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Status Report of New Wind Tunnels for the Australian Defence Department

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HISTORY OF PRESENT TUNNELS

Following the report of an expert consultant to the Australian Government in 1937, the Aeronautical Research Laboratories (ARL) was established in Melbourne and a 2.7m by 2.1m low speed tunnel planned. This tunnel was completed late in 1941 and put into service early in 1942. Shortly after the commissioning of the low speed tunnel a variable pressure tunnel designed to operate at high pressure and low speed, and low pressure and high speed, was designed and built at ARL. This tunnel was converted to transonic operation in 1956 and in its present form has a test section 0.8m by 0.5m. A 0.38m square supersonic tunnel designated S-1 was built during the period 1952 to 1955 at the Weapons Research Establishment (now the Defence Research Centre) at Salisbury, South Australia. This tunnel was commissioned in 1957 and converted for limited transonic operation in 1965. A 0.18m by 0.15m supersonic tunnel designated S-3 was commissioned at Salisbury in 1966 to extend the available test capability to Mach 5. These four tunnels have been steadily modified and upgraded during their lives and have supplied aerodynamic R&D support to the Australian Defence Forces and defence industry. A significant amount of work has also been conducted for non-defence industry where the, unique to Australia, capabilities of these tunnels was required. Pollock (1982) gives further details of these facilities and their maximum test Reynolds number capabilities are shown in Fig. 1.

PREVIOUS NEW TUNNEL PROPOSAL

From early in the life of the existing tunnels the operators were aware of deficiencies in the areas of test section size, Reynolds number capability and flow quality. The small test section sizes of the ARL Transonic and S-1 tunnels were particularly restrictive of the type of test that could be effectively conducted. This situation led to a proposal by Kerr (1963) for a 1.2m square blowdown tunnel with a speed range from low subsonic to Mach 5. It was intended that the cost could be reduced by copying an existing tunnel at a UK aircraft company. The estimated cost at the time, adjusted approximately into 1986 dollars, was $7.7M. On the basis of current more detailed costing information this would appear to be an under estimate by a factor of around two. Although not mentioned in the proposal it can be inferred that stagnation pressures above 1MPa would have been available, giving test Reynolds numbers about 40 times those available in the present tunnels.

The blowdown tunnel did not proceed primarily because the high supersonic capability was emphasised and this speed range was never considered to be of high priority for Australia. A second factor was the absence of complete agreement between the operators of the existing high speed tunnels at Melbourne and Salisbury.

PRESENT PROPOSAL

Background

Following the abortive 1963 tunnel proposal the deficiencies of the existing facilities became more evident despite continuing work on upgrading their capabilities. However due to the dispersion of tunnel testing expertise between the two laboratories and the relatively frequent changes in their departmental responsibilities, it was difficult for the tunnel operators to develop a firm plan and carry it through an extended approval process.

An opportunity to make a further proposal presented itself when a review of science and technology in Australia conducted by the Australian Science and Technology Council (ASTEC) conducted during 1977-78 highlighted the deficiencies of the existing tunnels. In its report (ASTEC, 1979) it recommended (para. 11.2.4, Vol. 1B): "That the Department of Defence be asked to develop a detailed plan for upgrading and extending facilities for R&D in aeronautics and aerospace, consulting with other government departments and agencies, including those with responsibility in civil aviation, and with industry, in preparation of the plan". The Government accepted this recommendation (Cabinet Decision No. 12489 of 15 August, 1980). In October 1980 the Chief Defence Scientist wrote to the Chief Superintendent (now Director) of ARL asking him to "- - take the lead in developing the plan - -". It was clearly evident that wind tunnels were the aeronautics and aerospace R&D facilities most in need of immediate attention and they were therefore considered separately from the other facility upgrading exercises. The momentum of the drive for new tunnels was maintained by a review of the Defence Science and Technology Organisation (IERC, 1980) which stated at paragraph 16.23: "The most serious obsolescence problem is to be found in aerodynamics, where the wind tunnel facilities in ARL and WSRL are so out of date that the research in this field is falling rapidly below what it should be if Australia's defence interests are to be secured".

As a starting point for defining new tunnel requirements, semi-official ARL views on low speed and transonic facility needs were prepared by Lemaire (1982) and Willis (1982). In addition, two well known wind tunnel design consultants; Sverdrup Technology Inc. of Tullahoma, USA and DSMA International of Toronto, Canada, were engaged to perform schematic design studies and indicative cost estimates. Following these preliminary studies a two day workshop with representatives from the defence forces, research organisations, academic institutions and industry was held at ARL. At the end of the workshop a representative panel of participants drafted a set of conclusions which were discussed by all those present, modified and finally agreed. The workshop concluded that a new transonic tunnel with a test section of at least 1.5m square had highest priority and a low speed tunnel of approximately double the linear dimensions of the existing ARL tunnel had second priority by a very small margin. A supersonic tunnel with a test section 0.7m to 1.0m square was judged to have significantly lower priority and the design of such a tunnel has not been pursued further. All papers presented and the full conclusions are included in the Workshop Proceedings (1983). Since the workshop, work on refining the technical requirements for the new tunnels and obtaining the necessary support and funding for their design and construction has continued. Progress in these areas is reviewed below.

Low Speed Tunnel Design

A design requirement for a new low speed tunnel is the capability to test fixed wing and helicopter models under high-lift, low-speed conditions. These tests tend to cause separation from the tunnel walls and so called "flow breakdown". Even prior to complete breakdown, large and uncorrectable tunnel interference occurs. Carbonaro (1975) and Hackett (1982) investigated the required solid wall test section size for valid high lift testing. Taking into account the minimum scale at which a model helicopter rotor can realistically be constructed, Lemaire (1982) concluded that a 9m square test section would be required. This was in agreement with current international practice. Due to the very high cost of a tunnel of these dimensions, a lower cost alternative involving some technical risk was proposed by Lemaire (1982). A 6m square test section fitted with partially open slotted walls to reduce the interference was suggested. For conventional low and moderate lift, higher speed testing, a solid wall 4.7m by 3.4m section in tandem with the 6m section was suggested. The tandem test section configuration was selected in preference to interchangeable test sections primarily due to capital cost considerations.

Further investigation of this concept suggested flow quality in the small test section could be compromised by the tandem configuration and that the interference in the slotted section, although of lower magnitude than that experienced in a solid wall section, would not be accurately correctable by normal methods. During the period of these investigations the adaptive wall concept, where the tunnel walls are deflected under computer control to lie along streamlines of an unconfined flow and therefore cause no interference, was developing rapidly. These circumstances and conflicting recommendations from the two consultants employed, made the selection of tunnel configuration difficult.

The design currently favoured is for a conventional tunnel with a 5m by 4m test section, initially fitted with solid walls, but with provision for fitting adaptive walls at a later date. It is proposed that the 10m by 12m settling chamber upstream of the 6:1 contraction would be of sufficient length to permit high lift testing at speeds up to 22m/sec. There are strong indications that if adaptive wall technology continues to develop at its present rate it should be possible to conduct much of the high lift testing in the main 4m by 5m section by the time the tunnel is built. The maximum speed in the main test section would be 135m/sec and the required drive power 12.5MW. The cost of a tunnel of this type is estimated to be approximately $25M.

The use of an extended settling chamber to provide a "back stop" high lift testing capability is not entirely satisfactory due to its impact on tunnel cost through the need to provide duplicate instrumentation and model support systems, and the increased shell dimensions. The flow quality in the big section would be poor and it would probably require additional screens at its downstream end to avoid an excessive wall boundary layer thickness in the main section. Adaptive walls have been used successfully for high blockage - low lift tests, but have yet to be fully proved for very high lift testing. If they have been shown to be effective for high lift testing prior to the commencement of the final design of the tunnel, the requirement for the extended settling chamber would probably be dropped.

Transonic Tunnel Design

The RAAF foresees a continuing requirement to conduct wind tunnel tests on military aircraft, stores (bombs, rockets, externally carried fuel tanks etc.) and particularly on the interaction between stores and the parent aircraft during their carriage and release. The existing tunnels are deficient in Reynolds number capability to provide adequate simulation of the full scale flow. Their small test section sizes limit model detail fidelity and test productivity (due to the absence of on-board control surface actuators). It is also impractical to provide a captive trajectory store release rig of the type described by Carman (1980), Wood (1986) and others. A tunnel to meet the foreseen needs was proposed by Willis (1982). This proposal was for a conventional closed circuit compressor driven tunnel with a test section 2m square and a maximum stagnation pressure of 400kPa. The total drive power required would be approximately 50MW. This proposal was never accurately costed, but the best information available suggests a figure in 1986 dollars of around $75M. Since this proposal was put forward there has been general agreement that it would meet all the technical requirements, but that it would be excessively costly to construct and operate.

Since the workshop attention has focused on lower cost options of reduced performance capability. From these considerations two specific alternatives emerged. The first was an intermittent (10 seconds to 1 minute per hour) blowdown tunnel with a 1.5m square test section, a Mach number range of 0.2 to 3.0 and a stagnation pressure range of 200kPa to 600kPa at sonic speed. The second option was for a continuous closed circuit compressor driven tunnel with a test section size in the range 1.5m to 1.8m square, a stagnation pressure capability at sonic speed of about 200kPa and a Mach number range of 0.4 to 1.4. The blowdown tunnel offered more than double the maximum Reynolds number for the same capital cost, a supersonic test capability and a large high pressure air storage that could be used to drive other facilities. The continuous tunnel energy consumption for a given Reynolds number and test duration was less than 1/20th that of the blowdown tunnel. The continuous tunnel also offered more than 60 times the total wind-on test time and the ability to test fragile models at low stagnation pressures. Pollock (1983) assessed the two tunnel types as to their suitability to meet the identified Australian requirements and recommended the continuous option. This preference was mainly due to a judgement that the proposed uses of the tunnel, and particularly the store separation work, required testing flexibility rather than maximum Reynolds number. There was strong evidence that the blowdown tunnel Reynolds number capability could not be used for many tests due to excessive model loads. For a blowdown tunnel exhausting to atmosphere the minimum operating stagnation pressure at sonic speed is approximately 200kPa and this would make some tests very difficult. If a significant supersonic requirement had existed, the choice may have been reversed. During the course of this investigation the FluiDyne Engineering Corporation of Minneapolis, USA, made an unsolicjted proposal for a transonic tunnel, providing a further perspective on tunnel design.

The question of the required Reynolds number for adequate simulation of full scale flows is critical to the selection of a transonic tunnel. Following an extensive literature survey, Pollock (1983) concluded:

a/ Different aircraft configurations vary widely in their Reynolds number sensitivity. This sensitivity is also highly dependent on the part of the operational envelope under consideration. Generalisations on Reynolds number sensitivity are difficult. Significant effects have been noted at Mach numbers from 0.16 to 1.0, for high and low lift conditions and for both high and low aspect ratio configurations.

b/ It is widely thought that a chord Reynolds number of 1×10^6 is the absolute minimum for any worthwhile transonic testing, regardless of configuration. The evidence suggests that this should be viewed as a minimum tip chord Reynolds number and not simply a mean chord Reynolds number.

c/ There is no convincing evidence that there is any generally applicable sub-full-scale Reynolds number above which Reynolds number effects can be neglected. Two dimensional aerofoil tests have shown characteristics that are still changing significantly at Reynolds numbers of 30×10^6 to 40×10^6, which is well into the full scale flight range.

d/ For particular configurations at particular test conditions there is the possibility of a minimum acceptable Reynolds number, below which the test flow is completely different to full scale. This occurs most commonly where the nature of the stall changes, say from the thin aerofoil type to the leading edge type (Van Den Berg, 1969). There is no generally applicable Reynolds number for these discontinuous flow changes and the only defence against them is an awareness on the part of the test engineer of the fundamental flow conditions on the model he is testing.

e/ For many, but not all, configurations there is a chord Reynolds number in the range 2.5×10^6 to 4×10^6 where higher Reynolds number conditions can be simulated using the trick of aft transition fixing suggested by Blackwell (1969). It would be clearly advantageous for a wind tunnel to have access to this Reynolds number range.

f/ To facilitate the extrapolation of test results to full scale it is helpful if the test Reynolds number can be varied over a range of at least 2 to 1.

These conclusions did not eliminate either of the alternative tunnel types, but they did suggest that the higher Reynolds number capability of the blowdown tunnel was not as major an advantage as it initially appeared.

At the time when a preference for a continuous tunnel was identified it appeared to be contrary to international opinion, blowdown tunnels having been constructed in Roumania, Yugoslavia, Korea and Taiwan during the previous few years. However since that time no major new blowdown tunnels are known to have been planned and during 1986 both Sweden and South Africa have made firm commitments to construct continuous tunnels of very similar capability to the Australian proposal. The Swedish decision is particularly relevant since they had earlier developed very firm plans for a blowdown tunnel.

The transonic tunnel design currently favoured would have a maximum stagnation pressure of 250kPa, but be power limited, and thus have to operate at lower pressures, above a Mach number of 0.8. The power required would be 12.5MW to 15MW and the estimated cost $32M.

General Aspects of Tunnel Facility

To minimise cost, the two tunnels will be grouped together to facilitate the sharing of buildings and equipment. Since the two tunnels have similar power requirements it is intended that the drive system, which will consist of a variable frequency synchronous motor and solid state inverter, should be shared between them with a resulting cost saving of about $3M. The data system, which will be a development of the design described by Fairlie (1985), will have some elements shared between the two tunnels. Instrumentation items such as pressure transducers and multi-component force balances will also be shared where possible. The total cost saving resulting from collocating the tunnels should be approximately $5M.

The details of the equipment to be provided in the two tunnels are not yet finalised, but the following significant decisions have been made:

a/ The transonic tunnel will be fitted with a six degree of freedom auxiliary model support for store release testing.

b/ The transonic tunnel will have interchangeable solid, slotted and perforated walls. Adequate plenum chamber volume will be provided to facilitate later fitting of adaptive walls.

c/ For pressure measurements on models and on tunnel walls for interference assessment and correction, electronically scanned solid state transducers will be used exclusively.

d/ The low speed tunnel will have a six component external load cell balance rather than the traditional weighbeam type.

e/ Tunnel testing will be highly automated to minimise operating costs.

The test Reynolds number capability of new two tunnel complex is shown in Fig. 1. It should be noted that the capabilities of the tunnels are well matched with the highest Reynolds number occurring in the critical transonic speed range where currently the capability is at its lowest.

Challenge From CFD

Early in this exercise there were strong reservations felt in some areas due to a perception that Computational Fluid Dynamics (CFD) would obviate the need for wind tunnel testing within a few years. This view was based largely on the very optimistic review of CFD by Chapman (1979). The appearance of a more restrained and authoritative review by the American National Research Council (NRC, 1983) contributed to a more realistic view and there is now general agreement that wind tunnels will remain important aerodynamic tools until well into the next century. There is growing evidence that wind tunnel tests and CFD calculations may form a long term complementary partnership. CFD methods are now being widely used to improve the quality of wind tunnel data and this has produced an explosion in the computing power associated with wind tunnel operations. An early review of this new and rapidly developing complementary relationship is given by Whitfield(1980).

Project Approval

Following the workshop held at ARL in December 1982 a response to ASTEC was prepared, since it was their recommendation that started the exercise. Comments on the first draft of this response, circulated in March 1983, raised two questions that had to be resolved before the tunnels could proceed. These were the location of the tunnels and the mechanism by which they would be funded.

A detailed investigation of alternative sites, including a comparative costing exercise by the Department of Housing and Construction, led to the selection of the existing ARL site at Fishermens Bend, Melbourne, as the best location for the tunnels. This decision was finally reached in July 1984. The reasons for the choice were: proximity to the main elements of the aircraft industry, proximity to RAAF Headquarters Support Command and ready access to existing ARL support facilities.

With the very large amount of money involved in designing and constructing tunnels of the proposed size (currently estimated to be about $50M) the formal project approval and funding process is very time consuming. However significant progress has been made and a study into the most appropriate way to handle the contracting of the design and construction is being conducted. As part of this study a senior engineer from the Department of Housing and Construction and the Superintendent of ARL Aerodynamics Division undertook an overseas visit . During the visit that took place during March and April 1986 discussions were held with tunnel designers, constructors and operators in the USA, Canada, UK, Holland and Sweden. Two international meetings of wind tunnel users were also attended.

Current Situation

At the time of Writing (May 1986) limited approval for preliminary design work has been obtained. It is hoped to commission a consultant to conduct a Concept Development Study during the second half of 1986 and then to seek approval to proceed to the full preliminary design.
If the project continues without interruption from now on, the tunnels could be commissioned in 1992.

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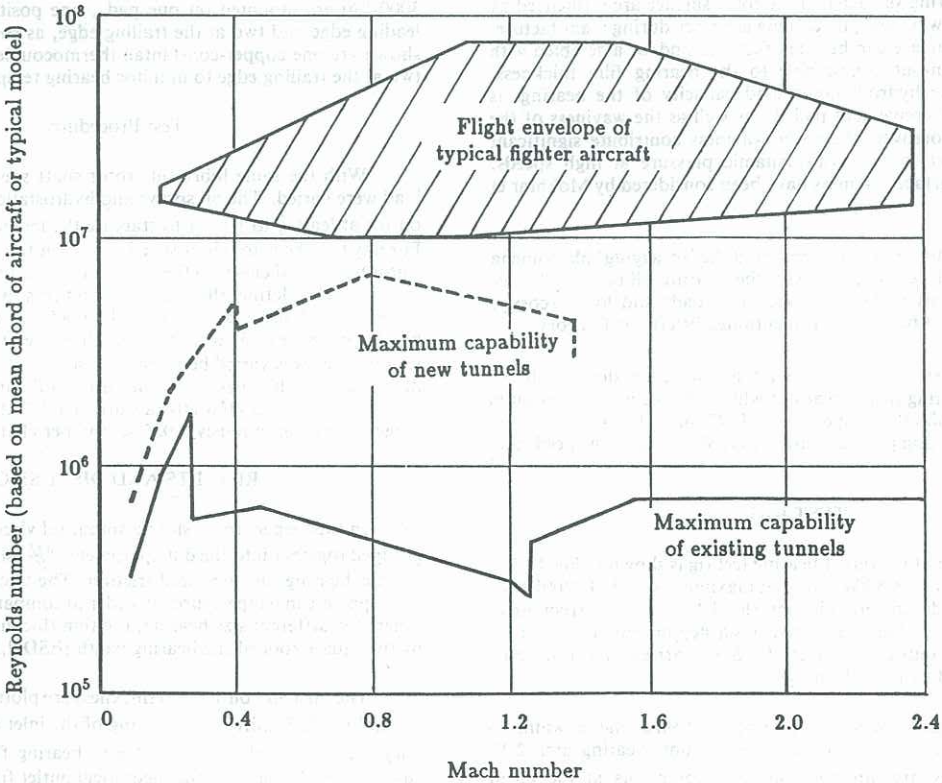

Fig. 1: Reynolds numbers of tunnels and flight.