ICAS-96-1.5 (R)

THE LOW SPEED TILTABLE WIND TUNNEL SWT112

by

John Rosén and Torbjörn Nyström

The Ecology House at Lund University has installed an "up and over", low speed tiltable wind tunnel for studying aerodynamic and performance aspects of birds, i.e. specific fuel consumption and related physical and physiological problems. Features include a maximum speed of 40 m/s, a wide contraction ratio (12.25 : 1), low turbulence, low noise level, low temperature (+4°C) and a device for tilting the tunnel from +8° to -6°, to simulate descent and climbing respectively.

The tunnel is of the closed return type with a partly open test section as its main feature. The framework of the octagonal transparent test section (1.12 m^2) is made of non-magnetic material. The sections downstream of the test section are easily interchangeable and a pylon for a high-speed video camera is planned in the diffusor.

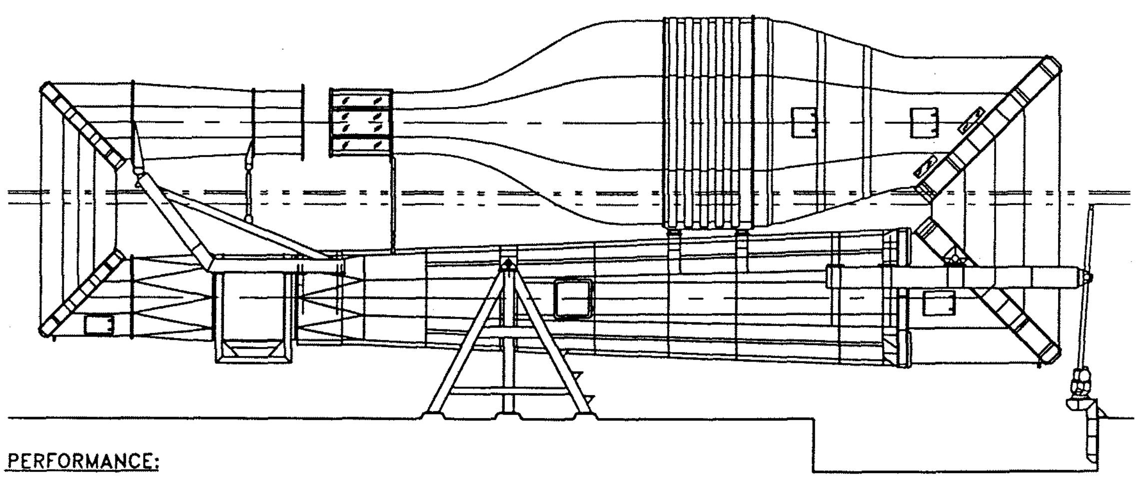
In order to attract interest from different faculties, the tunnel can easily accommodate different types of tests. Some new design features stem from the use of a sandwich material which has provided design advantages and enabled more versatile use of the tunnel.

Preface - Chronological Milestones

The idea of building a wind tunnel to study the aerodynamics of birds began to take shape in autumn 1991. The basis for a specification of the tunnel was provided in an "Outline of Objectives" (1). The original ideas for this project stem from a fruitful cooperation between the Animal Ecology Department at Lund University and Professor C. Pennycuick at Miami University and later at Bristol University. When ROLLAB was asked to prepare an application (2) to be submitted to the Knut and Alice Wallenberg Foundation, the motives for building a tunnel were extended to incorporate features which could be of use for other closely related departments, such as Geography of Nature, Architecture (Building Aerodynamics), Fluid Mechanics and Meteorology. With this in mind, ROLLAB prepared a cost-structured technical proposal (1) in March 1992. This proposal was submitted to the Foundation by the Animal Ecology Department and a grant was awarded in January 1994.

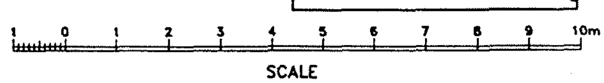
FIG. 1 THE LOW SPEED TILTABLE WIND TUNNEL SWT112

AT THE ECOLOGY HOUSE LUND UNIVERSITY
FINANCIALLY SUPPORTED BY THE
KNUT AND ALICE WALLENBERG FOUNDATION



PERFORMANCE:

AIR SPEED RANGE	0 – 40m/s
OCTAGONAL TEST SECTION	1,12m² (1,20m x 1,08m)
TEMPERATURE RANGE	4 – 40°C



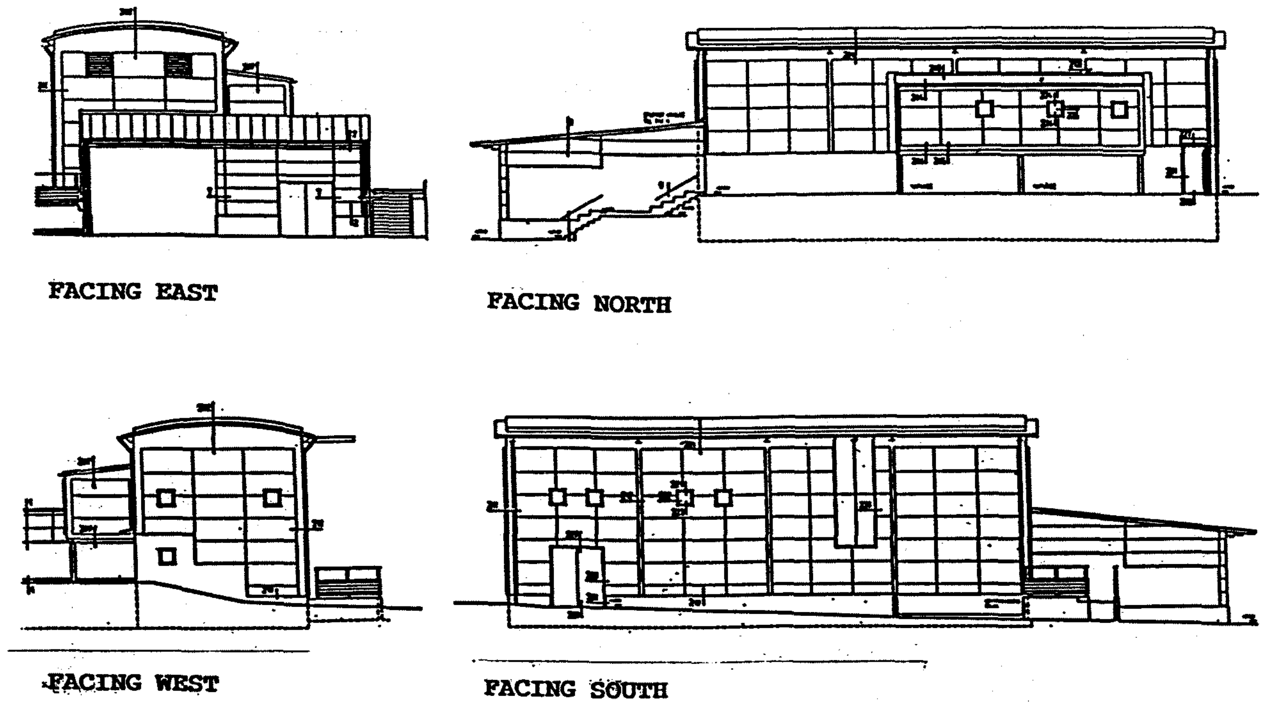


FIG. 2 Wind tunnel building

Project implementation could not start until the second quarter of 1994. In the following months the size of the laboratory was reduced, a cooler was introduced and the tilting range was increased.

The tunnel was installed on site in June 1994 and the shake down tests were ready by October. The birds were trained in advance so that they could make the first demonstration flight in the tunnel during the inauguration ceremony at Lund University (FIG. 1). At this ceremony, the entire Ecology Building had its first public viewing on November 24, 1994, in the presence of the Swedish King (FIG 2).

Introduction

The main objective of this wind tunnel was to create a suitable environment in and around the test section for carrying out a series of tests, which can be used for careful study of different aspects of the aerodynamics and orientation of birds under realistic free flight conditions.

Another aim was to incorporate development potential so that users outside the Ecological Department could benefit from the basic design of the tunnel.

The design was therefore adapted to some extent and special features for carrying out a variety of tests were added.

For example, the test section can be shortened, lengthened or even closed. In order to meet demands from researchers at the Department of Cultural Geography, the test section can also be extended and accommodated to fit the second flange (downstream the collector and diffusor sections in FIG. 3). Special modules can thus be introduced with different trays of soil material so that erosion, sun radiation, diffusion, etc. can be studied (FIG. 4) at varying speeds, temperature, humidity, etc.

To facilitate these studies, the final section upstream of the small double bend was built as an equilateral octagonal, allowing the double bend to swing out 45°. This explains the shape of the scaffolding carrying the collector and diffusor. This allows the tunnel loop to remain open; taking in fresh air via a collector (bellmounth) to the fan (FIG. 4) and expelling contaminated air from the test section alongside the tunnel in the basement, or directly into the open by removing the double bend.

The "swinging" of the double bend is managed by a cut-out in the floor between the two long legs of the tunnel. (FIG. 5 and 6).

An "up and over" type of tunnel was chosen so that climbing and gliding conditions for birds can be simulated. This will probably also provide a better flow symmetry around the vertical symmetry axes in the test section.

To enable rapid and direct control of the living test objects, an atmospheric semi-open test section

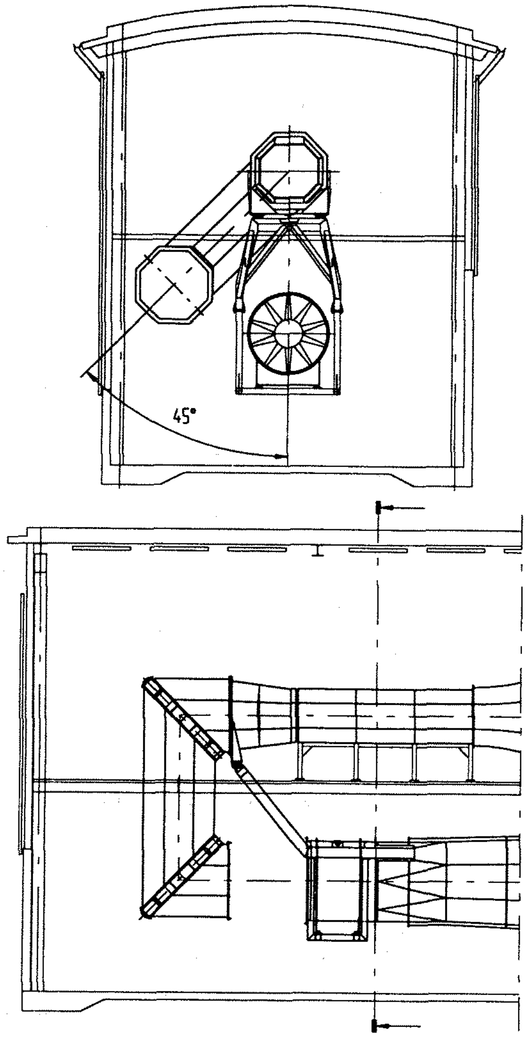


FIG. 3 ALTERNATIVE TEST SECTION WITH THREE MODULES AND AN OPTION TO RUN AN OPEN LOOP.

is imperative. (FIG. 7). If perfect communication and cooperation between operator and bird is to be obtained, the operator must also carry a portable control panel when positioned near the slot between the test section and collector. Also, air speed, tilt angle and temperature can be set from the control room containing the data acquisition systems. Test conditions can also be read from the operator's position.

Using the fan diffusor as a steel support for the superstructure of the wind tunnel allows the tilting point to be welded on to the diffusor. This means a light sandwich design of most of the sections in the test section leg can be built up on this conical structure. (FIG. 1). The tilting point was originally chosen as the tunnel's centre of gravity. This happened to be the optimum point as regards the position (height) of the roof when the tilting angles are changed between the two extremes +6° and -8°.

At a late stage in the design, came a request for the temperature to be between 0°C and 50°C. This meant adding a cooler downstream of the fan diffusor. The weight of the cooler and the downstream end of the fan diffusor combined with the steel fork overbridging the forces from the steel diffusor to the tilting screw, produced a radical change in centre of gravity. The tilting screw therefore had to withstand much greater force (4 tons instead of 1 ton). Since the design of the building was frozen by then, the tilting centre should no longer be displaced.

In order to prevent structural noise being transmitted through the tunnel sections upstream and downstream of the fan, it was equipped with flexible hoses and mounted on dampers in a steel framework below the scaffolding clamped to the fan diffusor. The scaffolding is a spacious framework which also determines the position of the collector test section diffusor, the double bend, and the transition unit. (FIG. 1).

To enable tests in artificially created electromagnetic fields, the almost transparent test section is made of non-magnetic materials. In addition to weight considerations this was another advantage of making the contraction unit of a sandwich material (foam plastic) instead of steel.

For future tests it was also important to have remote-controlled blinds for all the building's windows to allow schlieren optical methods or similar techniques to be used. This is also essential for simulating night flights of migratory birds.

Description of the Facility

The wind tunnel is located as an extension to the east of the Ecology Building with easy access to the basement and Test Section Area. (FIG. 1 and 2).

The basement contains a large trench to cater for the wide double bend which, when the tunnel is tilted, will be about 1 meter below the basement floor. The heavy trestle carrying the bearings for the tunnel tilting mechanism is attached to this floor. A water draining system is located to the trench.

All wind tunnel components were introduced through the west side of the wind tunnel building in a well-prepared sequence to facilitate assembly. This procedure became more critical after it was decided to reduce the width of the building from 11 meters to 8 meters. Once all the larger wind tunnel

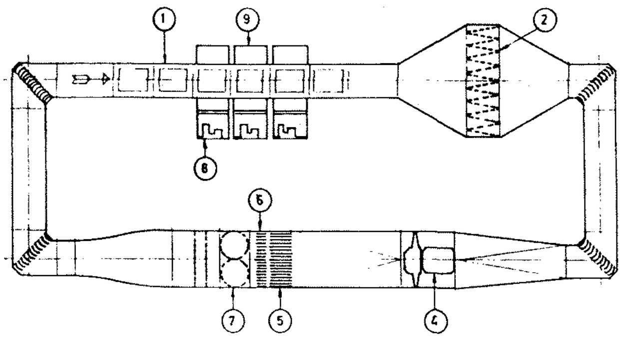


FIG. 4 Tunnel for agricultural studies prepared for Ultuna, Sweden. [1] Test section [2] Filter [4] Fan [5] Cooler [6] Heater [7] Humidifier [8] Temperature controlled earth probes [9] Sun simulator

sections had been assembled, the short wall was closed. The only remaining access to the basement for fairly large items, also designed to enable the cooler to be exchanged if necessary in the future, was a double port (2.40m wide and 2.7m high) with its threshold 0.60m above the basement floor.

The trench edge has a support for the motor-driven strong screw jack which will control the tilt angle. (FIG. 1).

A staircase runs from the basement along the east side of the building up to an intermediary level with a door on the long side. This door will facilitate communication with the main Ecology Building and allow access to the cages housing the birds underneath the control room on the laboratory level, to which the stairs continue along the inner sidewall. (FIG. 6).

The entire deck around the wind tunnel is covered by standard galvanized elements. Except for close to the test section where there is a thick rubber carpet designed to temporarily improve the operation of the tunnel. At a later state, it is intended to replace this with a heavy concrete floor, which can bear heavy, sensitive instruments.

The entire test section area can be observed from the sound-insulated room outside and along the south sidewall. Inspections can be made by going around the tunnel on the laboratory deck. All the inspection hatches on the tunnel can therefore be reached easily from this level. Opposite the control room at the settling chamber level, there is a large port (1.80m + 5.05m) in the north sidewall. This allows any of the five gauzes to be removed using a permanently installed traversing mechanism (1,500 kg). This mechanism runs perpendicular to the symmetry axis of the tunnel and stretches sufficiently far outside the building for the framed gauzes to be hoisted down to a spot on the soil for cleaning or replacement, if necessary.

Another traversing mechanism runs above and along the test section in order to facilitate handling of any future test section and diffusor items which may be introduced. It can also be used to turn the small double bend (45°) so that the closed tunnel can be converted into an open return circuit.

Semicircular wooden vault support a light roof. The sidewalls and control room only have a few small windows, all of which have remote-controlled curtains so the entire laboratory can be blacked out. This can also be done separately for windows between the control room and the laboratory hall.

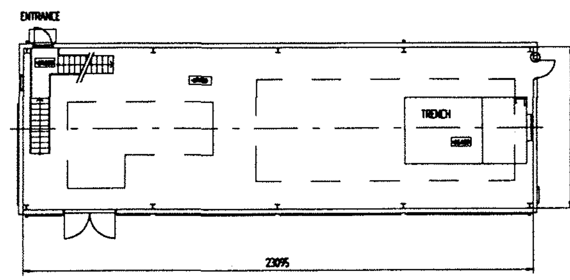


FIG. 5 LAYOUT OF LABORATORY, BASEMENT.

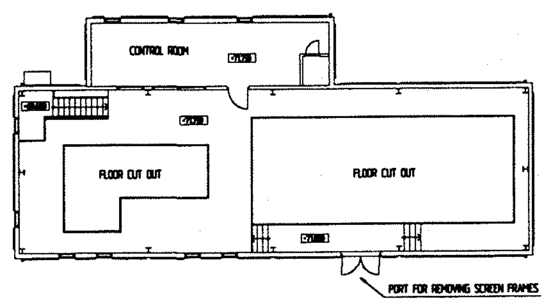


FIG. 6 LAYOUT OF LABORATORY HALL WITH CONTROL ROOM AND FLOOR CUT OUTS FOR TUNNEL

A Tiltable Low Speed Wind Tunnel

Arguments concerning general layout will be presented. The advantages of using sandwich material in a large number of sections will be underlined.

After the description of tunnel components, special design features and the tunnel's development potential will be mentioned.

General Layout

The wind tunnel is divided into 10 sections, for design see FIG. 1 and 2. [3]

The tunnel is of the "up and over" type and mounted on a heavy trestle around which the entire tunnel body can be tilted using a strong (4 ton) remote control screw jack at the large double bend.

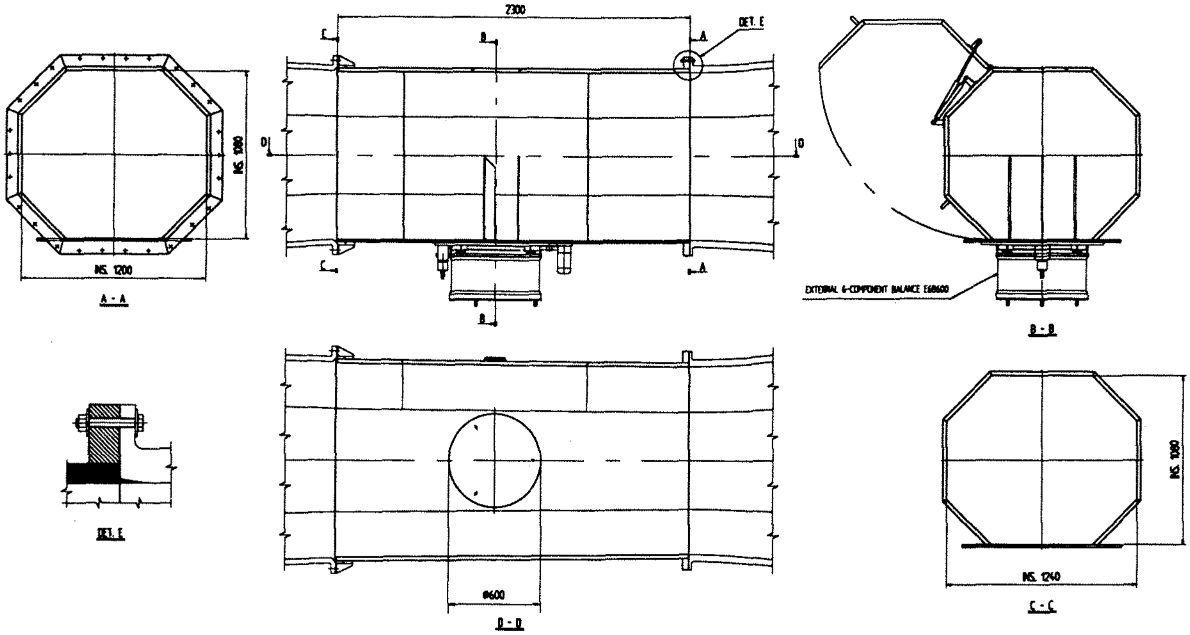


FIG. 7 DESIGN DETAILS OF AERODYNAMIC TEST SECTION.

(FIG. 1). Gliding and climbing angles from -8° to +6° can be achieved before the floor or roof of the building is reached. (FIG. 8).

The fan drive unit (1.6m in diameter) is connected to the structure by elastic hoses up and downstream of the fan. The thermal dilatation of the fan leg can thus take place freely from a fixed point in the third corner. (FIG. 1).

Another fixed point is placed in the downstream flange of the test section diffusor. An air gap after the test section (also valid for closed test sections) makes the section leg free to move longitudinally. The wide-angle diffusor, the settling chamber and the contraction unit are heavy sections which are supported primarily on gliding shoes on the carrying fan diffusor, which is a welded steel design.

The cooler is mounted at the downstream end of the fan diffusor. In order to overbridge the forces from the tilt control screw to the fan diffusor, a heavy steel yoke is rigidly clamped to the diffusor's downstream end. A steel housing had to be built around the cooler to carry over forces from the fan diffusor end to the third corner. The total weight of the wind tunnel (including trestle) is 21.5 tons.

The heavier steel parts are concentrated at the fan diffusor which also serves as the main support of the superstructure which is primarily made of a sandwich material (fiberglass-reinforced plastic skin with a thick layer of hard foam in between).

One exception is the settling chamber which is made of steel.

It is easy to cut out windows and hatches in all components made in the sandwich material. This can be done during manufacturing or on site (without causing ridges or disturbances along the surfaces).

Inspection and access hatches are therefore provided along the tunnel. A few Plexiglas windows are also provided to facilitate flow quality control, after the corner vanes, for example. For cleaning with water, drainage is provided at the base of the two double bends and at the sink between the wide-angle diffusor and the contraction unit.

To prevent air leakage in these draining passages, they all have water locks.

Material Considerations

This is presumably the first wind tunnel largely manufactured in a sandwich material using foam plastic (divinycell surrounded by a thin layer of fibreglass-reinforced plastic). The main reason for this choice was the weight advantage which provides easier handling, transport and on-site assembly.

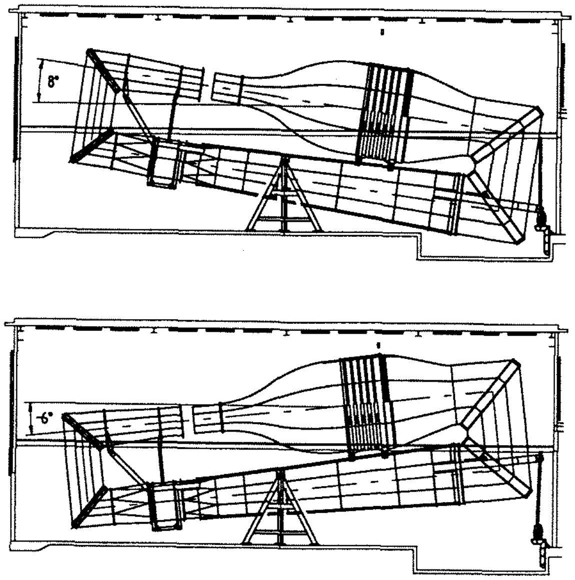


FIG. 8 TUNNEL SHOWN IN TWO EXTREME TILTING POSITIONS 8° AND -6°.

Tunnel Description

The designation SWT112 is derived from Subsonic Wind Tunnel with an area of $1.12 m^2$ in the octagonal test section. The maximum speed, 42 m/s, is not dictated by tests using birds where the preferred speeds are 11 to 20 m/s. This report focuses on the bird version, but two other versions will be mentioned shortly, since they were originally part of the specification in order to attract other faculties to use the basic features of the tunnel.

Any changes to comply with these extra requirements will be limited to sections between the contraction unit and the first corner.

The general layout of the tunnel (FIG. 1) is very similar to the tunnels [3] and [4].

Test Section

The octagonal test section (W x H x L = 1,200 mm x 1,080 mm x 1,200 mm) has eight steel bars clamped between the exit of the contraction unit and a flange at the downstream end. These bars (FIG. 9) have longitudinal slots in which Plexiglas or other panels can be introduced from the downstream end. This will facilitate future mounting of instruments on any wall panels. For example, an external balance attitude mechanism (max. diameter 560 mm) can be mounted on the floor panel. (W = 620 mm). (FIG. 7).

Two-dimensional models on circular plates placed in the parallel top and bottom surfaces are another possibility. (Boundary layer compensation is only added on non-horizontal surfaces).

The test section is kept short because it is essential for the operator to be in close contact with the test object (the bird). Therefore the open gap upstream of the collector is restricted to 0.5 m.

The test section is designed without magnetic material so that artificial terrestrial magnetic fields can be introduced to study alleged orientation capacity of migratory birds.

All sections upstream of the test section up to the third corner have black internal surfaces to simulate night conditions for the birds.

The test section can easily be removed by means of a traversing system above the tunnel and be replaced by other test sections.

Alternative A and B.

A. Test Section for Building Aerodynamics.

This test section will comprise three modules (each 1.2 m long) and interchangeable with each other (without boundary layer compensation), with a total length of 3.6 m. The remaining distance to the equilateral octagonal corner section can only be negotiated by a short wide angle diffusor with a gauze to prevent flow separation.

A 10 mm slot will be provided downstream of this test section. To create different boundary layer profiles, a set of fences can be installed in the two first modules.

For smoke diffusion tests, or when using tracing gases, recirculation of the air can be avoided by using an airing system whereby the small double bend is turned 45° around the symmetry axis of the upper leg, forcing all the air away from the tunnel. Fresh air can enter the tunnel through a bellmouth directly connected to the fan inlet. (FIG. 3).

Disruption of the loop leads to reduction of maximum speed.

B. Test Section for the "Geography of Nature" Department.

A set of three test modules, containing soil probes and apparatus for establishing the correct testing conditions, such as cooler, heater, water and wind with corresponding measuring systems, can be directly connected to the contraction. A typical similar set up is shown in FIG. 4. Earth probes can thus be studied with regard to drying, permeabil.ity, temperature profiles, etc. The influence of sun radiation can be simulated from above.

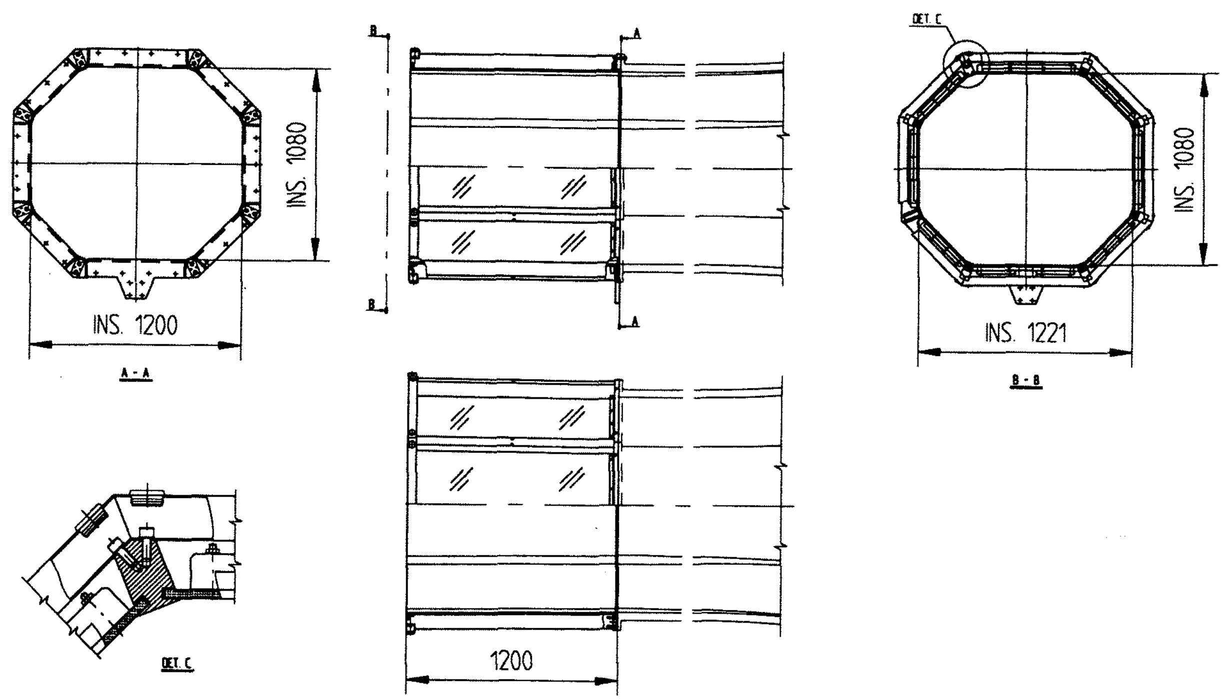


FIG. 9 THE OCTAGONAL TEST SECTION.

Collector/Diffusor - Conventional Test Section

The total length of the collector and the terminating diffusor section has been chosen so that a closed conventional test section can be installed in the future. Extrapolation of the existing short test section, i.e. with the same boundary layer compensation, means the same dimensions will be obtained as in the junction between collector and diffusor inlet. Thereafter the existing transition (diffusor) to an equilateral octagonal takes place upstream of the double bend.

The collector and diffusor (both made of sandwich material) have a catch net between them. There is a hatch on the top of the diffusor which can be exchanged by a platform carrying a pylon upon which a video camera will be mounted.

The Double Bend and Transition Unit

The cross section of the ducts in the double bend is an equilateral octagonal.

The corner vanes [5] are welded on to steel frames (in corners one and two).

Transition Unit

The transition unit goes directly from the octagonal into the circular shape of the fan (1,600 mm diameter). In order to ensure vibration - free contact between these two sections, they are bound together by a flexible hose.

Fan Drive Unit - Performance

The fan is mounted on a supporting structure underneath the framework which is rigidly anchored to the heavy fan diffusor and designed to carry total loads from the collector, test section diffusor, double bend and transition unit (FIG. 1).

The fan stands on four vibration dampers. Elastic hoses up and downstream of the fan housing will prevent structural noise from spreading to the rest of the tunnel.

The axial fan (ACN-1600-578-10) is from Novenco A/S in Denmark and has the following characteristics:

Fan Data

Fan diameter	1,600 mm
Hub diameter	578 mm
Number of blades	10
Chosen blade angle	51.9 Deg.
Max. blade angle	55.1 Deg.
Static pressure	500 Pa
Dynamic pressure	182 Pa
Total pressure	682 Pa
RPM	970
Efficiency	76%
Power	31.24 kW
Fan air speed	17 m/s

Motor Data

Delivered by	ABB
Voltage	380 Volt
Power	37.80 kW
Efficiency	90.00%
Current	74.0 Ampere
Starting time	1.2 sec
Size	250
Frequency	50 Hz
RPM	970
Cos	0.83
Starting current	444 Ampere
Power marginal	18.4%

The above performance figures have taken into account the additional pressure drop (20%) which resulted from introducing the cooler at a later stage. The motor is remote controlled by a SAMI (ABB) frequency converter unit placed in the basement, with a cable loop which will adapt to the tilting motion of the tunnel.

Fan Diffusor, Cooler and Cooling Device

The transition unit after the fan is integrated with the octagonal part of the fan diffusor. The diffusor is strong and made of stiff-welded steel so that it can serve as a carrying beam for all the tunnel sections which can be tilted around an axis supported by a pair of heavy trestles. An encoder incorporated in the tilting device allows tilt angles to be transmitted to the control room computer. Limiting switches are also provided. It is also possible, from a distance, to read a pointer directly on a scale at the tilting point.

Housing for the cooler is located at the downstream end of the fan diffusor. This will prevent air from escaping. Above all, it will overbridge forces from the diffusor to the downstream double bend, although the main support for the double bend is the fixed point at the third corner. Here it is fixed on the yoke arm, which is clamped to the diffusor and supported at the far end of the tunnel by the motor-driven screw jack mounted on the concrete frame of the 1 m deep trench.

The Large Double Bend and Wide Angle Diffusor with Honeycomb

The octagonal duct is made in one piece of sandwich material. It is then cut up and adapted to the two frames for the 90° corner vanes designed according to (5). All the parts are provided with hatches for inspecting and cleaning the interior.

The wide angle diffusor is integrated with the last cylindrical part of the double bend. One of the advantages of sandwich material is that it allows considerable freedom to incorporate large radii in the contour at the entrance and exit of the wide angle diffusor.

To prevent separation in the wide angle diffusor (half angles are 16.7° and 18.4° in the vertical and horizontal planes respectively), two gauzes have been installed as recommended in [6]. At the outlet from this section a honeycomb has been installed in a recess enclosed by the steel flange of the settling chamber.

An inspection and access door is located between the last gauze and the honeycomb. (FIG. 1).

Settling Chamber

Five screens have been mounted in octagonal frames and rolled into position from the side. This section is all steel and therefore heavy. However, it is directly supported by four pads on the diffusor.

Stainless screens can be cleaned or exchanged with the help of a beam placed perpendicular to the tunnel. The beam supports a yoke on which gauzes can be attached and torn out, first on rollers and then - after passing the high port in the side wall - outside the building hoisted down to a prepared surface with separate draining facilities, where they can be cleaned or exchanged.

The Contraction Unit

The Contraction Ratio is 12.25 : 1 (3.5^2 :1) and the total length of the contraction unit is 5,620 mm and the entrance octagonal is 4,200 mm wide and 3,780 mm high.

This aspect ratio is unchanged along the contraction. The profiles are a 6th-degree polynom as suggested by Professor S. Laine [7].

A sequence of 5 static pressure measuring holes along one horizontal and two vertical walls are located at the downstream end. These will be used as references when determining velocity distribution in an undisturbed test section.

The contraction terminates with an internal octagonal cross section cut out in steel and machined together with two identical plates. One was sent to the manufacturer of the test section, and one which can be used as templet for new test sections, thus assuring a perfect (stepfree) connection.

Special Design Features

Some special design features have already been mentioned in the previous pages and a short summary is provided below. [1] [2]

A short transparent anti-magnetic test section is adapted, primarily for tests with birds.

A short 0.5 m gap exposed to the open air is due to the necessity of having a close cooperation operator - bird - wind tunnel.

The fact that the tunnel can be tilted, will provide new opportunities for studying birds during climbing, gliding and straight flight.

Built-in development potential allows versatile use of the tunnel for those wishing to modify it to their specific requirements. This primarily applies to the sections between the contraction unit and the fan.

A pylon submerged into the flow downstream of the test section and equipped with a high-speed video camera for detailed study of the movement pattern of the bird and the consequences of this in the airflow pattern.

The influence on birds of artificially applied electromagnetic fields.

Most sections in the wind tunnel have been made of fibreglass-reinforced plastic covering a core of divinycell. The advantages are:

- The paint is integrated
- The surface is hard and impact-resistant
- The acoustic properties are good
- It is easy to keep the tunnel clean
- Smooth and fine surface (can be built up towards glass, or Plexiglas surfaces).
- Easy design work compared with steel
- Light and stiff material
- It is easy to drill holes to saw and glue the material, if modifications need to be carried out on site.

Acknowledgement

The initiative to this project was a result of a close cooperation between Professor Thomas Alerstam and Professor Colin Pennywick, whose ideas and support throughout have contributed to realize the unique features of this tunnel.

They have also succeeded in creating a special atmosphere around the project.

References

(1) Pennycuick, C.J. The Lund Wind Tunnel: Outline of Ojectives, 28 December 1991.

(2) Rosén, J., Nyström, T. "La Cage au Vol" The Low Speed Tiltable Wind Tunnel SWT 112, ROLLAB MEMORANDUM RM131. An application in Swedish was presented by the Animal Ecological Department, Thomas Alerstam to the Knut and Alice Wallenberg Foundation), March, 1992.

(3) Ridder, S.O., Rosén, J., Eriksson, P.O., Nilsson, R. Preliminary Design Study of the LST 8m + 6m Project at NLR. ROLLAB MEMORANDA RM41 and 44, July 1968.

(4) Barrett, R.V. Design and performance of a new low turbulence wind tunnel at Bristol University. AJRAS, March 1984.

(5) Salter, C. Experiments on thin turning vanes. RM No. 2469, 1952.

(6) Schaubauer, G.B., Spangeberg, W.G. Effects on screens in wide angle diffusors NACA Report 949, 1949.

(7) Laine, S., Harjumäki, J. A theoretical study of axisymmetric contractions for low speed wind tunnels, Helsinki University of Technology Report No. 75-A2, 1975.