P.A. HILTON LTD.

EXPERIMENTAL

OPERATING

AND

MAINTENANCE MANUAL

OPTIONAL

FREE AND FORCED CONVECTION FROM FLAT, FINNED AND PINNED PLATES

H112P

H112P_E_1_023
JAN 12

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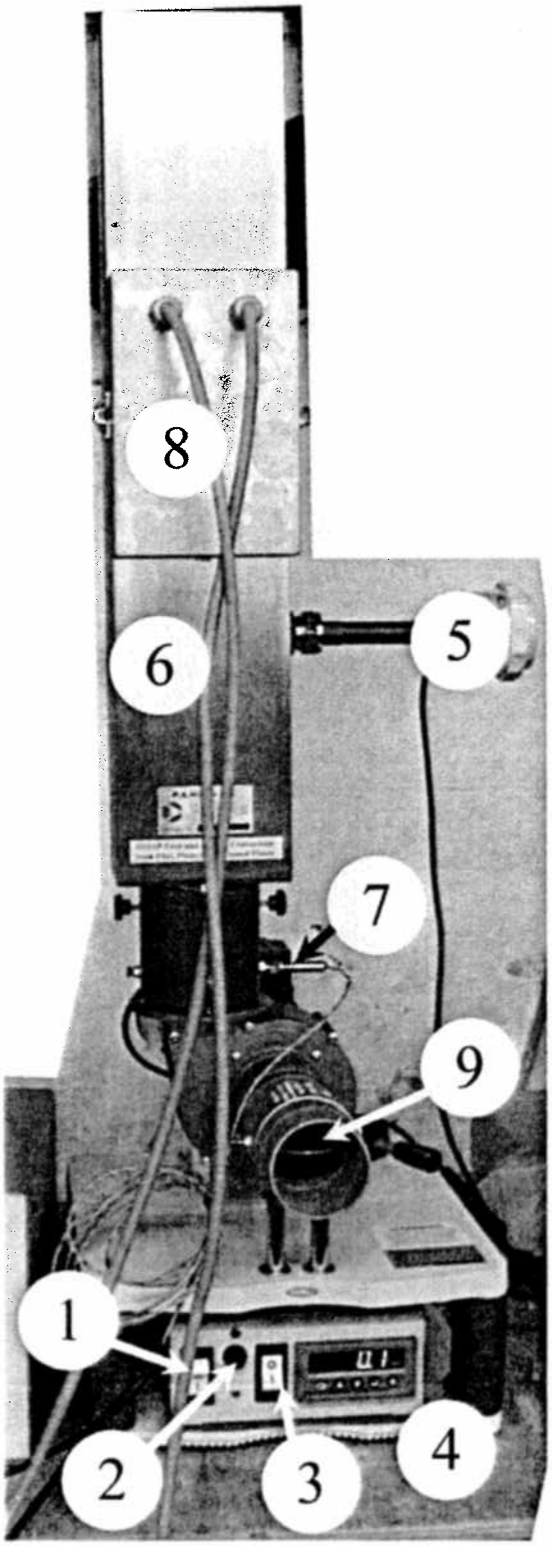
EXPERIMENTAL CAPABILITIES

SCHEMATIC DIAGRAM H112P

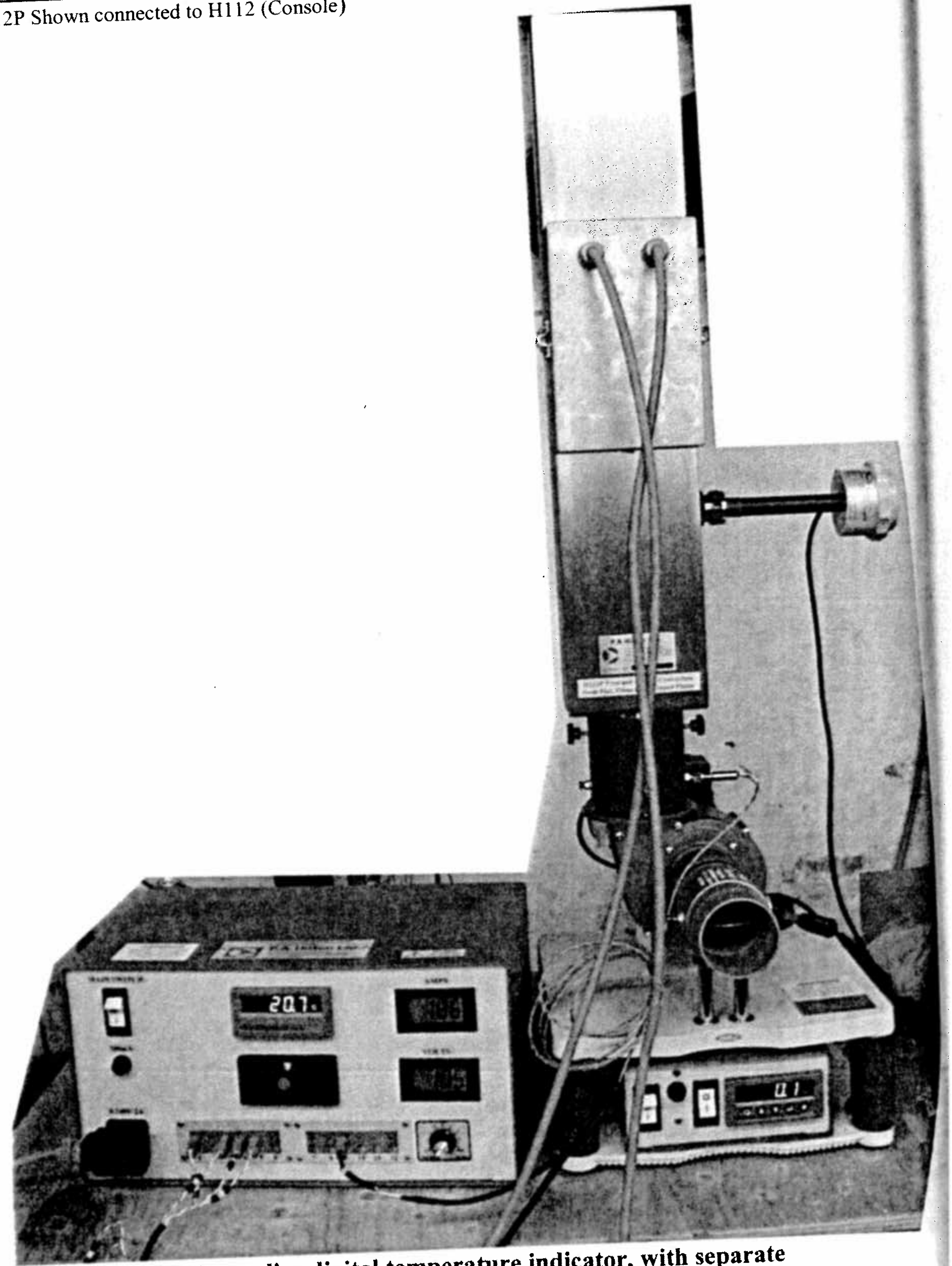


Key

1. Main Switch
2. Instrument Fuse
3. Fan Switch
4. Air Velocity Display (m/s)
5. Air Velocity Sensor(Hot Wire Anemometer)
6. Duct
7. T9 Air Temperature
8. Heated Plate
9. Air Throttle

TYPICAL INSTALLATION

H112P Shown connected to H112 (Console)



Note this shows the earlier digital temperature indicator, with separate temperature selector switch.

SYMBOLS AND UNITS

Symbol	Quantity	Fundamental Unit
A	Area	m^2
h	Surface Heat Transfer Coefficient	$W\ m^{-1}\ K^{-1}$
I	Heater Current	Amps
k	Thermal Conductivity	$W\ m^{-1}\ K^{-1}$
P	Pressure	$N\ m^{-2}$
$\dot{Q}$	Heat Transfer Rate	Watts
R	Heater Element Resistance	Ohms
t	Temperature (Customary)	^0C
T	Temperature (Absolute)	K
U	Velocity	$m\ s^{-1}$
V	Heater Voltage	Volts

TEMPERATURE CHANNELS	**LOCATION**
T1	Element surface t_s
T3	Pin 10mm from heater
T4	Pin 30mm from heater
T5	Pin 50mm from heater
T6	Fin 10mm from heater
T7	Fin 30mm from heater
T8	Fin 46mm from heater
T9	Air Temperature t_a

Suffixes

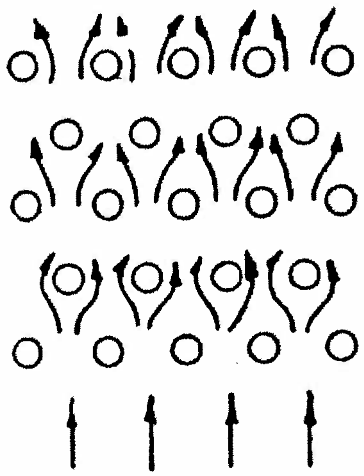
a	Refers to the air or bulk fluid
s	Refers to surface conditions

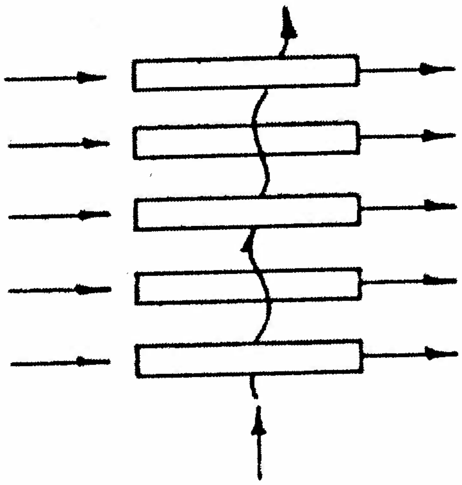
INTRODUCTION

If a flat surface is heated to a temperature above that of its surroundings heat will be transferred from it by means of convection and radiation. The amount of heat apportioned to each method of heat loss will depend upon the temperature of the surface and its emissivity.

Assuming the surface is not at elevated temperatures the majority of heat will be lost due to convection caused by a local increase in buoyancy adjacent to the surface causing an upward flow. For a simple flat plate the amount of heat lost will be small due to the low heat transfer coefficient.

In order to increase the rate of heat transfer one method is to extend the surface by the addition of conducting fins or pins.





Various tube and fin layouts have been devised in order to improve the efficiency heat exchangers and thereby reduce the physical size for a given heat transfer rate. However, the objective of all of the arrangements is to promote turbulence in the fluid flowing across the extended surfaces.

This turbulence may be increased by raising the stream velocity by means of a fan or pump. Alternatively, the tube layout may be changed in order to maximise turbulence. This is achieved by ensuring that each row of tubes is positioned such that turbulence induced by the preceding row is incident upon the next row. Hence a cascade effect is produced such that the degree of turbulence increases with the depth of the tube bundle.

Alternatively the surface may be increased by the use of fins rather than pins. These can result in lower aerodynamic drag and enhanced heat transfer rates. An area where this may be important for example is in an aero engine.

The optional Free and Forced Convection from Flat, Finned and Pinned Plates H112P allows students to compare flat, pinned and finned plates in a graphic form. For vocational and undergraduate students the demonstrations can be undertaken without prior knowledge of the theory in order to aid understanding.

SCHEMATIC DIAGRAM NOTATION

Please refer to the schematic diagrams on page 1
To assist in identifying all of the components each relevant component has a number identifier. In order to simplify component identification in the text the relevant number is placed alongside the component name which is also in **bold text**. For example on page 1 the main switch would be identified in text as **main switch (1)**
In addition where computer screen displays are being referenced relevant labels will be shown in **Bold Text.**
This convention is used throughout the manual.

DESCRIPTION

The H112P Free and Forced convection from Flat Finned and Pinned Plates enables students to investigate heat transfer from various surfaces in free and forced convection. The range of heated plates demonstrates the effect of extended surfaces (fins and pins) on the rate of heat transfer. The H112P is designed to be used with, and to be installed alongside, the Heat Transfer Service Unit H112.

The accessory comprises a rectangular **duct (6)** mounted on the discharge of a base mounted centrifugal fan. In the middle of the duct is an **air velocity sensor (5)** that allows the air velocity within the duct to be measured and displayed (metres/second) on the **air velocity display (4)** below the base. At the centre of the duct is an aperture that allows any of the three **heated plates (8)** supplied to be installed.

A flat plate, pinned plate, or finned plate heat exchanger may be installed in the duct and secured by two toggle clamps. Each exchanger incorporates an electric heater mat rated at 100W at 240V. Each of the heated plates incorporates thermostatic protection against overheating.

The heater surface temperature (T1) is continuously monitored and displayed by the temperature indicator when plugged in to the console.

The Pinned plate is fitted with three extra thermocouples (T3, 4 and 5) to measure the temperature of extended surfaces. T5 is furthest from the heater.
The Finned plate is fitted with three extra thermocouples (T6, 7 and 8) to measure the temperature of extended surfaces. T8 is furthest from the heater.
The T9 **air temperature (7)** sensor is located at the base of the duct and records the temperature of the air flowing over the heated plate.

Thermocouple attachment points on the heat exchangers are protected by a covering of adhesive.

The air velocity passing the heated plates can be varied from zero to more than 8m/s depending upon the local mains voltage and supply frequency. The **air velocity sensor(5)** is permanently mounted in the duct and connects to the console below using a line plug and socket.

The air velocity is controlled by the use of an intake **air throttle (9)**. For natural convection experiments, the fan may be switched off using the **fan switch (3)** on the H112P console.

All thermocouples are 'Duplex'. The primary set of thermocouples terminates with a miniature plug (identifiedT1, and T3 to T8) for insertion into the control console sockets.

The secondary set of thermocouples terminates with 2-way edge-connectors suitable for the Hilton Data Logger. These are utilised when the optional HC112A Data Acquisition Upgrade is installed. The panel mounted socket labelled 'T1 out' provides a link to the Data Logger, where applicable.

NOTE TO TEACHERS

Experiments using forced convection (fan operating and high air velocity) are relatively fast to reach stable conditions. Free or natural convection experiments are slow to reach equilibrium. A fixed heat input will produce a rapid temperature rise initially, but the rate of rise will reduce very slowly before the rate of heat loss becomes constant. Such experiments can consume a complete lesson period and students must be patient.

Comparative results may be obtained more rapidly by observing the transient response of different heat exchangers when subjected to the same conditions of heat input and airflow. Use a stopwatch to record and then plot temperature rise or fall against time. A number of plotted points will demonstrate the trend to students, without having to wait for steady-state conditions.

Experiments may take the form of 'Stepped Voltage' at constant air velocity or 'Stepped Velocity' at constant voltage (power input) and recording the stabilised temperatures at each setting. More difficult, are experiments aimed at a 'Target Temperature' achieved by variation in power input or air velocity.
These methods are detailed where applicable in the following text.

INSTALLATION AND COMMISSIONING

FREE AND FORCED CONVECTION FROM FLAT FINNED AND PINNED PLATES WITH HEAT TRANSFER SERVICE MODULE H112

The duct was removed for packing so first-time installation requires the duct to be fitted to the fan outlet and connection of the velocity sensor cable.
Refer to the schematic diagram on page 1. Insert the duct in the round grey aperture and tighten the two black thumb screws.

Take GREAT care when moving the unit to support BOTH the DUCT and the FAN UNIT.

Place the Free and Forced Convection from Flat, Finned and Pinned Plates H112P on a flat surface to the left of the Heat transfer Service Unit H112.

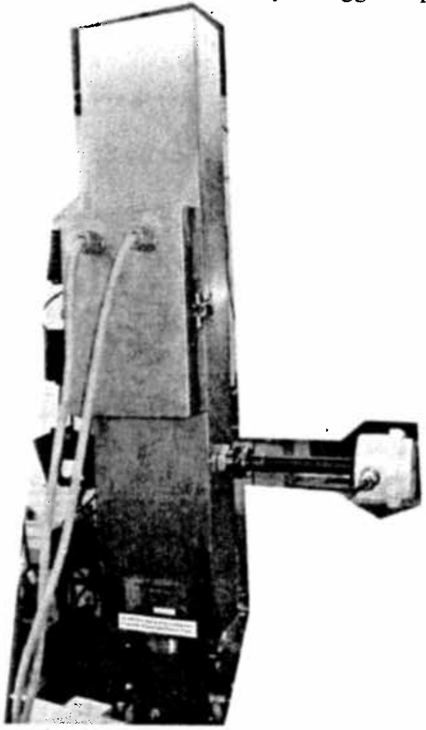
It is assumed that the basic INSTALLATION AND COMMISSIONING procedures for the Heat Transfer Service Unit H112 have been completed as detailed in the base unit manual on pages 4 to 7.

Ensure that the H112 main switch is in the OFF position.

Temperature Sensors
Insert the T9 probe into the coupling at the fan outlet and tighten finger-tight. Connect the miniature thermocouple plug from temperature sensor T_9 in the duct to the socket marked T9 on the front of the Heat Transfer Service Unit H112.

Similarly connect the thermocouple plug from the cylinder surface T_{10} to the socket marked T10 on the front of the Heat Transfer Service Unit H112.

Heated Plates
Each of the heated plates fit into the duct and is secured by t2 toggle clips.



Set the heater **Voltage Control** on the front of the H112 Heat Transfer Service Unit to zero (turn anti-clockwise).

Connect the 8-pole plug from the heated cylinder to the power socket on the front panel of the Heat Transfer Service Unit H112.

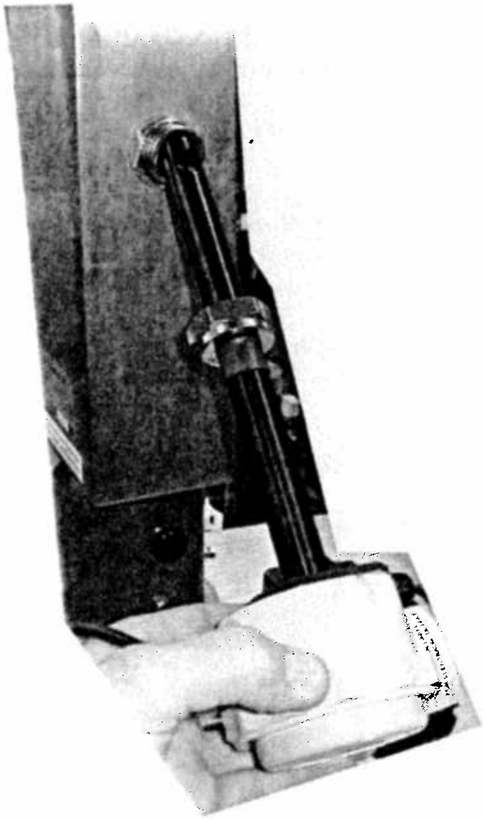
Fan Motor and H112P instrument console

The centrifugal fan is supplied with power from the socket at the rear of the Heat Transfer Service Unit H112. In countries where the local supply is 110/120V, a step up transformer will have been supplied for use with the Heat Transfer Service Unit H112 and hence in all cases the supply to the fan will be nominally 230V, 50 or 60Hz.

Connect the power lead between the outlet socket on the rear of the H112 Heat Transfer Service Unit and the inlet socket on the rear of the H112P console.

Anemometer

The anemometer is inserted in the duct with the hot wire sensor aligned with the air stream as shown. The securing nut only requires hand (finger) tightening as the O ring seal will ensure adequate sealing.



The lead from the sensor connects to the plug emerging from the rear of the small instrument console below the fan unit.

The digital indicator is fitted with buttons on the fascia. These were used during manufacture for calibration of the Hot-Wire probe and should not be disturbed.

The right hand ✱ button has been assigned to perform an 'Auto-Zero' to correct any electronic drift over time.

With the instrument powered and the Fan Switch OFF, press the ✱ button, the word 'Zero' will flash.

Press the ✱ button again, the display will count down to read zero.

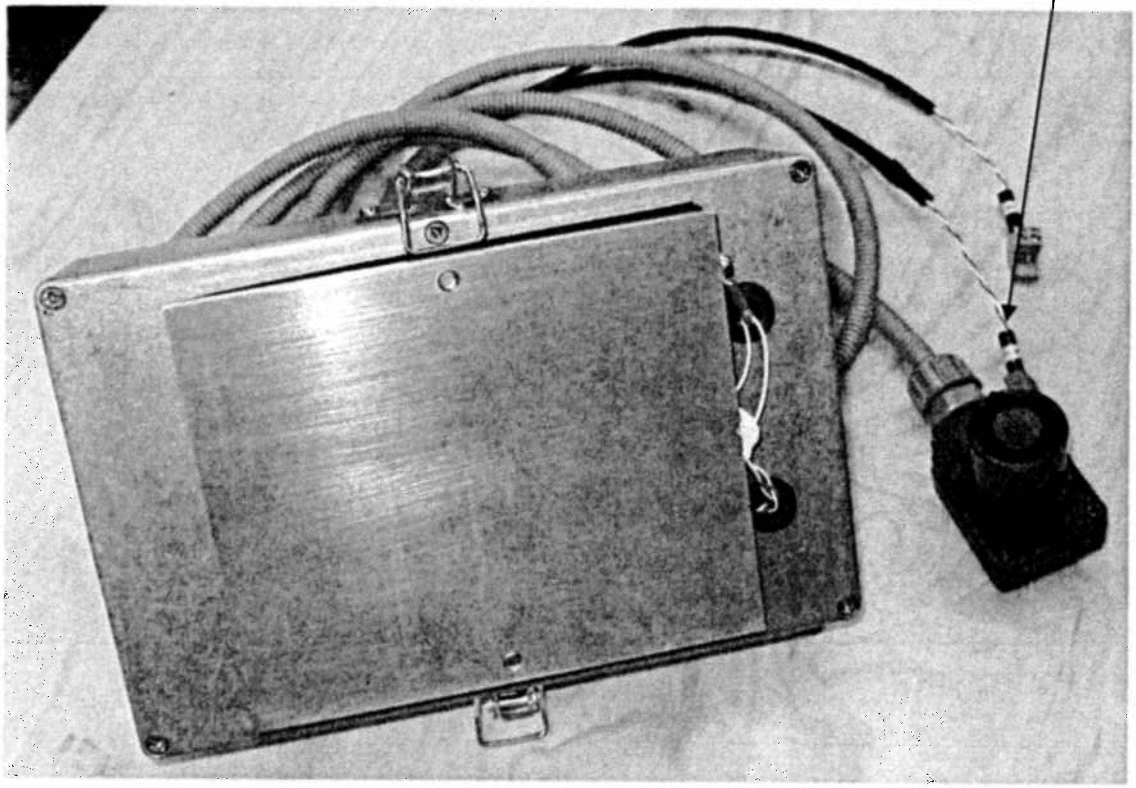
If the ✱ button is ever pressed at velocities other than zero, the calibration will be in error.

This is easily rectified by re-zeroing when the fan is stopped.

COMPONENT IDENTIFICATON

1) Flat Plate Heat Exchanger

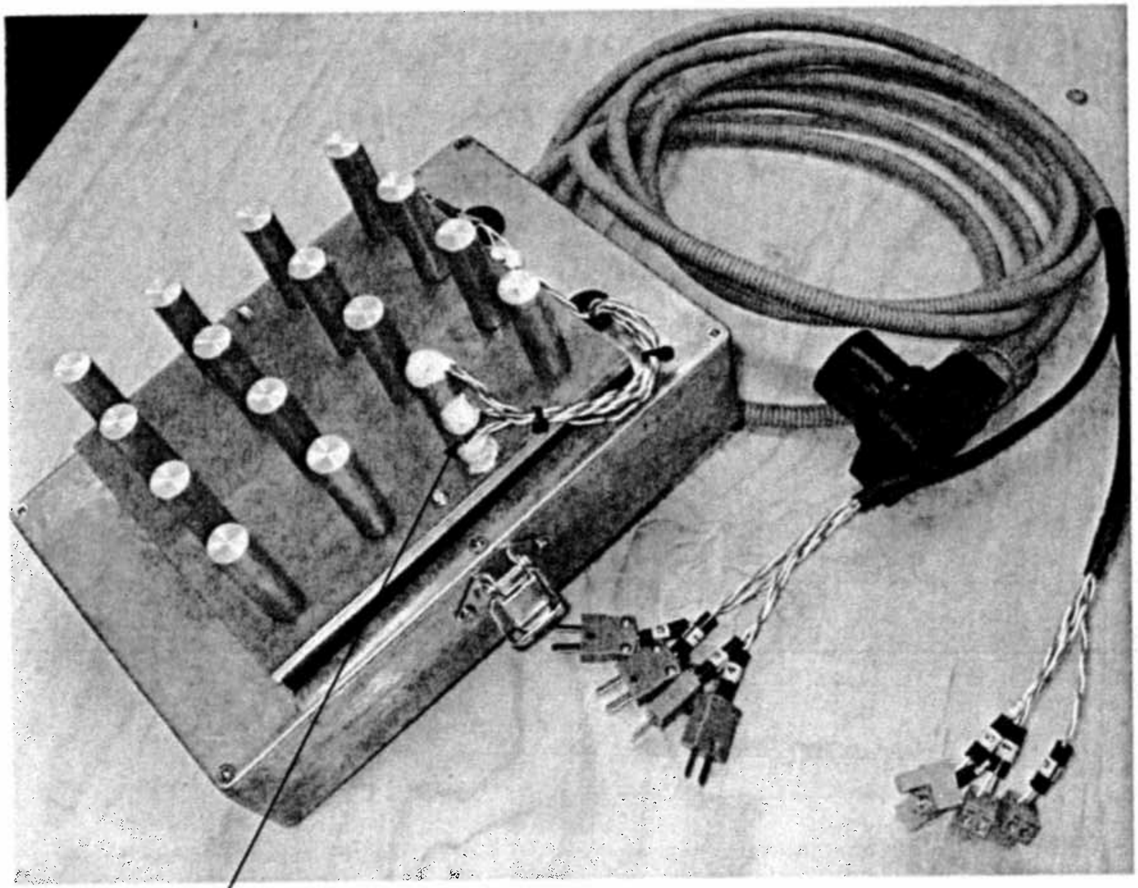
This is the Flat Plate heat exchanger. Note that the surface thermocouple T1 recording the plate temperature is connected to the control console through the plug shown at the bottom of the picture.



There are no extra surface thermocouples on the flat plate that require connection unless the unit is being used with the optional Data Acquisition Upgrade HC351A and this is dealt with in a separate manual.

The flat plate is located in the open section of the tunnel and secured with the two toggle clamps.
Ensure that the heater is located in the tunnel with the power connection at the top as shown on page 1

2) Pinned Plate Heat Exchanger
This is the Pinned Plate heat exchanger. Note that the surface thermocouple T1 recording the plate temperature is connected to the control console through one of the four connecting plug shown at the bottom of the picture.

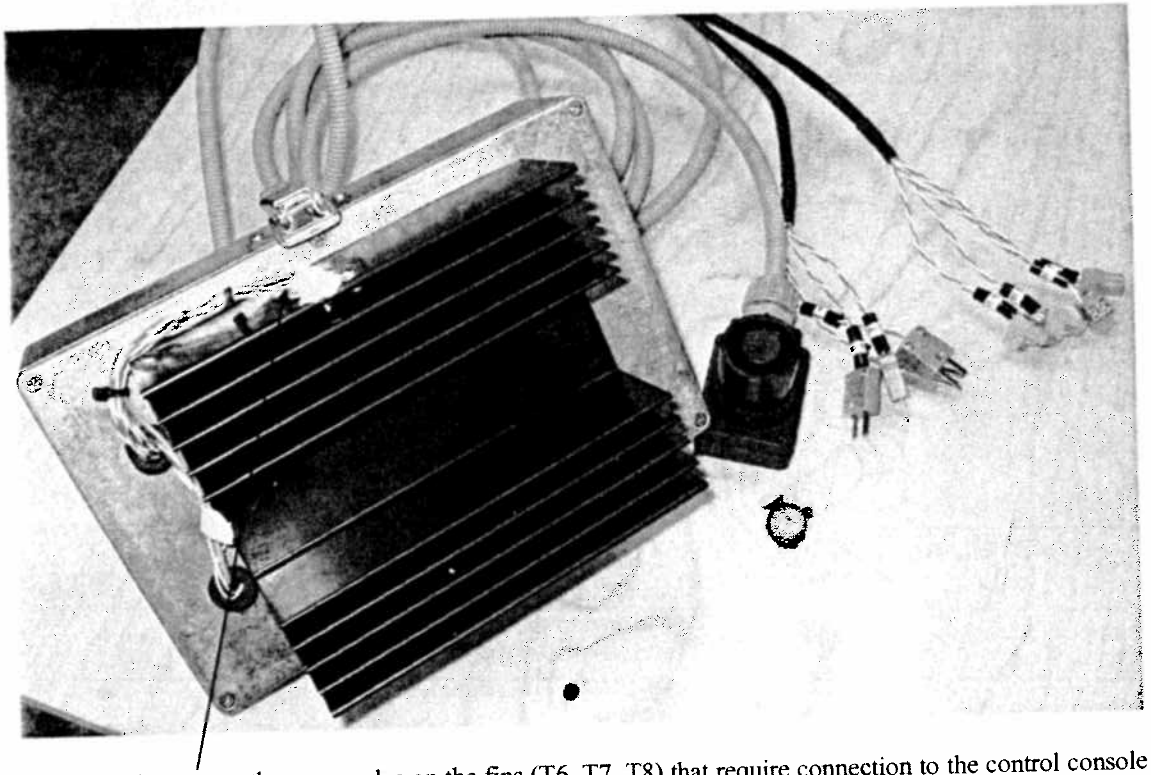


There are three extra thermocouples on the pins (T3, T4, T5) that require connection to the control console extra sockets. These are fitted with thermocouple plugs (shown above) that match the sockets on the console.

Unless the unit is being used with the optional Data Acquisition Upgrade HC112A the duplex set of thermocouples are not used. This is dealt with in a separate manual.
The pinned plate is located in the open section of the tunnel and secured with the two toggle clamps.
Ensure that the heater is located in the tunnel with the power connection at the top as shown on page 1

3) Finned Plate Heat Exchanger

This is the Finned Plate heat exchanger. Note that the surface thermocouple T1 recording the plate temperature is connected to the control console through one of the four connecting plug shown at the right of the picture.



There are three extra thermocouples on the fins (T6, T7, T8) that require connection to the control console extra sockets. These are fitted with thermocouple plugs that match the sockets on the console. Note that duplex thermocouples are no longer supplied as thermocouples connect through the digital temperature indicator to the Hilton Data logger

The pinned plate is located in the open section of the tunnel and secured with the two toggle clamps. Ensure that the heater is located in the tunnel with the power connection at the top as shown on page 1

SPECIFICATION H112P

Duct and Blower	Rectangular duct with aperture to accept any one of 3 plate heat exchangers. Forced air supply is from a centrifugal blower with damper control on the inlet to control air velocity. Air velocity is measured by a hot wire sensor mounted in the duct and a digital display located under the fan.
Flat plate Heat Exchanger	Carrier plate fits into the duct aperture and incorporates a 100W heater mat and flat aluminium plate with surface thermocouple. A power plug and thermocouple plug connects to the Heat transfer Service Unit H112
Pinned Plate Heat Exchanger	Carrier plate fits into the duct aperture and incorporates a 100W heater mat and flat aluminium plate with 16 pins of 12.7mm diameter. Thermocouples are attached to the heater surface and at three points on the extended surface of the pins. A power plug and thermocouple plugs connect to the Heat transfer Service Unit H112
Finned Plate Heat Exchanger	Carrier plate fits into the duct aperture and incorporates a 100W heater mat and finned aluminium plate. Thermocouples are attached to the heater surface and at three points on the extended surface of the fins. Plugs connect to the 70V power source and temperature measurement console.

USEFUL DATA

All heat exchangers have a plain heated area (not considering the fins or pins) of 125mm x 150mm the same as the flat plate heat exchanger. This allows students to make direct comparisons between the performance of the flat plate and the two extended surfaces.

Pinned Plate Thermocouple Locations,

Thermocouple	T3	T4	T5
Effective distance (mm) from heater surface	10	30	50

Finned Plate Thermocouple Locations,

Thermocouple	T6	T7	T8
Effective distance (mm) from heater surface	10	30	46

Duct Cross Sectional Area $A_d = 0.01278\ m^2$

H112P EXPERIMENTAL CAPABILITIES

1. To Demonstrate the Relationship Between Power Input and Surface Temperature in Free Convection
2. To Demonstrate the Relationship Between Power Input and Surface Temperature in Forced Convection.
3. To Demonstrate the use of Extended Surfaces to Improve Heat Transfer From the Surface.
4. To Determine the Temperature Distribution Along an Extended Surface.

All of the above experiments may be undertaken with the three plates supplied and for experiments 3 and 4 the procedures are equally applicable to forced convection or natural convection.

Note that due to variations in component availability and local mains voltage and frequency(this will affect fan speed), the blockage effect of the pinned and finned plates may vary from the results contained in this manual. Hence the maximum free stream air velocity indicated by the air velocity display(4) may vary from the results shown in this manual.

OPERATION WITH OPTIONAL DATA ACQUISITION UPGRADE

Note that the H112P may be operated with the HC112A Data Acquisition Upgrade. With the addition of this option all data relating to the following experimental procedures may be recorded automatically and transferred to spreadsheet format for subsequent detailed analysis and calculation.

The operation of the data acquisition upgrade is detailed in a separate manual but experimental procedures are identical to those described in the following text.

CAUTIONS

Active Element High Temperature Protection

Each of the heated plates (Flat, Finned and Pinned) incorporate a thermal protection thermostat. This is designed to turn off the power to the heater if the element temperature exceeds approximately 90-100°C. This will show on the H112 console as a ZERO current demand. The mains voltage display may not show zero as the voltage is measured at the console and the thermal switch is in the heater box.

If the thermal cut out operates allow the element to cool and the thermostat will reset automatically.

Hot Surfaces

Even with the high temperature protection the heated plates can reach 100°C and this is sufficient to cause burns. NEVER touch the metal surface of the plates with bare hands when the element is plugged into the control console. Handle the plates using the plastic backing plate only. Do not place the plates on any surface that can be damaged by heat.

General Notes

Applicable to all experimental work.
Before using the Cross Flow Heat Exchanger the user should:

(i) Study the unit and schematic diagram to identify all switches and controls relating to both the H112 Heat Transfer Service Unit H112 and the Free and Forced Convection from Flat, Finned and Pinned Plates H112P Accessory.
(ii) Understand the action of the various controls. Refer to the main H112 Heat Transfer Service Unit manual.
(iii) Be aware of the Cautions regarding handling of hot surfaces.
(iv) Be aware of how to obtain stable running conditions..

1To Demonstrate the Relationship Between Power Input and Surface Temperature in Free Convection

Optional Methods

As the rate of heat transfer in natural convection is typically very small, the time taken to reach stability can be very long and may exceed a laboratory period. For this reason two methods of demonstrating natural convection using the three plates are described below.

a) Steady State Method

If time permits, or for a student project the steady state experimental procedure may be adopted. This allows the heat transfer rate from the three heat exchangers to be compared at similar hot plate temperatures. Due to the requirement for small adjustments and the time taken to assess stability the experimental period can be long.

b) Transient Method

However for a rapid demonstration the transient method may be adopted where a fixed heat input is applied in turn to each of the three heat exchangers and the temperature rise plotted against time until the 100°C cut out point is reached.

With this method the slope of the temperature rise is an indication of the rate of heat transfer from the plate.

Procedure a) Steady State Method

The same procedure is utilised for the three types of plate, Flat, Pinned and Finned.

(i) Ensure the instrument console main switch is sin the off position. Ensure the fan is switched off. For the natural convection experiments the fan will not be used.

(ii) If the flat (pinned or finned) plate is not in position, open the toggle clamps. Replace with the flat(pinned or finned) plate and close the toggle clamps. Note that with the plate heat exchangers the power leads exit from the top of the plates. Refer to the diagram on page 1

(iii) No air velocity will be measurable under natural convection conditions unless specialised instrumentation is available.

(iv) Switch on the main switch and set the heater voltage to minimum.

The objective with the steady state method is to obtain the same T1 surface temperature on each of the heat exchangers and determine the steady state power input required to achieve this. From factory tests under "typical" conditions the following heat inputs were required to maintain T1 (approximately) 100°C

	Flat Plate	Pinned Plate	Finned Plate
$\dot{Q}$ (Watts) for 100°C	22	50	90
Voltage V for $\dot{Q}$ input	$\sqrt{22 \times R}$	$\sqrt{53 \times R}$	$\sqrt{90 \times R}$

Where **R** is the electrical resistance (Ohms)of the heater element . The nominal resistance of the standard heater is 529 Ohms. The actual figure can be checked by calculating the resulting measured V (volts) and I (current) to the heater and calculating

$$\dot{Q} = V \times I$$

Note that the above figures are approximate and may require adjustment for individual machines. The best technique is to set the voltage input to maximum and monitor T1 on the digital temperature indicator. When T1 approaches 100°C, reduce the voltage to the appropriate level for the plate heat exchanger in use.

(v) When the temperature T1 has stabilised(this may take 10's of minutes) record the actual temperature T1, the actual voltage V and the ambient air temperature T9. If either the Finned or Pinned plates are in position the pin temperatures (T3,T4,T5) or fin temperatures (T6, T7, T8) may be recorded.

(vi) Before removing the heat exchanger from the duct turn on the fan and cool the heat exchanger . **Note that this cooling procedure may be used to quickly demonstrate to students the increased heat transfer coefficient due to forced convection if the voltage setting is left at the**

natural convection condition and the fan turned on to give maximum flow. T1 will be seen to rapidly fall from the natural convection condition.

(vii) Finally reduce the heater voltage to zero and allow to cool before removing the plate from the tunnel and replacing with one of the alternative plates.

Test results from the steady state method are shown on page 16.

Procedure b) Transient Method

The same procedure is utilised for the three types of plate, Flat, Pinned and Finned.

(i) Ensure the instrument console main switch is in the off position. Ensure the fan is switched off. For the natural convection experiments the fan will not be used.

(ii) If the flat (pinned or finned) plate is not in position, open the toggle clamps retaining the plate in the tunnel and removes the existing plate from the tunnel. Replace with the flat (pinned or finned) plate and close the toggle clamps. Note that with the plate heat exchangers the power leads exit from the top of the plates. Refer to the diagram on page 1

(iii) No air velocity will be measurable under natural convection conditions unless specialised instrumentation is available.

(iv) Switch on the main switch and set the heater voltage to minimum. The objective with the transient method is to apply the same heat input to all three heat exchangers an record the rise in T1 temperature with time. Factory tests have shown that under a 100W input is acceptable and allows sufficient time for data to be collected. The voltage V required for 100W input is

$$V = \sqrt{100 \times R}$$

Where **R** is the electrical resistance (Ohms)of the heater element . The nominal resistance of the standard heater is 529 Ohms.

The actual figure can be checked by calculating the resulting measured V (volts) and I (current) to the heater and calculating

$$\dot{Q} = V \times I$$

(v) Record the starting surface temperature T1,air stream temperature T2 and, if the pinned or finned heat exchangers are in use record the pin(T3,T4,T5) or fin(T6,T7,T8) temperatures. Select a suitable time interval for recording data that is achievable (say 10-15 second intervals). Note that it may be beneficial for more than one student to be involved in data collection and recording.

If the optional HC112A Data Acquisition system is available then all parameters may be recorded simultaneously at 10 second intervals or less with ease.

(vi) Set the heater voltage to the required value and begin recording (all) the temperatures at the set interval. Once the surface temperature reaches the 100°C value the high temperature cut out will operate and the experiment can be concluded. Before removing the heat exchanger from the duct turn on the fan and cool the heat exchanger. Note that this cooling procedure may be used to quickly demonstrate to students the increased heat transfer coefficient due to forced convection if the voltage setting is left at the natural convection condition and the fan turned on to give maximum flow. T1 will be seen to rapidly fall from the natural convection condition.

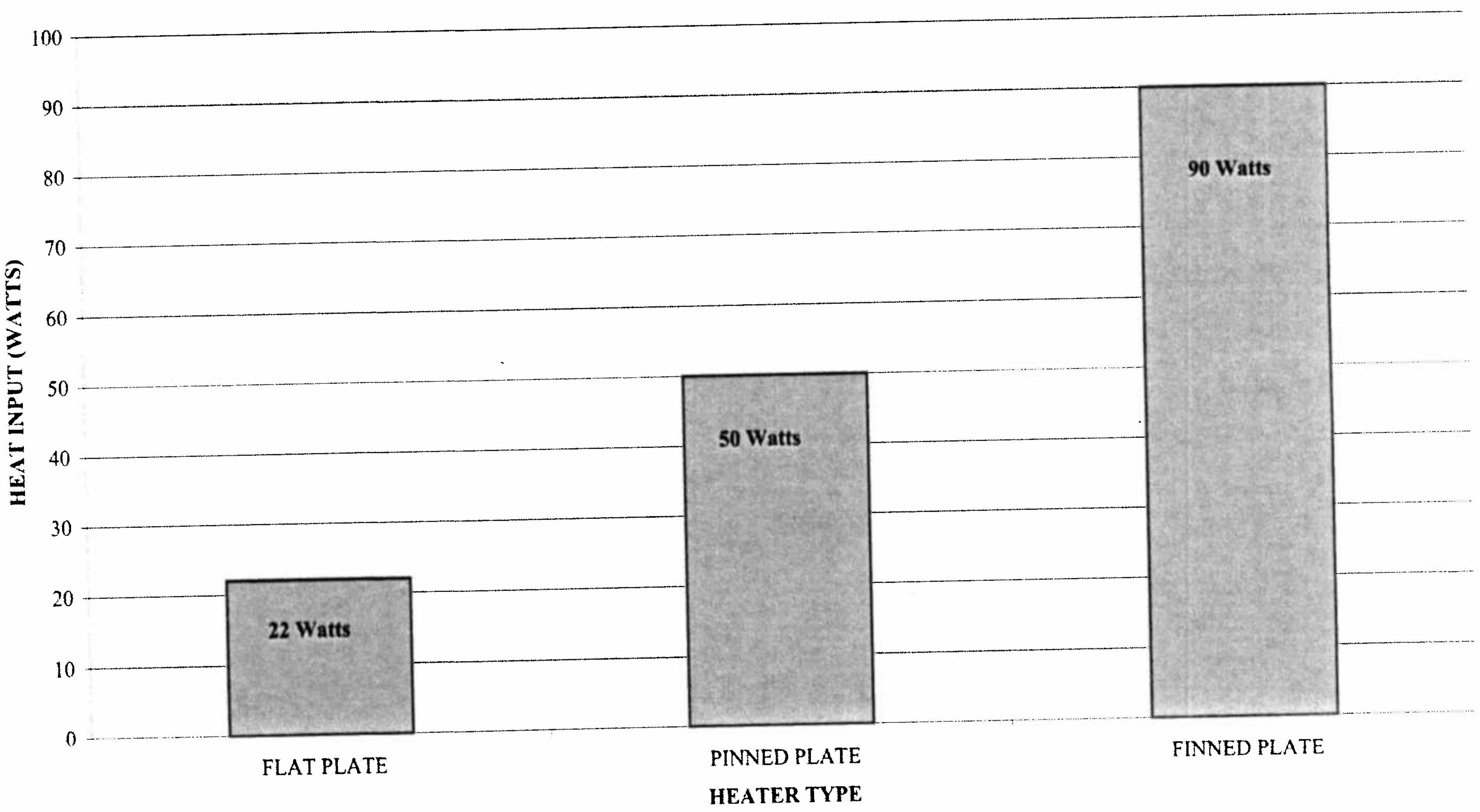
Typical data for the three plates is shown on page17

The steady state tests give direct results and it may be seen that the flat plate has the lowest rate of heat transfer.

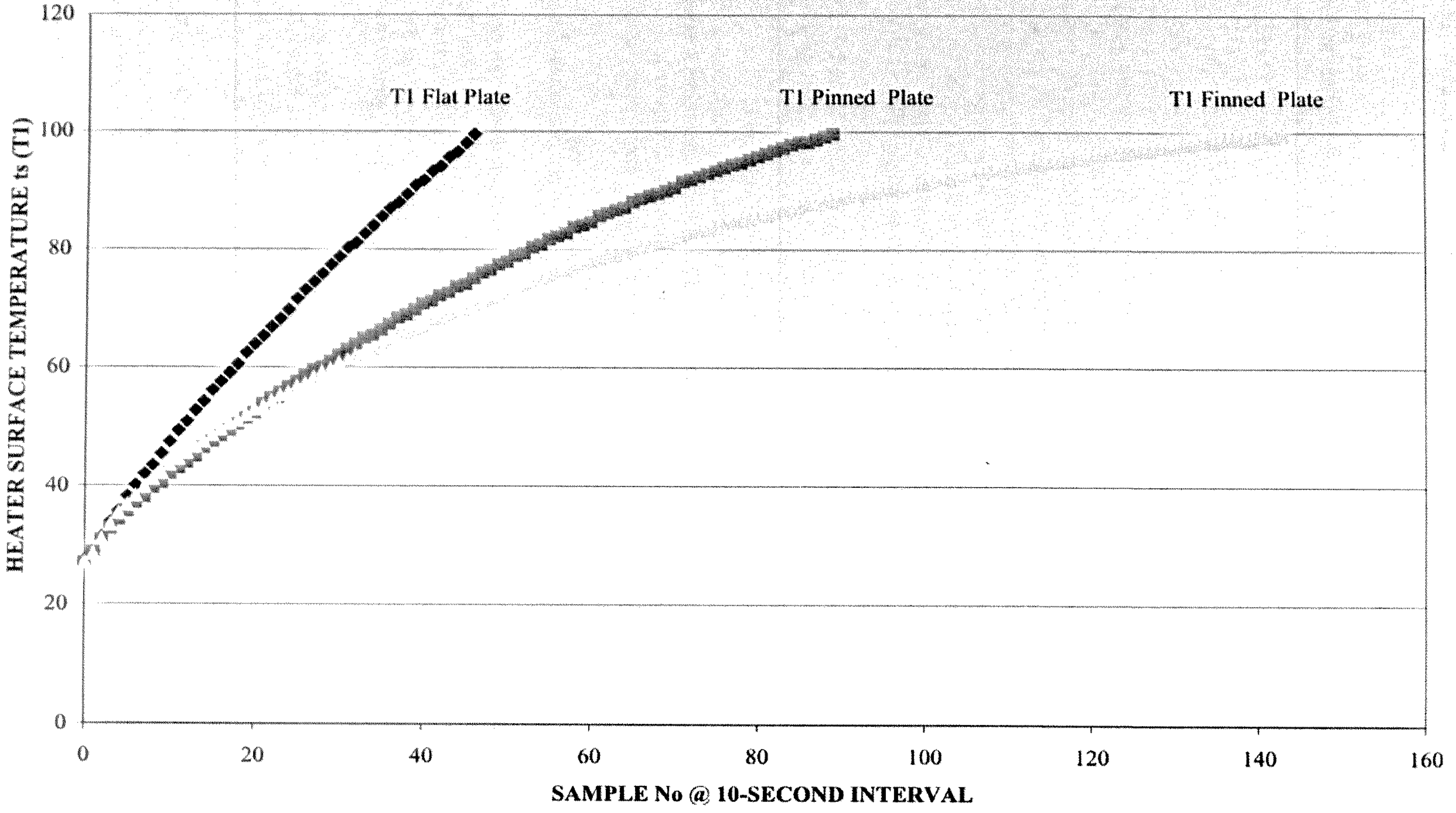
The transient data shows that for the same heat input the flat plate shows the highest rate of temperature rise. This indicates that the rate of heat "loss" by the flat plate is lowest which confirms the steady state tests.

Note that individual test results will vary from unit to unit and with local operating conditions.

H111PP - HEATING IN FREE CONVECTIVE COOLING - MAX WATTS INPUT FOR ts(T1) 100C
(ta(T2) = 23C DURING THIS TEST)



H351D PLATE HEAT EXCHANGERS
NATURAL CONVECTION HEATING CURVE AT 100W HEAT INPUT



2 To Demonstrate the Relationship Between Power Input and Surface Temperature in Forced Convection

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Procedure

The rate of heat transfer in forced convection is higher than for natural convection. Hence it is possible to undertake steady state experimental procedures within a reasonable time period as the plates will stabilise relatively quickly..

The same procedure is utilised for the three types of plate, Flat, Pinned and Finned.

(i) Ensure the instrument console main switch is sin the off position. Ensure the fan is switched off.

(ii) If the flat (pinned or finned) plate is not in position, open the toggle clamps. Replace with the flat(pinned or finned) plate and close the toggle clamps. Note that with the plate heat exchangers the power leads exit from the top of the plates. Refer to the diagram on page 1

(iii) Note that the flat plate will have the minimum blockage effect upon the air stream and the pinned plate will have the maximum. Hence it will not be possible to achieve the same maximum air velocity reading (fan at full speed) with the pinned plate in position as with the flat plate in position. If direct comparison between finned, pinned and flat plate performance is required then it would be beneficial to test the pinned plate first in order to establish the maximum possible velocity reading U. Then the remaining plates can be tested under similar or lower air flow conditions.

(iv) Switch on the **main switch (1)** and set air velocity to a low value by closing the **air throttle (9).** Increase the heater power to a suitable level such that ts (T1) does not exceed 100°C.Allow the temperatures to stabilise and then record the surface temperature ts (T1), the heater supply voltage V , heater current I and the air velocity U.

(v) Maintain the heater voltage at the same condition and then increase the air velocity by opening the **air throttle (9).** Once again allow the temperatures to stabilise and repeat the readings. Repeat the procedure at increasing air velocity if required.

(vi) For direct comparison repeat the procedure for the three plates under similar heat input conditions and at similar velocities.

Typical data for the finned plate is shown on page 19

SAMPLE DATA
Heater Used :- Pinned Plate
Atmospheric Pressure =1 .013 x 10^5 kNm^{-2}

Sample No.	1	2	3	4	5	6
Time 1/s						
Heater Volts V	242	242				
Heater Current I (Amps)	0.362	0.364				
Heater Power $V \times R$ Watts	87.84	88.08				
Ambient ta (T9)/°C	21.0	21.0				
Flat Plate ts (T1)/ °C						
Pinned Plate ts (T1/°C)	52.1	43.4				
Pinned Plate T3/°C	52.0	43.4				
Pinned Plate T4/°C	47.7	39.5				
Pinned Plate T5/°C	47.5	39.3				
Finned Plate ts T1/°C						
Finned Plate T6/°C						
Finned Plate T7/°C						
Finned Plate T8/°C						
Surface-Air Temperature Difference (ts – ta) / K						
Duct Air Velocity U m/s	6.8	10.1				

CALCULATIONS

For the Finned plate(Sample No.1) the following data was collected.

ts (T1) = 52.1°C
ta (T9) =21.0°C
V = 242V

The heat input

$$\dot{Q} = V \times I$$
$$= 242 \times 0.363$$
$$= 87.84 \text{ Watts}$$

Under these conditions the surface temperature ts(T1) was. 55.9°C

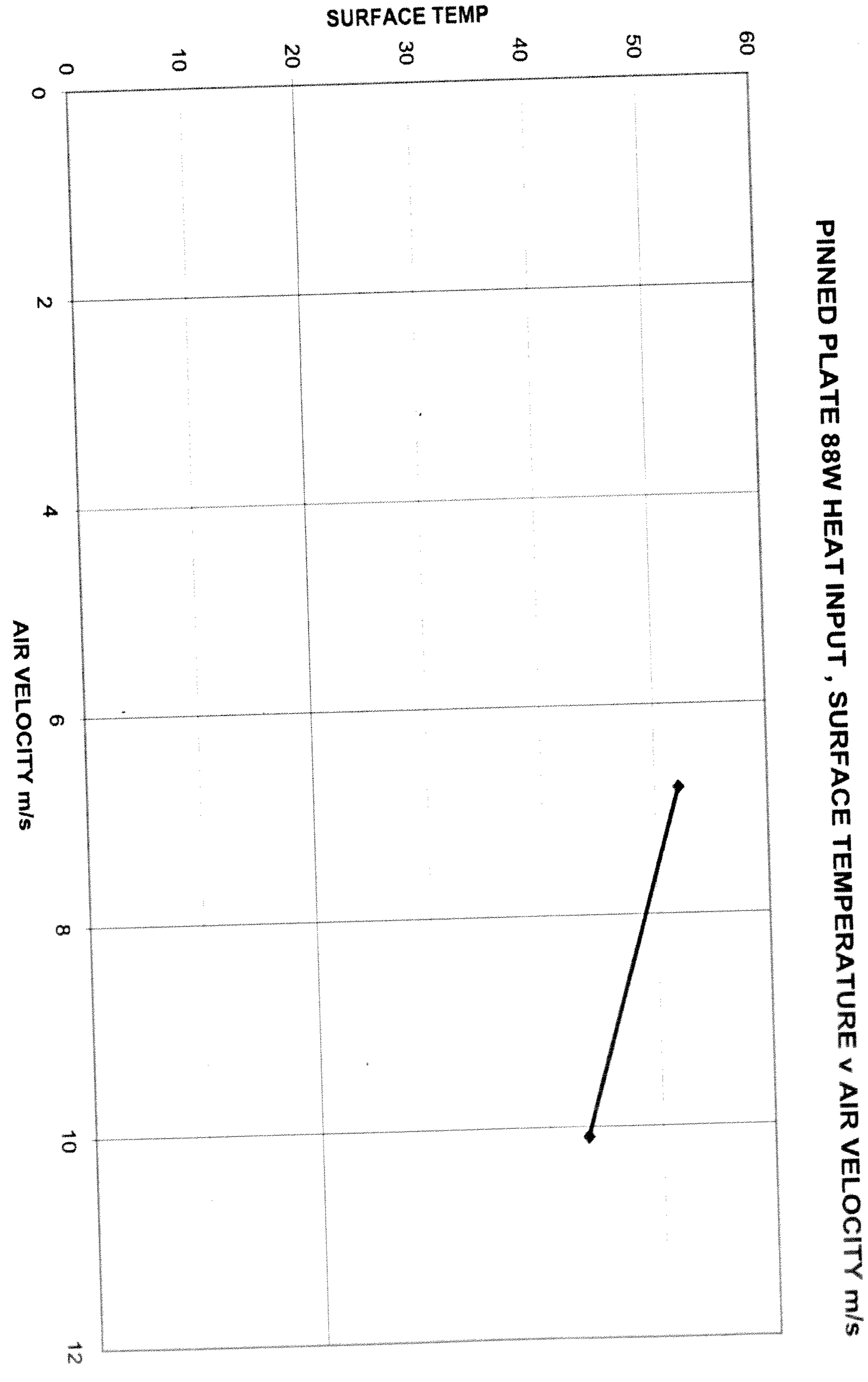
Similar calculations were undertaken for increasing velocity and the data is shown plotted on page 19
The data plotted on the following page shows the effect of increasing air velocity on the surface temperature. As the heat input remains constant at approximately 100 Watts the surface temperature falls with increasing air velocity.

The procedures may be repeated for the flat plate and pinned plate and it will be found that the extended surface plates will exhibit lower surface temperatures than the flat plate under similar conditions. As all of the plates have the same face area excluding the fins or pins (see useful data page 12) and the heat input was kept constant he lower surface temperature ts indicates an improved heat transfer.

The effect of the fins or pins is to increase the surface area from which heat can be transmitted and to increase turbulence that enhances heat transfer. This in turn reduces the surface temperature ts that is recorded on each of the plates

Extended surfaces are utilised in many heat transfer situations where enhanced heat transfer is required. For example cooling electronics, air cooled engines and electric motor casings.

However one effect of the fins or pins is to increase the "drag" or wind resistance of the surface being cooled.



PINNED PLATE 88W HEAT INPUT , SURFACE TEMPERATURE v AIR VELOCITY m/s

3To Demonstrate The use of Extended Surfaces To Improve Heat Transfer From the Surface.

Procedure

The following procedure may be undertaken either in natural convection conditions (fan not operating) or in forced convection conditions. In both cases the use of extended surfaces does increase the rate of heat transfer. However as demonstrated in experiment No 1 the time taken to achieve stable temperatures when investigating natural convection can be considerable.
Therefore a forced convection experiment is described as follows.

The same procedure is utilised for the three types of plate, Flat, Pinned and Finned.

(i) Ensure the instrument console main switch is sin the off position. Ensure the fan is switched off. For the natural convection experiments the fan will not be used.

(ii) If the flat (pinned or finned) plate is not in position, open the toggle clamps retaining the plate in the tunnel and remove the existing plate from the tunnel. Replace with the flat (pinned or finned) plate and close the toggle clamps. Note that with the plate heat exchangers the power leads exit from the top of the plates. Refer to the diagram on page1.

(iii) Note that the flat plate will have the minimum blockage effect upon the air stream and the pinned plate will have the maximum. Hence it will not be possible to achieve the same maximum velocity reading (with the **air throttle** (9) fully open) with the pinned plate in position as with the flat plate in position. If direct comparison between finned, pinned and flat plate performance is required then it would be beneficial to test the pinned plate first in order to establish the maximum possible velocity reading U. Then the remaining plates can be tested under similar or lower air flow conditions.

(iv) Switch on the **main switch (1)** and set the air speed to a low value by closing the **air throttle** (9). Increase the heater power to a suitable level such that ts (T1) does not exceed 100°C.Allow the temperatures to stabilise and then record the surface temperature ts (T1), air stream temperature ta (T9), the heater supply voltage V and the air velocity reading U m/s.

(v) Maintain the heater voltage at the same condition and then increase the air velocity by opening the **air throttle (9)** Once again allow the temperatures to stabilise and repeat the readings. Repeat the procedure at increasing air velocity if required.

(vi) For direct comparison repeat the procedure for the three plates under similar heat input conditions and at similar velocities.

Typical data for the finned plate is shown on the following pages.

SAMPLE DATA
Heater Used :- Finned Plate
Atmospheric Pressure =1 .013 x 10^5 kNm^{-2}

Sample No.	1	2	3	4	5	6
Time 1/s						
Heater Volts V	242	242				
Heater Current I (Amps)	0.370	0.371				
Heater Power $V \times R$ **Watts**	89.54	89.78				
Ambient ta (T9)/°C	20.0	20.0				
Flat Plate ts (T1)/ °C						
Pinned Plate ts (T1/°C)						
Pinned Plate T3/°C						
Pinned Plate T4/°C						
Pinned Plate T5/°C						
Finned Plate ts T1/°C	42.1	35.5				
Finned Plate T6/°C						
Finned Plate T7/°C						
Finned Plate T8/°C						
Surface-Air Temperature Difference (ts – ta) / K	22.1	15.5				
Duct Air Velocity U m/s	6.7	10.3				

CALCULATIONS

For the Finned plate(Sample No.2) the following data was collected.

Air Velocity = 10.3 m/s
ts (T1) = 35.5°C
ta (T9) =20.0°C
V = 242V
I =0.371 A

The heat input

$$\dot{Q} = V \times I$$
$$= 242 \times 0.371$$
$$= 89.78 \text{ Watts}$$

Under these conditions the surface temperature ts (T1) 35.5°C and the air stream temperature ta (T9)was 20.0°C. Hence the surface to air stream temperature difference ts - ta = 35.5 – 20.0 = 15.5K

Similar calculations were undertaken for different velocities and the data is shown plotted on page 23
The data plotted on page23 shows the effect of increasing air velocity on the surface temperature to air stream temperature difference. As the heat input remains constant at approximately 100 Watts the reducing surface to air stream temperature difference indicates an increasing heat transfer coefficient for the surface.

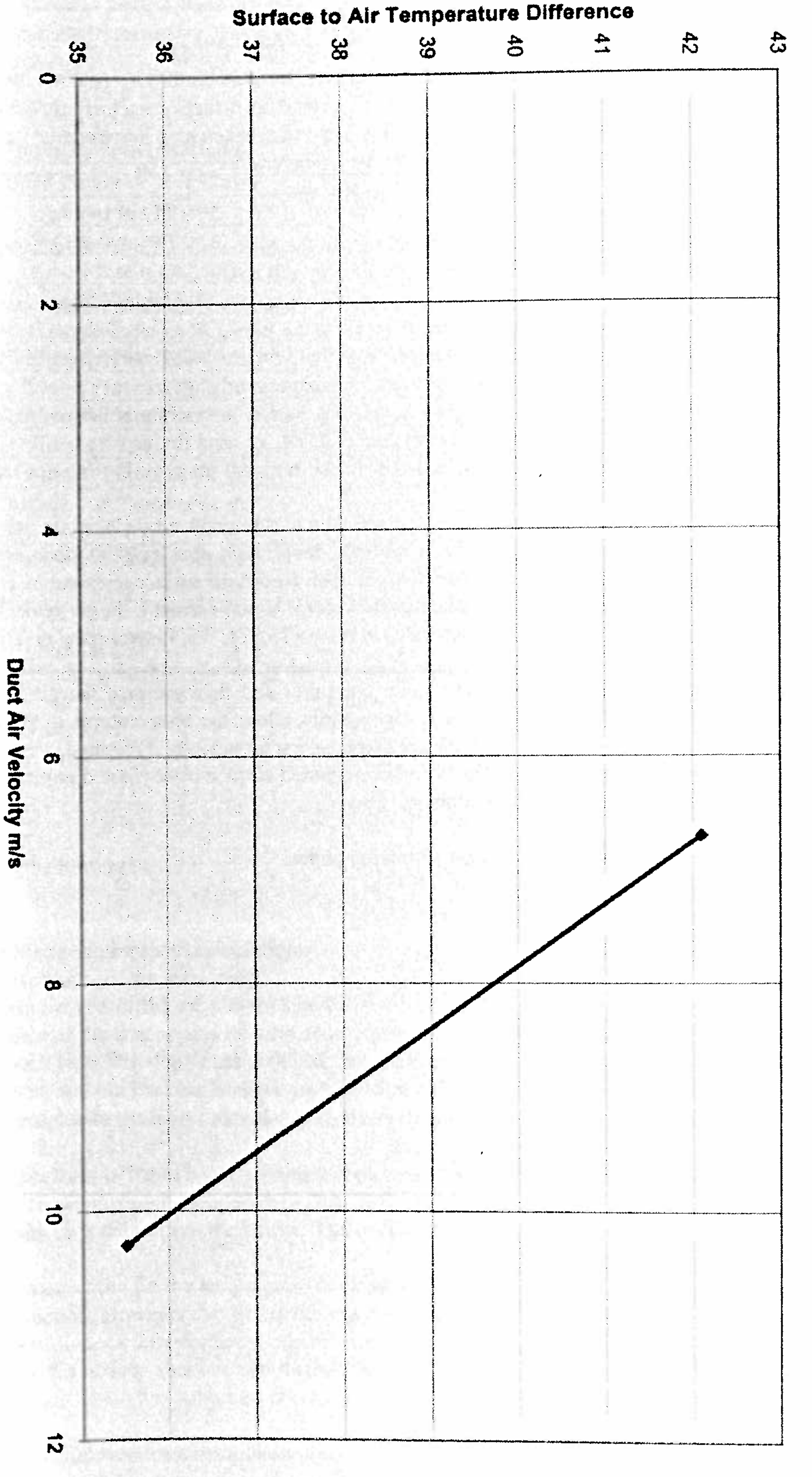
The procedures may be repeated for the flat plate and pinned plate and it will be found that the extended surface plates will exhibit lower temperature differences than the flat plate under similar conditions. As all of the plates have the same face area excluding the fins or pins (see useful data page 12) and the heat input was kept constant he lower surface temperature difference ts – ta indicates an improved heat transfer.

The effect of the fins or pins is to increase the surface area from which heat can be transmitted and to increase turbulence that enhances heat transfer.

Extended surfaces are utilised in many heat transfer situations where enhanced heat transfer is required. For example cooling electronics, air cooled engines and electric motor casings.

However one effect of the fins or pins is to increase the "drag" or wind resistance of the surface being cooled

FINNED PLATE, 89W HEAT INPUT. SURFACE to AIR TEMPERATURE DIFFERENCE (ts-ta) v AIR VELOCITY



4 To Determine the Temperature Difference Along An Extended Surface.

Procedure

The following procedure may be undertaken either in natural convection conditions (fan not operating) or in forced convection conditions. In both cases the use of extended surfaces does increase the rate of heat transfer. However as demonstrated in experiment No 1 the time taken to achieve stable temperatures when investigating natural convection can be considerable.

Therefore a forced convection experiment is described as follows.

(i) Ensure the instrument console main switch is sin the off position. Ensure the fan is switched off. For the natural convection experiments the fan will not be used.

(ii) If the flat (pinned or finned) plate is not in position, open the toggle clamps retaining the plate in the tunnel and removes the existing plate from the tunnel. Replace with the flat(pinned or finned) plate and close the toggle clamps. Note that with the plate heat exchangers the power leads exit from the top of the plates. Refer to the diagram on page1

(iii) Ensure that the air temperature thermocouple T9, surface temperature thermocouple T1 and additional thermocouples fitted to the pinned (T3, T4, T5) and finned (T6, T7, T8) plates are connected to the instrument console. Refer to the diagram on page **Error! Bookmark not defined.**

(iv) Switch on the main switch and set the air velocity to a low value by closing the **air throttle (9)**. Increase the heater power to a suitable level such that ts (T1) does not exceed 100°C.Allow the temperatures to stabilise and then record the surface temperature ts (T1), air stream temperature ta (T9), the heater supply voltage V and current I, the air velocity reading U and the thermocouples on the extended surface (T3, T4, T5, Pinned plate or T6, T7, T8, Finned plate).

(v) Maintain the heater voltage at the same condition and then increase the air velocity by opening the **air throttle (9)** slightly. Once again allow the temperatures to stabilise and repeat the readings. Repeat the procedure at increasing air velocity if required.

For direct comparison, repeat the procedure for the other extended surface plate (finned or pinned) under similar heat input conditions and at similar velocities.

Typical data for the pinned plate is shown on the following pages.

SAMPLE DATA
Heater Used :- Pinned Plate
Atmospheric Pressure =1 .013 x 10^5 kNm^{-2}

Sample No.	1	2	3	4	5	6
Time 1/s						
Heater Volts V	241	241				
Heater Current I (Amps)	0.357	0.357				
Heater Power $V \times R$ Watts	86.03	86.03				
Ambient ta (T9)/°C	19.0	19.0				
Flat Plate ts (T1)/ °C	51.7	42.4				
Pinned Plate ts (T1/°C)	51.6	42.3				
Pinned Plate T3/°C	47.6	38.5				
Pinned Plate T4/°C	47.5	37.8				
Pinned Plate T5/°C						
Finned Plate ts T1/°C						
Finned Plate T6/°C						
Finned Plate T7/°C						
Finned Plate T8/°C						
Surface-Air Temperature Difference (ts – ta) / K						
Duct Air Velocity U m/s	6.8	9.8				

CALCULATIONS

For the Pinned plate(Sample No.2) the following data was collected.

Air Velocity =9.8 m/s
ts (T1) = 42.4°C
ta (T9) =19.0°C
V = 241V
I = 0.357 A

Hence the heat input

$$\dot{Q} = V \times I$$
$$= 241 \times 0.357$$
$$= 86.03 \text{ Watts}$$

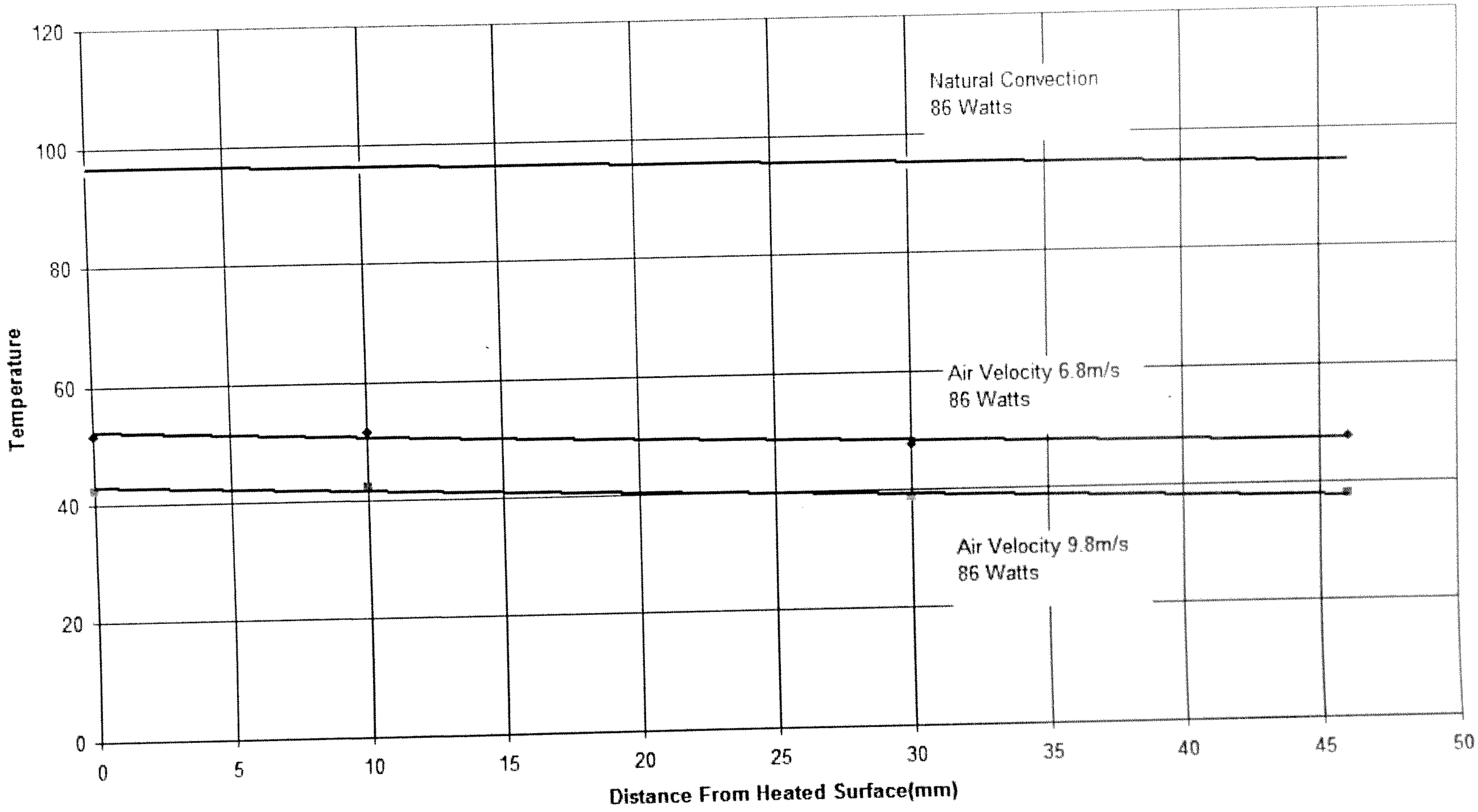
Similar experiments and calculations may be undertaken for different velocities and for the remaining extended surface plate. If the temperatures recorded are plotted against the location of the thermocouples along the extended surface the effect of the fins or pins may be seen. Refer to Useful Data on page 12 for the thermocouple locations. Note that due to the physical limitations of locating the tip thermocouples the location of these on the fin and pin heat exchangers are at different distances from the heater surface.
However due to the high thermal conductivity of aluminium this has little effect .

Test data for the finned heat exchanger is plotted on page 27
It may be seen from the plotted data that the temperature along the fin reduces rapidly from the surface temperature ts adjacent to the heater. The difference between the temperatures along the fin is very small.
At the base of the fin the temperature is close to that of the heater and this causes heating of the fin due to conduction. However due to the fin area and the air stream the heat is conveyed rapidly to the air. This establishes a temperature gradient along the fin. The effectiveness of the fins depends not only upon the fin surface area but also its thickness and conductivity. The material used for all of the plates is aluminium, which has a thermal conductivity of approximately 230 W/m K.

If the material were cast iron for example (as used on many early air cooled engines) the thermal conductivity of this material is approximately 55 W/mK. Hence the "resistance" to heat conduction along the fins would be approximately four times as great and the slope of the temperature gradient would be expected to be higher.

It can be seen that at the higher air velocity the temperatures are slightly lower but the gradients remain the same along the fin.

Sample data for the same plate operating under natural convection conditions is also shown. Here it can be seen that in order to dissipate a lower heat input (90Watts) the temperatures are higher both at the base ts and along the fin. Also the gradient along the fin is slightly higher than in the forced convection situation.
REPLACE GRAPH DATA


Temperature Distribution Along a Fin

OBSERVATION SHEET

Heater Used :-

Atmospheric Pressure =

Sample No.	1	2	3	4	5	6
Time 1/s						
Heater Volts V						
Heater Current I Amps						
Heater Power $V \times I$ Watts						
Ambiant ta (T9)/°C						
Flat Plate ts (T1)/ °C						
Pinned Plate ts (T1/°C)						
Pinned Plate T3/°C						
Pinned Plate T4/°C						
Pinned Plate T5/°C						
Finned Plate ts T1/°C						
Finned Plate T6/°C						
Finned Plate T7/°C						
Finned Plate T8/°C						
Surface-Air Temperature Difference (ts – ta) / K						
Duct Air Velocity U m/s						