



C15-10 shown with the C15-11 Inclined Manometer Bank Accessory fitted

*A small, benchtop wind tunnel, with visible working section. A wide range of accessories and instrumentation options are available, allowing a comprehensive study of subsonic aerodynamics. The facility is suitable for undergraduate training and project work.*

#### FEATURES

- > Computer controlled air flow
- > 150mm (6" nominal) square working section
- > Transparent working section for visibility
- > Wide range of models for both aerodynamics and air flow studies
- > Choice of water or electronic manometer banks
- > Quick release connectors on manometer tubes and quick release fastenings for easy model changing
- > Simple flow visualisation technique incorporated

*The Armfield C15 is a new computer controlled subsonic benchtop wind tunnel designed for undergraduate teaching.*



## DESCRIPTION

### C15-10

The C15-10 is a small wind tunnel designed for benchtop operation. Air is drawn through the working section by a variable speed fan at the discharge end of the tunnel.

A honeycomb flow straightener is incorporated at the inlet, and a 9.4:1 contraction ratio ensures well developed airflow through the working section.

The working section is fabricated from clear acrylic to give good visibility of the models, and appropriate model connection points are included in the side wall and roof of the working section.

A unique feature of the working section is that its entire base is removable to allow the insertion of large or complex models such as the C15-24 Bernoulli Apparatus, C15-25 Boundary Layer Plate or alternative models constructed by the user.

The basic wind tunnel is supplied with a USB interface to allow it to be controlled from a PC (not supplied). An electronic pressure sensor mounted in the wall of the working section measures the static pressure, allowing the air velocity to be calculated and displayed on the computer.

A manometer bank is required for use with the optional models and instruments. Two options are available, a 13 tube water manometer or a sixteen channel electronic manometer.

With the electronic manometer the readings and data logging are integrated with the wind tunnel operational software. With the water manometer the readings can still be integrated and recorded, but need to be entered into the computer manually.

The optional models are mounted through a circular hatch (120mm diameter), the models being permanently mounted on a hatch cover to seal the opening (flush with the inside wall of the working section to avoid disturbing the flow). They are secured by quick release clamps on the side wall of the working section. Where necessary the hatches incorporate an angular scale allowing the model to be manually rotated to known angles.

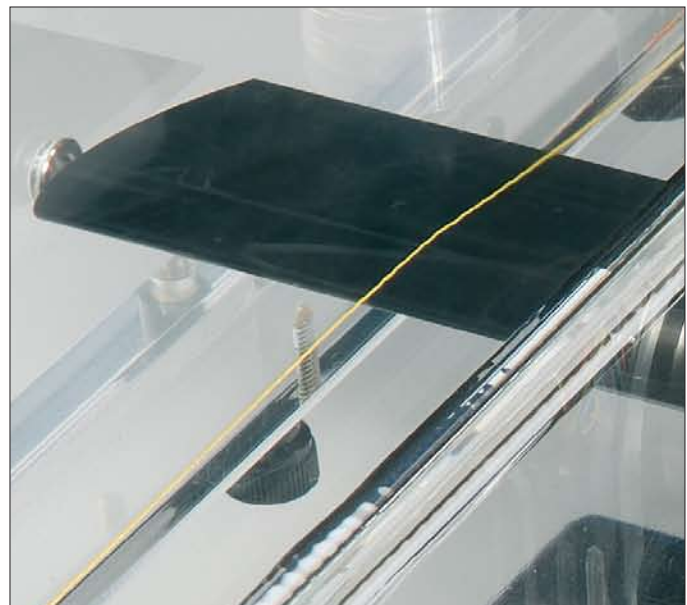
A plain, clear acrylic cover is supplied for applications where no model is fitted but this may be adapted by the user to mount alternative models.

A second, smaller hatch behind the model mounting position allows the optional Wake Survey Rake (C15-15) to be installed downstream of the various optional models. A plain hatch cover is installed until this option is fitted.

The working section incorporates a simple technique for flow visualisation around any of the optional models. A lightweight twine follows the flow contour around the model and shows if and where boundary layer separation (breakaway) occurs.

A simple adjustment arrangement allows the length of twine and its vertical and horizontal position to be easily varied.

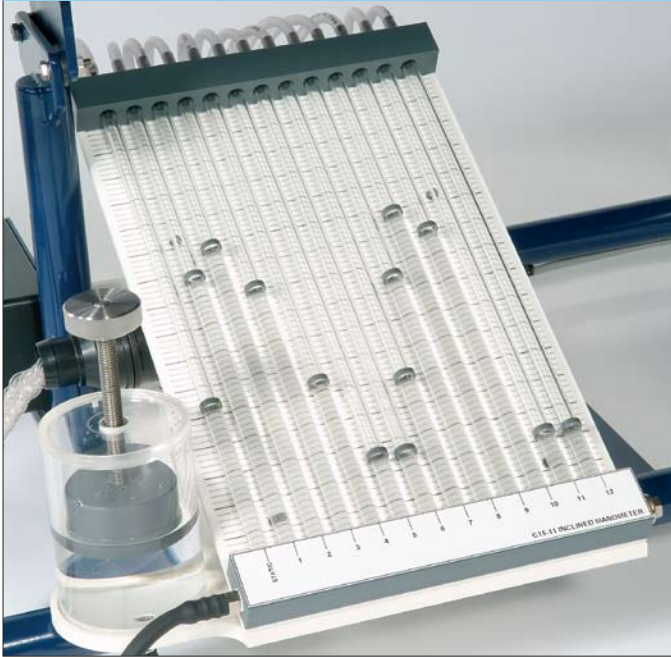
Three tappings in the roof of the working section, each with a blanking plug flush with the inside wall, allow the flow visualisation system or the Pitot static tube (option C15-14) to be inserted. These tappings are located at the start of the working section, upstream and downstream of the model mounting position.



Visualisation of flow over the C15-21 Pressure Wing at low angle of attack.

## ACCESSORIES AND INSTRUMENTATION

### C15-11: INCLINED MANOMETER BANK



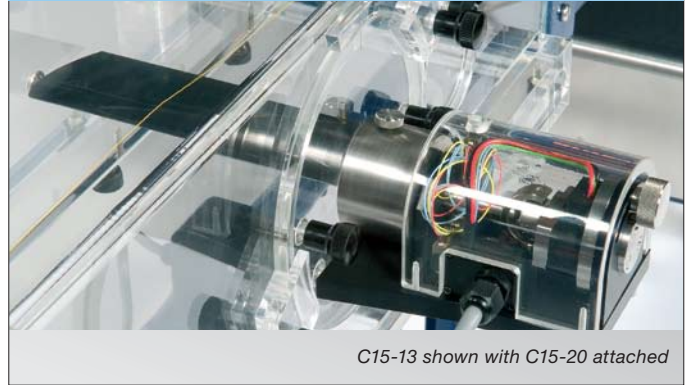
A bank of 13 transparent tubes inclined at 30° to measure small pressure differences (0–160 mm H<sub>2</sub>O). It includes a water reservoir with screw operated displacer to allow rapid adjustment of the datum level in the manometer, and is fitted with quick release connectors for rapid connection to models and instruments. Water is used as the manometer fluid for safety and convenience in use.

### C15-12: ELECTRONIC MANOMETER BANK



An electronic console incorporating 16 differential pressure sensors, each with a range of 0-178 mm H<sub>2</sub>O. (It connects to the control PC using a second USB port, and the readings are fully integrated with the wind tunnel control software.) A common tapping allows all sensors to be referenced to atmospheric pressure. Quick release connectors allow for rapid connection to models and instruments.

### C15-13: LIFT AND DRAG BALANCE (requires C15-20 or C15-22)



C15-13 shown with C15-20 attached

A 2-component, electronic balance used to measure the lift and drag on appropriate models (not used with models having multiple internal tapping points). The lift and drag models connect to the balance using a simple fixing that ensures correct orientation of the model.

Electronic sensors are used to measure the lift and drag forces, the drag being measured directly, and the lift by a reduction in the model weight. The model being tested can also be rotated on the mounting and the angle of rotation measured electronically. The readings from the lift and drag sensors and the rotation sensor are displayed on the control software screen running on the PC, and are available for data logging.

The balance is designed to accommodate the C15-20 or C15-22 but can also accommodate alternative models manufactured by the user.

## DESCRIPTION

### C15-14: PITOT STATIC TUBE (requires C15-11 or C15-12)

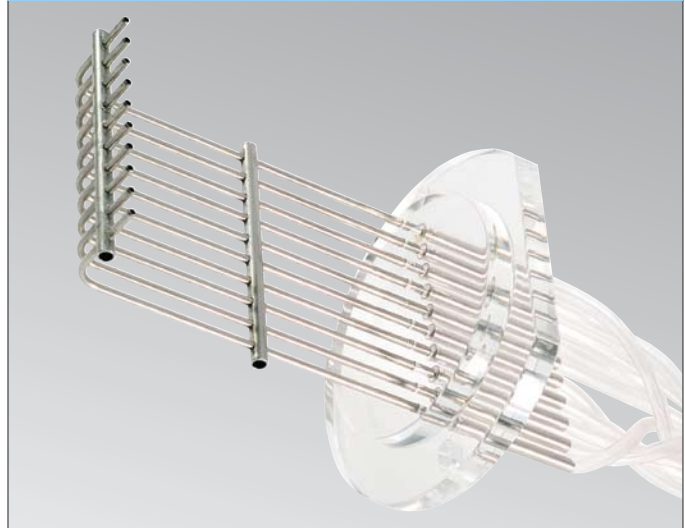


A small Pitot static tube mounted in a bush that can be located in the roof of the working section at three alternative positions, i.e. the start of the working section and upstream and downstream of the model mounting position.

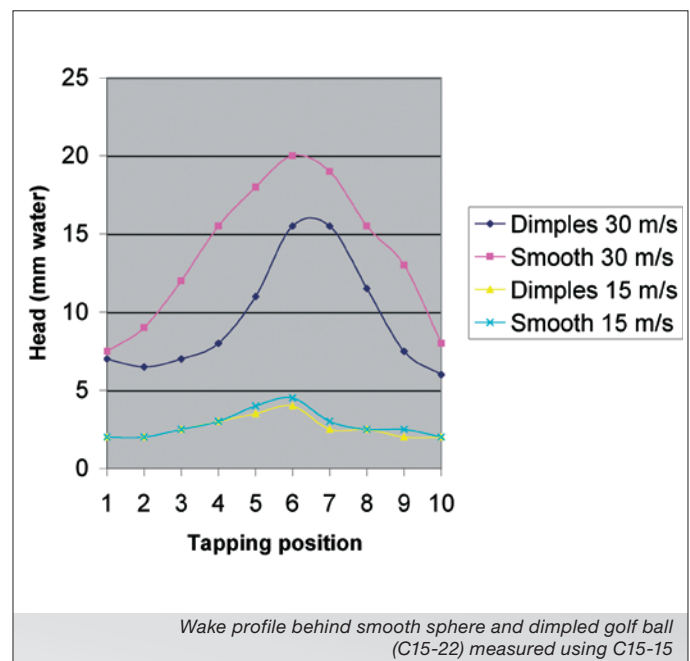
The bush allows the tube to traverse over the full height of the working section to measure the velocity profile inside the working section of the tunnel. The flexible tubing from the Pitot Static Tube incorporates two quick release connectors.

The forward-facing hole measures the total pressure and the side-facing holes measure the static pressure. The difference between these readings is used to calculate the air velocity. The Pitot static tube supplied is of classical design with an ellipsoidal nose giving a tube coefficient that may be taken as unity and readings that are not highly sensitive to inclination/yaw of the tip.

### C15-15: WAKE SURVEY RAKE (requires C15-11 or C15-12)

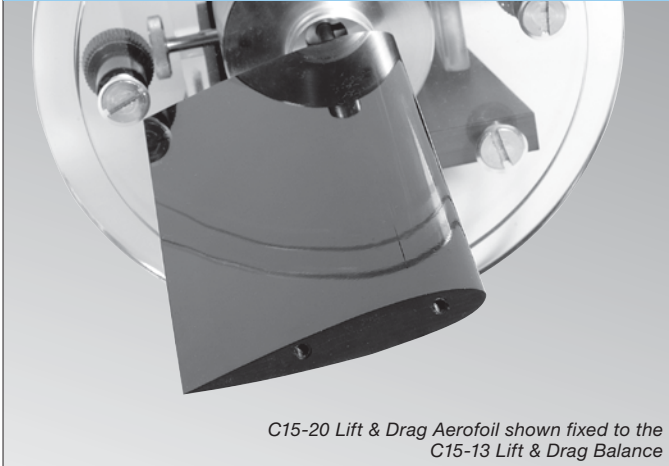


The rake consists of 10 tubes positioned vertically in a row and pointing towards the airflow. The rake is mounted downstream of the model being used. The tubes are mounted at a fixed pitch of 5mm but the assembly can be displaced 2.5 mm allowing measurements at intervals of 2.5 mm by interlacing two sets of readings. The tubes are connected via flexible tubing to a multi-way quick release connector.



## MODELS

### C15-20: LIFT AND DRAG AEROFOIL (requires C15-13)

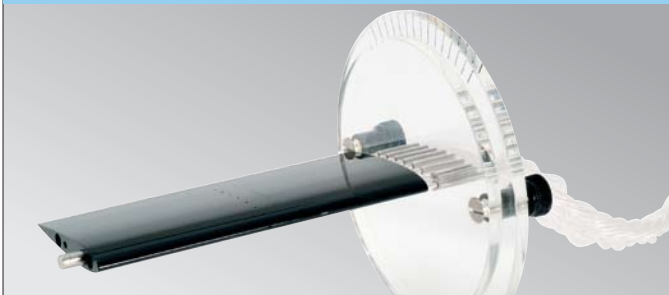


C15-20 Lift & Drag Aerofoil shown fixed to the  
C15-13 Lift & Drag Balance

A plain symmetrical aerofoil to NACA 0015 profile, incorporating a mounting rod that allows it to be installed on the C15-13 Lift & Drag Balance, thus allowing the lift and drag to be measured with the aerofoil at different angles of attack.

The aerofoil has the same section as the C15-21 to allow direct comparison of lift characteristics with the pressure distribution.

### C15-21: PRESSURE WING (requires C15-11 or C15-12)



A symmetrical aerofoil incorporating 10 tapping points distributed along the wing profile on one side, which allows the pressure distribution to be measured from the leading edge to the trailing edge. The pressure distribution on the upper and lower surface can be obtained by inclining the aerofoil at positive and negative angles of attack. Machined to NACA 0015 profile, the aerofoil has the same section as the C15-20 to allow direct comparison of pressure distribution with the lift characteristics.

The tapping points are all flush with the surface of the aerofoil and connected via flexible tubing to a multi-way quick release connector.

### C15-22 DRAG MODELS (requires C15-13)



Seven different models are provided for use with the C15-13 Lift and Drag Balance for investigations into the influence of shape on the drag forces. Five models are supplied with a common equatorial diameter of 50mm, thus all presenting the same cross section to the airflow:

- Sphere
- Hemisphere, convex to airflow
- Hemisphere, concave to airflow
- Circular disk
- Streamlined shape

Additionally a dimpled golf ball and plain sphere demonstrate the difference in drag force due to the dimples.

A spare support rod is supplied for drag calibration purposes or for mounting alternative, user generated models.

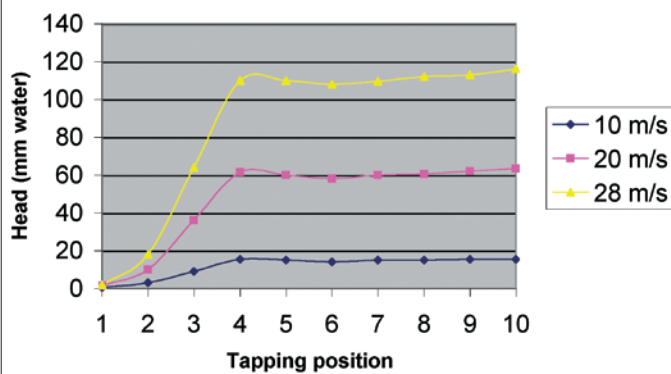
### C15-23: PRESSURE CYLINDER (requires C15-11 or C15-12)



A plain cylinder, 30mm diameter, incorporating 10 equi-spaced tapping points around half of the circumference that allow the pressure distribution around the cylinder to be measured. The cylinder can be rotated through 180° to plot the pressure distribution over the whole circumference.

The tapping points are all flush with the surface of the cylinder and connected via flexible tubing to a multi-way quick release connector.

### C15-23: PRESSURE CYLINDER continued



Pressure distribution around one side of cylinder  
(C15-23) - Tapping 1 upstream.

### C15-24: BERNOULLI APPARATUS (requires C15-11 or C15-12)



A Venturi profile that is installed in the working section of the tunnel via the removable floor.

The Venturi incorporates 11 pressure tapings in the floor, connected via flexible tubing to quick release connectors.

The Venturi occupies the full height of the working section and the width varies from 150mm (full width of the working section) at the inlet and outlet to 100mm at the throat. It is manufactured from clear acrylic for full visualisation.

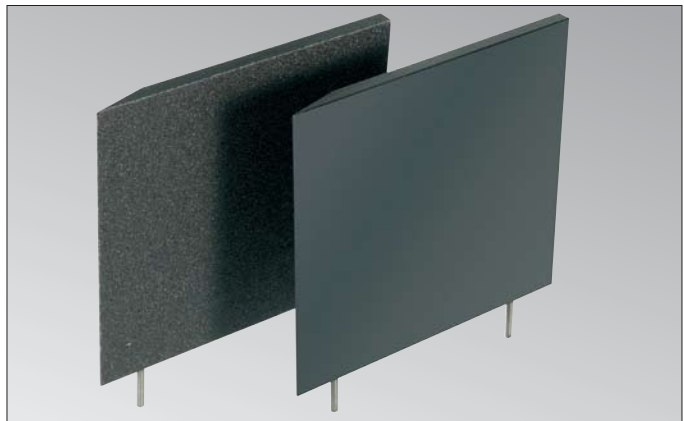
By itself the C15-24 may be used to show the variation in static pressure with change in cross section, but when used in conjunction with the Pitot Static tube (C15-14) the Bernoulli equation can be fully demonstrated.

### C15-25: BOUNDARY LAYER PLATE (requires C15-11 or C15-12)



A flat plate, with a bevelled leading edge, that is mounted vertically in the working section via the removable floor. A flattened Pitot tube, mounted on a traversing micrometer, allows the air velocity to be measured at different distances from the surface of the plate.

The plate can be moved relative to the Pitot tube to allow the velocity profile to be measured at any position between the leading edge and the trailing edge of the plate.



A smooth plate and artificially roughened plate (above) are included to show the difference between laminar and turbulent boundary layers. The flexible tubing from the Pitot tube incorporates a quick release connector.

### C15-26: PROJECT KIT

A selection of components that allow alternative models to be constructed by the user. Comprises a floor panel, a circular hatch and a set of quick release connectors with appropriate flexible tubing.

## SOFTWARE CAPABILITY

*Full educational software is provided with the C15-10 for all of the optional instruments and models available.*

*The software is used to control the wind tunnel, including switching on the fan and controlling the speed, and to display and record all the data. These facilities are incorporated in mimic diagram control screens, which display a graphical representation of the apparatus, the electronic sensor values, values calculated from the sensors (such as wind speed, lift, etc) and allow values from instrumentation such as the water manometer bank to be entered manually and recorded.*

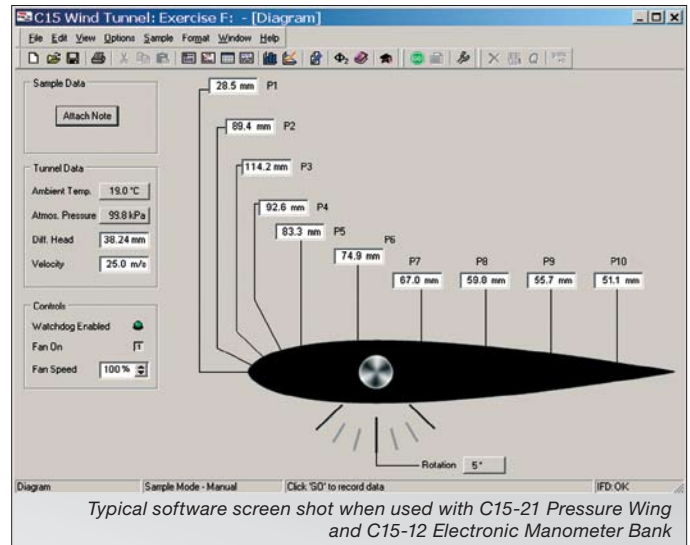
*Powerful and flexible data logging and graph plotting facilities are included, together with a sensor calibration facility and a wide variety of data display and data export options.*

*Also provided are presentation screens giving an overview of the software, the equipment, the procedure and the associated theory. This is backed up by a detailed 'Help' facility giving in depth guidance and background information.*

*The software is supplied with a number of pre-determined student exercises, each with specific mimic diagrams and full instructional help texts. These predetermined strategies have been carefully chosen to introduce the user to the principles of air flow and aerodynamics using the various optional models and instruments.*

*The exercises are structured, allowing the various models to be evaluated using appropriate available instrumentation. These range from simple flow visualisation studies when no instrumentation is available to a complete analysis when a Manometer, Lift and Drag Balance, Pitot tube etc is available.*

*Additionally, for full flexibility, a user configurable 'Project Work' option is included with the software, for use when the user wishes to extend the investigations or use their own models.*



## UNIVERSAL SOFTWARE INTERFACE

*Included separately on the software CD are the 'drivers' required to allow other software applications to communicate with the C15-10 via the USB interface. This allows users to write their own software instead of using the Armfield provided software. This software can be written in many different systems. Typically LabView, MatLab, 'C', 'C++', Visual Basic, Delphi, and any other software environment which allows calls to external drivers can be used.*

*In this way the user can write software to suit their specific requirements, in an environment which they are fully familiar with and which is compatible with their other equipment.*

## SPECIFICATIONS

### C15-10:

- Square test section, nominally 150 x 150mm, length 455 mm
- Air velocity in the test section variable from 0 to 34m/s (note: some models can only be used at lower velocity)
- Profiled inlet with a 9.4:1 (nominal) contraction ratio

### C15-11

- Tube length 320mm
- Inclination 30°
- Measurement range 0-160 mm H<sub>2</sub>O

### C15-12

- 16 channels 0-178 mm H<sub>2</sub>O (differential)

### C15-13

- Lift force 3.4N at model
- Drag force 3.4N at model
- Inclination +/- 45°

### C15-20

- Aerofoil NACA 0015
- Cord length 61.5mm
- Thickness 9.2mm

### C15-22

- Equatorial diameters:
- Large models 50mm
- Golf ball and small sphere 43mm

### C15-23

- Cylinder diameter 30mm
- Tapping spacing 20°

### C15-24

- Throat width 100mm
- Upstream/downstream width 150mm

## ESSENTIAL EQUIPMENT

The user must have access to a PC with a free USB port, running Windows 98, 2000, ME or XP.

An additional USB port will be required when using the optional C15-12.

Depending on the models being used, C15-11, C15-12 or C15-13 will be required (see model descriptions).

## REQUIREMENTS

### Electrical supply:

- C15-10-A: 220-240V/1/Phase, 50Hz, 10Amps
- C15-10-G: 220-240V/1/Phase, 60Hz, 10Amps

G version has optional 1.5kVA transformer available to accommodate 120V/1Ph/60Hz supply.

## OVERALL DIMENSIONS

- Height: 0.700m
- Width: 2.250m
- Depth: 0.460m

## SHIPPING SPECIFICATION

- Volume: 1.5m<sup>3</sup>
- Gross weight: 220kg

## ORDERING SPECIFICATION

- Small computer controlled wind tunnel for undergraduate teaching
- Clear acrylic working section (150mm x 150mm x 455mm) for excellent visibility
- Inverter controlled AC fan for accurate speed control up to 34m/s air velocity
- Wide range of optional models and instrumentation
- Multi-way or single-way quick release connectors between models and manometers
- Models mounted in side wall of working section incorporate quick release catches
- Complete with data logging and educational software
- Electronic watchdog allows for remote operation

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