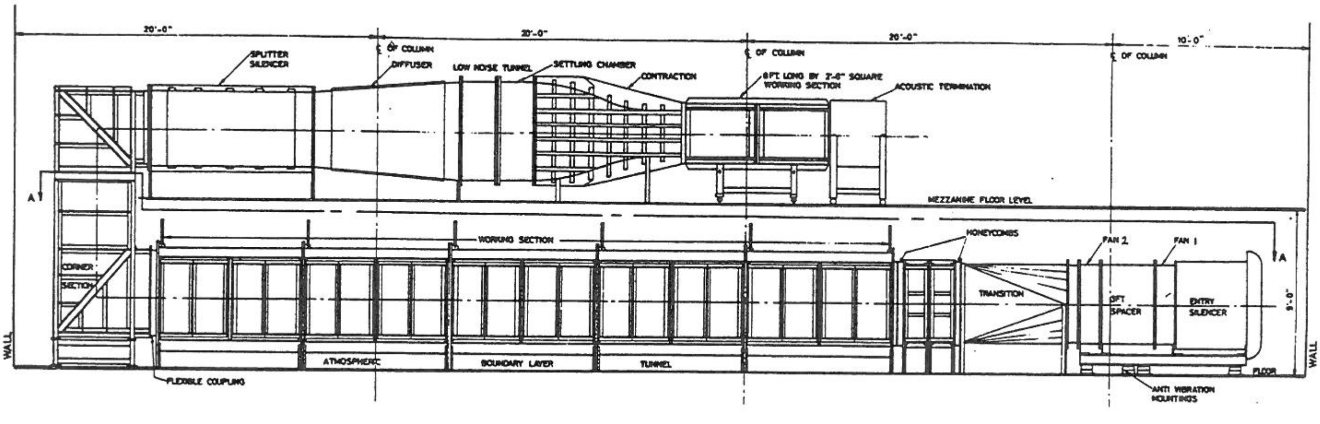

Figure 1a Original open-circuit layout of the boundary-layer wind tunnel at the University of Canterbury (Stevenson and Raine 1976).

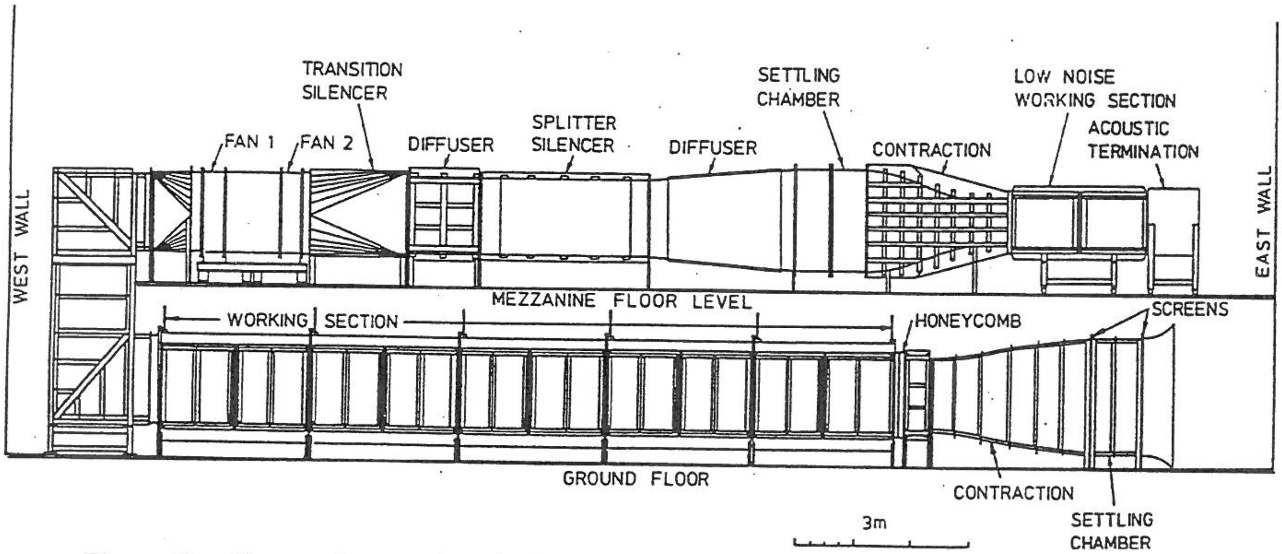

Figure 1b Current layout after the fan unit was moved downstream of the boundary-layer working section (Stevenson and Raine 1976).

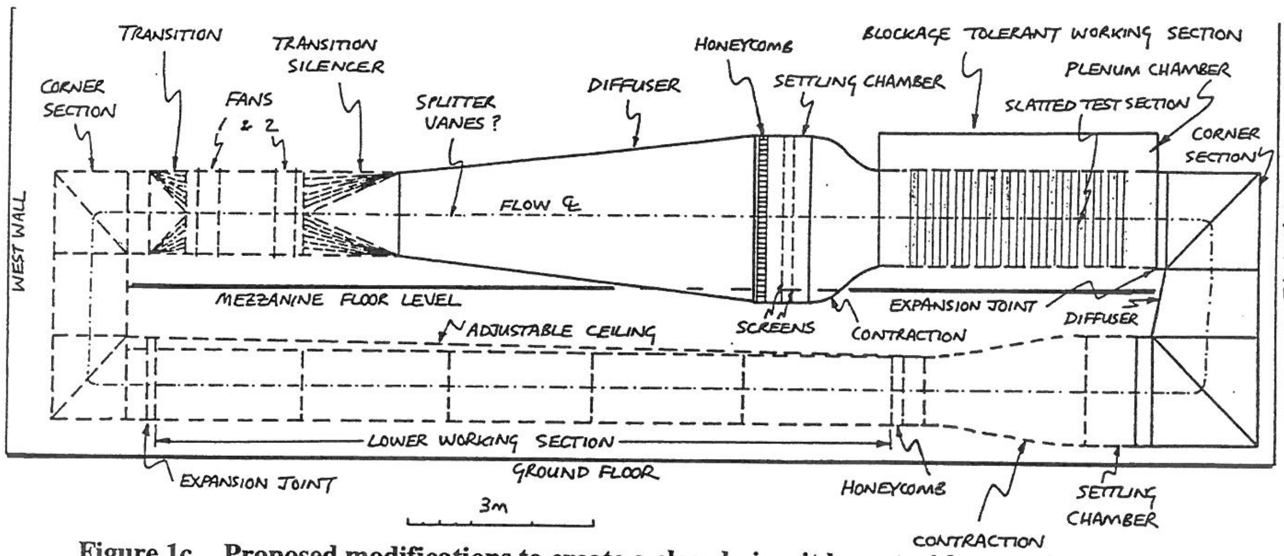

Figure 1c Proposed modifications to create a closed-circuit layout with a new blockage-tolerant working section (Lamb 1993).