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TECHNICAL REPORT

WSRL-0343-TR

INVESTIGATION INTO THE INTERNAL AERODYNAMIC DESIGN AND ASSOCIATED
ERRORS IN A FAST DESCENT DUCTED SONDE FOR THE MEASUREMENT OF
ATMOSPHERIC PRESSURE AND TEMPERATURE (AMPARS PHASE 2)

P.H.O. PEARSON

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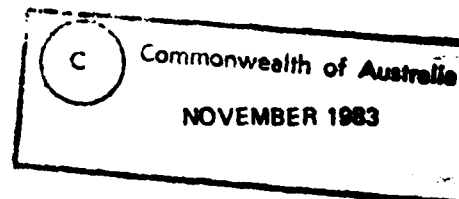
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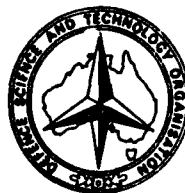
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INVESTIGATION INTO THE INTERNAL AERODYNAMIC DESIGN AND ASSOCIATED
ERRORS IN A FAST DESCENT DUCTED SONDE FOR THE MEASUREMENT OF
ATMOSPHERIC PRESSURE AND TEMPERATURES (AMPARS PHASE 2)

P.H.O. Pearson

S U M M A R Y

→ This report investigates aspects of the atmospheric pressure and temperature measuring technique for a fast descent sonde. The sonde, which is drogue stabilised, is released from a rocket vehicle in the vicinity of the apogee which is 20 km. Low speed wind tunnel tests have been conducted to check any errors in the measurement of atmospheric pressure resulting from the positioning of the static tube mounted inside an internally ducted sonde. It shows that no errors occur for the chosen position up to an external airflow incidence of 30° . Errors owing to heat transfer into a centrally mounted thermistor are examined for various thermistor positions and incidence angles and the thermistor response time has been measured and compared with theoretical results. Overall it is shown that the duct design is suitable for a fast descent sonde with errors well below those specified by the Bureau of Meteorology for standard ascending meteorological sondes. ⚡



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1. INTRODUCTION

This report describes a series of tests undertaken to verify the design of a duct containing a static pressure tube and a yoke mounted thermistor to measure atmospheric pressure and temperature on a descending dropsonde released from a rocket. The rocket/sonde system has been designed to demonstrate the practical measurement of atmospheric parameters as Part 2 of the ANPARS (Artillery Meteorological Parameter Acquisition Rocket System) Task (ARM 81/110) in response to Army Research Request 1148/80.

The feasibility of the overall system was examined in Part 1 of this task which was reported in reference 1. In that report a system was proposed in which the air flows, while the sonde is descending, through an internal duct in the sonde. The flow is over the thermistor past the static pressure sensing tube around the telemetry and battery compartment and out of the rear face of the sonde.

In this report a detailed theoretical study is made of the response of the thermistor over the expected descent trajectory and comparisons are made with practical results obtained from a series of low speed wind tunnel tests carried out at velocities up to the expected descent dynamic pressure. In addition, tests were conducted with two thermistor positions relative to the forward face of the sonde, and at various sonde incidences to the flow, to check for heat conduction from the sonde body to the thermistor. Pressure measurements were also taken at the full range of airflow velocities and incidences to check on any errors associated with the positioning of the static pressure tube.

2. PRESSURE TESTS

A sketch of the location of the sensors in the sonde is at figure 1.

A static tube was mounted adjacent to the thermistor yoke support. The tube, which was 3 mm in diameter, had a $1\frac{1}{2}$ mm bore and the static hole of $1\frac{1}{2}$ mm diameter was positioned 7 mm from the closed front end of the static tube. The static hole was set 37 mm from the forward face of the sonde in a region where, it was hoped, there would be little effect on the static pressure owing to sonde incidence or variations in the dynamic pressure. A series of tests was then made at various tunnel velocities up to 18 ms^{-1} and at flow incidences between -30° and $+30^\circ$ with the thermistor yoke in the incidence plane and also with the sonde rotated through 90° .

Table 1 gives a list of the tests conducted and the first 12 tests at zero incidence are shown in figure 2 as a variation in apparent measured pressure as a function of wind tunnel velocity. In addition the theoretical pitot pressure is shown for sea level conditions and up to the maximum tunnel velocity. The accuracy of pressure measurements was to 1mV which is the equivalent of 0.167 mb of atmospheric pressure. These tests show that the pressure variations are primarily owing to temperature and atmospheric pressure changes probably combined with an experimental and instrumentation settling down period. Any changes in pressure owing to velocity appear to be less than or similar to the accuracy of measurement, 0.167 mb, and certainly well within the Bureau of Meteorology system accuracy specification of $\pm 4 \text{ mb (ref.2)}$.

The latter tests in this series were all conducted at a wind tunnel velocity of 10 ms^{-1} and consisted of runs at 10° incidence steps between -30 and $+30^\circ$. No significant changes in pressure were detected at any incidence up to 30° either with the thermistor yoke in the incidence plane or when the sonde was

rotated through 90°.

3. THERMISTOR TESTS

3.1 Theory

The response of the thermistor is caused by the convection of heat from the airflow through the surface of the thermistor and by conduction into and along the support wires. The support wires have to therefore be of sufficient length so that conduction of heat from the thermistor support yoke along the wire to the thermistor is of no significance.

The heat transfer from the airflow to the thermistor bead can be considered similar to that for a sphere and theoretical and practical values for "zero" Mach number are given in Eckert and Drake(ref.3) for low subsonic Mach numbers in the form of a dimensionless heat transfer coefficient or Nussult number $h_s d_t$ as a function of Reynolds number.

Typical Reynolds numbers are in the order of 10 with Nussult numbers between 3 and 4. The value of the Nussult number for $M=0$ can be approximated by:

$$(Nu)_s = 2 + 0.43(Re)^{0.52} = \frac{h_s d_t}{k_a} \quad (1)$$

$$\text{where } Re = \frac{V d_t}{\nu}$$

and V = air velocity passed thermistor (ms^{-1})
 d_t = thermistor diameter (m)

ν = kinematic viscosity of air ($\text{m}^2 \text{s}^{-1}$)

h_s = sphere heat transfer coefficient ($\text{Jm}^{-2} \text{s}^{-1} \text{K}^{-1}$)

k_a = thermal conductivity of air ($\text{Jm}^{-1} \text{s}^{-1} \text{K}^{-1}$)

The response time of the thermistor by itself is derived in reference 4 and is given by

$$t_R = \frac{K_{ps} \rho_m d_t}{6h_s} \quad (2)$$

where K_{ps} = specific heat of thermistor material ($\text{J kg}^{-1} \text{K}^{-1}$)

and ρ_m = density of thermistor material (kg m^{-3})

A major contribution to the response time of a wire mounted thermistor is the conduction of heat, either positively or negatively, from the thermistor along the mounting wires. The heat is then transferred as forced convection by the airflow. The equation governing the flow of heat from the thermistor into the wires at the two joints was derived in reference 4 as:

$$Q_T = \frac{\pi d_w^2}{2} k_w A \left\{ (T_t - T) \sinh Al + \left(\frac{(T_t - T) - (T_t - T) \cosh Al}{\sinh Al} \right) \cosh Al \right\} (J s^{-1}) \quad (3)$$

where

$$A = \frac{2}{d_w} \sqrt{\frac{(Nu)_w k_a}{k_w}} (m^{-1})$$

and d_w = support wire diameter (m)

$(Nu)_w$ = Nusselt number for wire

k_w = thermal conductivity of wire ($J m^{-1} s^{-1} K^{-1}$)

l = length of support wire (m)

T = airflow temperature (K)

T_t = thermistor temperature (K)

T_b = thermistor support temperature (K)

For all cases under study, whether at ground level in the wind tunnel or at altitude in the sonde, the value of Al is in excess of 30. For all values of Al above 2 it can be assumed that $\sinh Al = \cosh Al$ and thus equation (3) reduces to:

$$Q_T = - \frac{\pi d_w^2}{2} k_w A (T_t - T) (J s^{-1}) \quad (4)$$

Equation (2) for the thermistor with support wires then becomes:

$$t_{R(s+w)} = \frac{K_{ps} \rho_m d_T^3}{6 h_s d_T^2 + 3A k_w d_w^2} (s) \quad (5)$$

The results for thermistor alone and with wires attached are given in figure 3 at various flow velocities at sea level conditions for two different thermistor diameters. The nominal value of 0.254 mm diameter is shown together with a diameter of 0.290 mm which represents the equivalent spherical volume for an ellipsoid with major and minor axes of 0.381 and 0.254 mm which appears, from examination, to be a more realistic dimension for the nominal "10 thou" thermistor.

3.2 Wind tunnel tests - incidence effects

The thermistor tests covered the measurement of the air temperature from the wind tunnel with the thermistor mounted in two different positions. The forward position was 4 mm aft of the sonde front face in a centre line position while the aft position was 22 mm from the forward face (figure 1). The cone was heated with lamps up to about 25°C and the wind tunnel operated at 6 ms⁻¹ with the incidence set at 15°. Three temperatures were monitored, the first was the wall temperature of the sonde body, the second

the temperature of the airflow in the wind tunnel and the third the measured thermistor temperature initially 22 mm back (aft position) from the sonde entrance. This was repeated at incidences between 15° and 30° with the final reading at zero incidence. Figure 4 shows that the temperature of the wind tunnel air flow was the same as the sonde thermistor reading, except for a small calibration error, up to an incidence of 20° . Above this value the thermistor gained heat from the boundary layer separating from the lip of the sonde duct entrance giving a progressively false temperature value as the incidence was increased until at 30° incidence the thermistor error was about one third of the difference between the free airflow temperature and the sonde body temperature.

The second test was with the sonde thermistor in the forward position, 4 mm back from the sonde front face, which is the proposed position for the flight measurements. In this test the sonde casing was again heated by heat lamps but to a considerably higher temperature, 36°C , than in the first test. The wind tunnel was again run at a velocity of 6 ms^{-1} and the incidence increased progressively from 0 to 30° . The tunnel speed was then increased to 18 ms^{-1} and the incidence reduced progressively to zero. During the test period the temperature of the sonde body reduced from 36°C to 24.5°C . Figure 5 shows that the temperature of the air as measured by the sonde thermistor showed no significant change relative to the tunnel value throughout the test. It can therefore be concluded that, with the thermistor mounted in the forward position, there is no effect on the atmospheric temperature measurement owing to the proximity of the sonde body up to an incident airflow of 30° .

3.3 Wind tunnel tests - thermistor response

Any temperature measuring device mounted in either an ascending or descending sonde must have a response time sufficiently fast to give an accurate reading of the atmospheric temperature within specified limits. In the case of a fast descent this is especially important owing to the much higher velocity compared to a conventional ascending balloon sonde. A theoretical model, described in Section 3.1, was used to determine the thermistor response at a range of velocities and altitudes. Tests were conducted at ground level, using a low speed wind tunnel, to confirm the theoretical treatment. The method used consisted of running the wind tunnel at different velocities (2 , 6 and 12 ms^{-1}) and heating the thermistor by focusing a heat lamp on to the bead. The lamp was then switched off and the response of the thermistor was recorded on a paper chart as it returned to the ambient flow temperature. The practical results denoted in figure 3 by the "bars" at 2 , 6 and 12 ms^{-1} of air velocity show a satisfactory agreement with the theoretical values, for the "observed" dimensions of the nominal "10 thou" thermistor bead especially in view of the assumed values of the specific heat and density of the thermistor material which has been taken as that of glass. The confirmation of the theoretical response times at sea level conditions enabled response times and heights to be confidently predicted throughout the sondes descent for various values of sonde drag. Figure 6 shows the sonde velocity profile as well as the response times and heights for three values of sonde vertical velocity at sea level, the nominal 18 ms^{-1} and also values of 21 and 25 ms^{-1} which cover the velocity range expected in the fully telemetered research sondes programmed in Phase 2 of the ANPARS project.

The requirement for temperature accuracy specified for the ANPARS sonde is that it should be the same or better than that adopted by the Bureau of

Meteorology in its specification(ref.2) for their conventional ascending balloon sonde which states that the overall steady state accuracy shall be less than 0.5°C . This corresponds to a response height, that is the height through which the sonde falls in the response time, of 18.2 m at sea level and 44 m at 20 km altitude(ref.1). Figure 6 gives values of 2.5 m at sea level and 16 m at 20 km altitude which is clearly far more accurate than the required specification from the unsteady aspects of temperature error. The steady state errors, from radiation considerations, have previously been shown(ref.1) to be in the order of 0.1°C . To achieve an error of 0.5°C at 20 km altitude a lapse rate in excess of $30^{\circ}\text{C}/\text{km}$ would be required which is about ten times the normal Standard Atmosphere lapse rate value.

It is therefore concluded that the described temperature measurement system will give atmospheric values well within the specified temperature errors.

3.4 Wind tunnel tests to examine the use of thermistors for incidence measurement

A requirement exists for the measurement of airflow incidence during the sondes' descent. One suggested method is to place a series of thermistors near the centre line of the sonde at varying distances from the front sonde face and by calibration in the wind tunnel examine the angle at which heat transfer occurs between the sonde body and the thermistors. In order to examine this technique in some detail a test sonde body was constructed with an electrical heating coil wound around the outer casing. By this means an elevated sonde body temperature can be maintained for a given flow velocity and the incidence varied to find when a detectable transfer of heat occurs for different thermistor positions. The thermistors were mounted, on an extended yoke, at 6, 13 and 23 mm from the sonde front face. The positions of the thermistor beads is shown in figure 7 and while the front thermistor A was on the centre line of the sonde body, thermistors B and C were slightly offset in the incidence plane by up to 2 mm.

Results were obtained for three wind tunnel velocities, 6, 12 and 18 ms^{-1} , and the incidence varied between -40 and $+45^{\circ}$ with a body temperature in the steady state elevated to between 12 and 25°C above the wind tunnel air temperature.

The results are shown in figures 8 to 10 where it is seen that, while for the forward thermistor A no apparent transfer of heat occurred, the two rear thermistors B and C "broke away" from the airflow temperature at incidences above 20° . The differences between the breakaway in the positive and negative incidence tests can be wholly accounted for by the centreline offset of thermistor beads B and C. Figure 11 shows the mean detected incidence angle for a thermistor mounted on the sonde centreline as a function of distance from the front sonde face. It is seen that there is a range of about 10° between the detected angle and the geometric line between the thermistor and the sonde lip showing the extent of the "boundary layer" mixing and three dimensional effect aft of the sonde lip.

The results show that thermistors with a fast response time, 0.1 to 0.15 s, can be used to qualitatively detect angular movement of the sonde relative to the airflow to an accuracy, from observation, of at least $\pm 5^{\circ}$ incidence providing that the sonde body is at a significantly different temperature from the ambient air flow. For much of the flight of a fast descent sonde this would be so, as a large airflow temperature range, over 60°C (ref.5), would be experienced during the descent. The response of the body would be relatively slow as shown in figure 5 where the test took in excess of 10 min. In this case the second half of the test, at 18 ms^{-1} , was at full flight dynamic pressure.

4. CONCLUSIONS

Three basic conclusions result from the series of wind tunnel tests referred to in this report.

(1) The selected aerodynamic design of the sonde body in conjunction with the position of the static pressure sensor orifice shows no detectable variation from the atmospheric pressure throughout the range of velocities. This range includes the full dynamic pressure for the fast descent AMPARS sonde and airflow incidences in any plane up to 30° .

(2) For a nominal 10 thou thermistor mounted in the preferred position, 4 mm from the sonde front face on the centreline, there is no detectable effect on the atmospheric temperature measurement due to the proximity of the sonde body, up to an incidence of 45° .

(3) The response time of the thermistor is such that any temperature errors are well within those specified by the Bureau of Meteorology(ref.2) when applied to the fast descent AMPARS sonde.

Overall it has been shown that the design of the sonde duct system for measurement of atmospheric pressure and temperature is suitable for use in the AMPARS fast descent sonde and will provide readings with no significant measurement errors that can be associated with the sonde duct design.

In addition a qualitative airflow incidence measurement detector can be made up from a series of axially mounted thermistors in the sonde duct.

5. ACKNOWLEDGEMENTS

The author wishes to acknowledge the contribution of Messers A.D. Hind and C.J. Beach of Field Experiments Group, WSRL for the preparation of the test sonde and conduct of the experiments.

TABLE 1. RESULTS OF WIND TUNNEL TEST ON SONDE STATIC PRESSURE SENSOR

TEST NUMBER	WIND TUNNEL VELOCITY	SONDE INCIDENCE	PRESSURE TRANSDUCER OUTPUT	EQUIVIENT PRESSURE CHANGE
(see figure 2)	(ms^{-1})	($^{\circ}$)	(V)	(mb)
0	0	0	-1.952	REF ZERO
1	2	0	-1.955	0.498
2	4	0	-1.956	0.664
3	6	0	-1.959	1.162
4	10	0	-1.961	1.494
5	14	0	-1.964	1.992
6	0	0	-1.965	2.158
7	10	0	-1.962	1.660
8	14	0	-1.964	1.992
9	18	0	-1.965	2.158
10	14	0	-1.965	2.158
11	10	0	-1.962	1.660
-	10	10	-1.963	1.826
-	10	20	-1.963	1.826
-	10	30	-1.963	1.826
-	10	20	-1.963	1.826
-	10	10	-1.963	1.826
-	10	0	-1.963	1.826
-	10	-10	-1.963	1.826
-	10	-20	-1.962	1.660
-	10	-30	-1.963	1.826
Sonde rotated through 90°				
-	10	30	-1.962	1.660
-	10	0	-1.962	1.660
-	10	-30	-1.962	1.660

NOTATION

d_t	thermistor diameter
d_w	support wire diameter
h_s	sphere heat transfer coefficient
k_a	thermal conductivity of air
k_w	thermal conductivity of wire
l	length of support wire
$(Nu)_s$	Nussult number - sphere
$(Nu)_w$	Nussult number - wire
t_{RS}	response time - thermistor
T	airflow temperature
T_b	thermistor support temperature
T_t	thermistor temperature
V	airflow velocity
K_{ps}	specific heat of thermistor material
ν	kinematic viscosity of air
ρ_m	density of thermistor material

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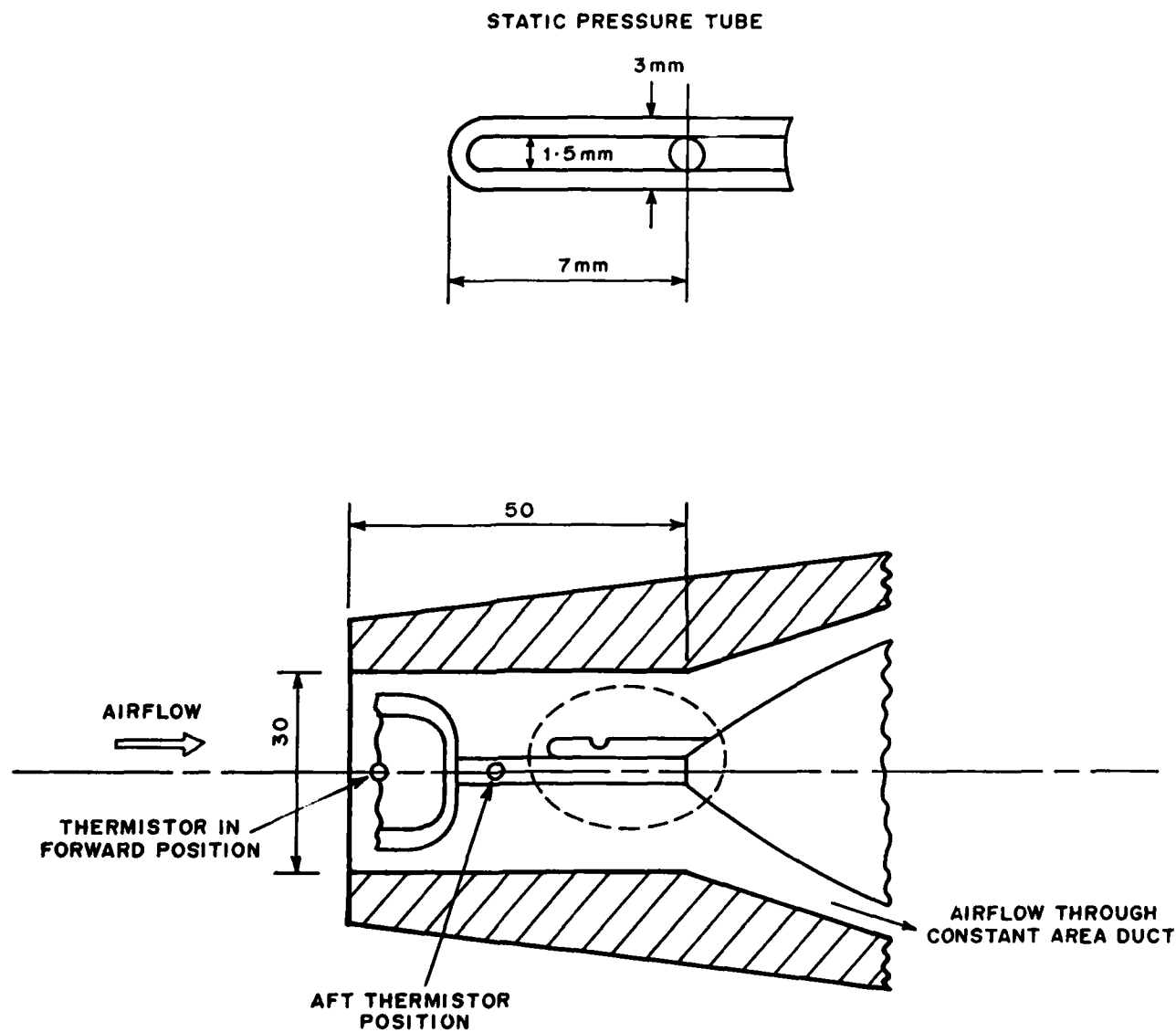


Figure 1. Diagram of sonde duct with location of pressure and temperature sensors

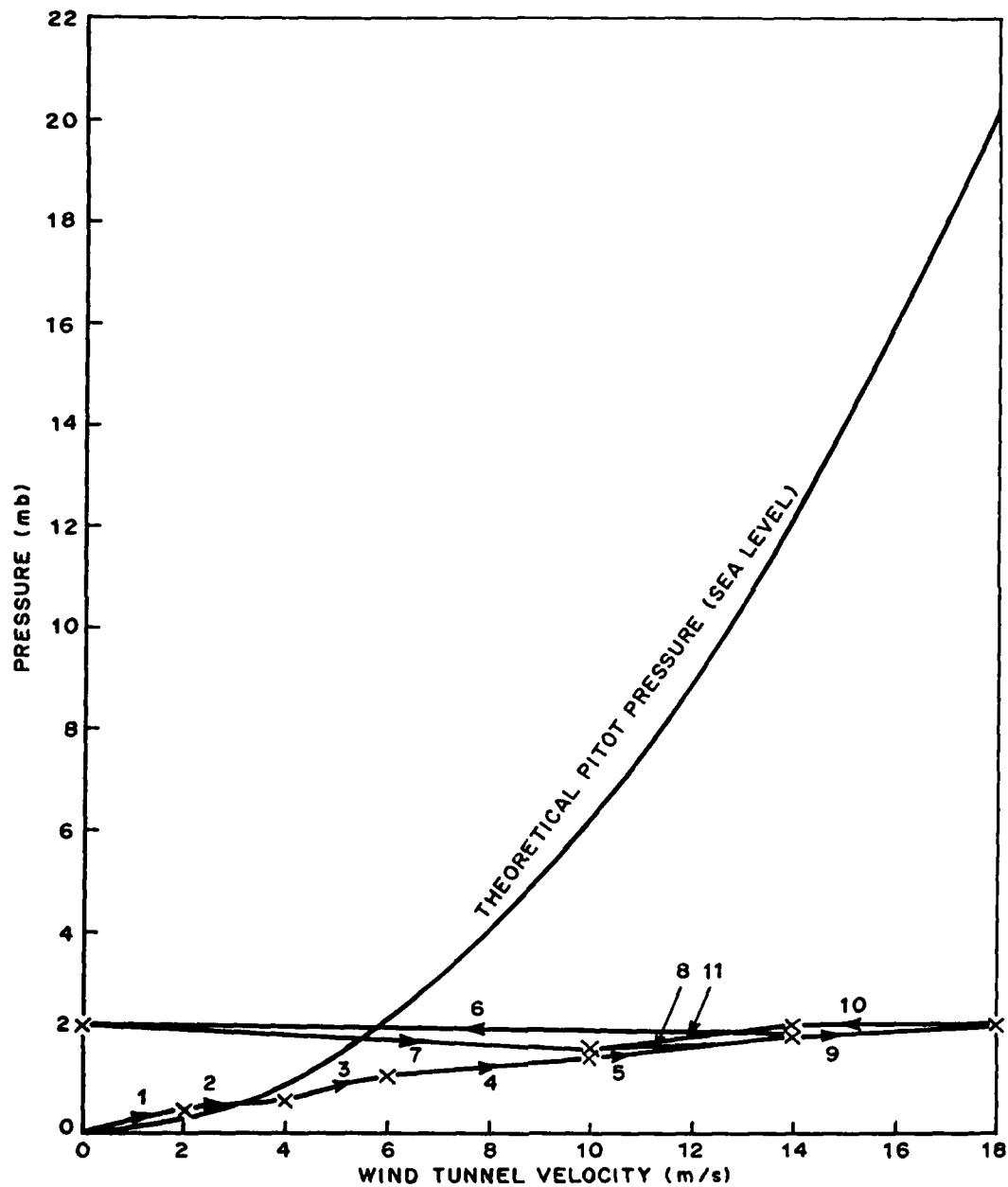


Figure 2. Static pressure measurements from wind tunnel tests

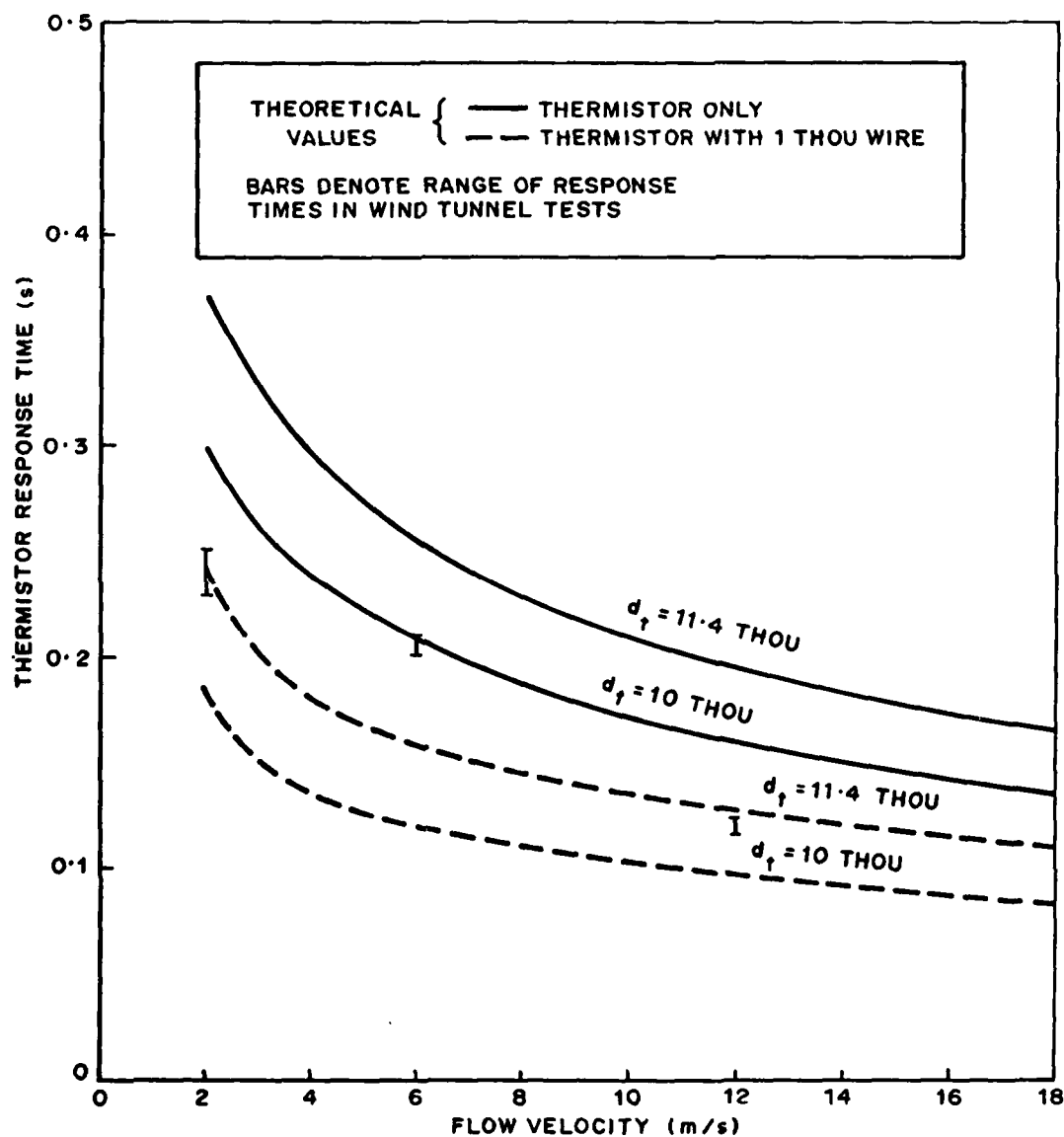


Figure 3. Thermistor response time as a function of flow velocity

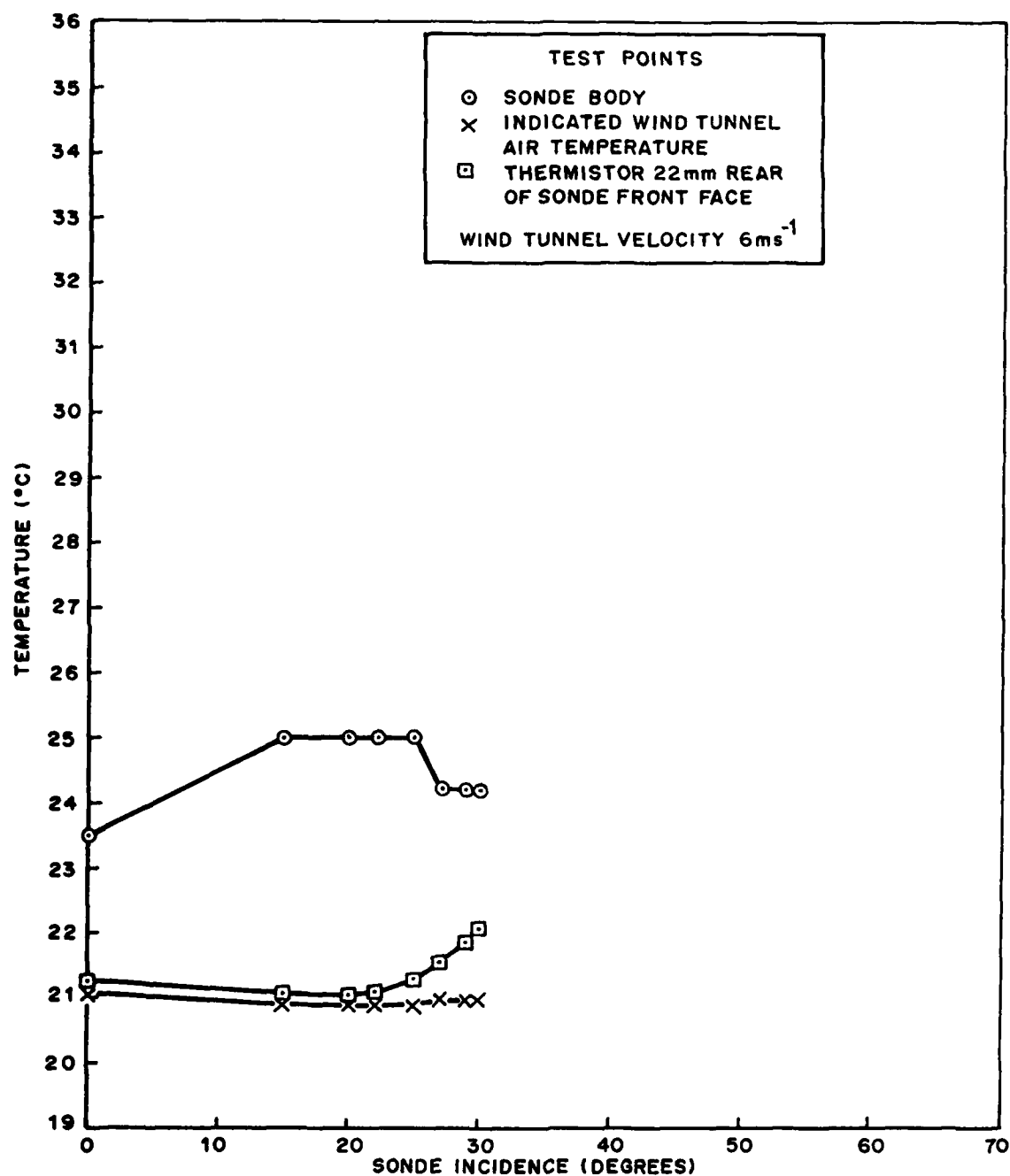


Figure 4. Temperature measurement as a function of sonde incidence (rear thermistor position)

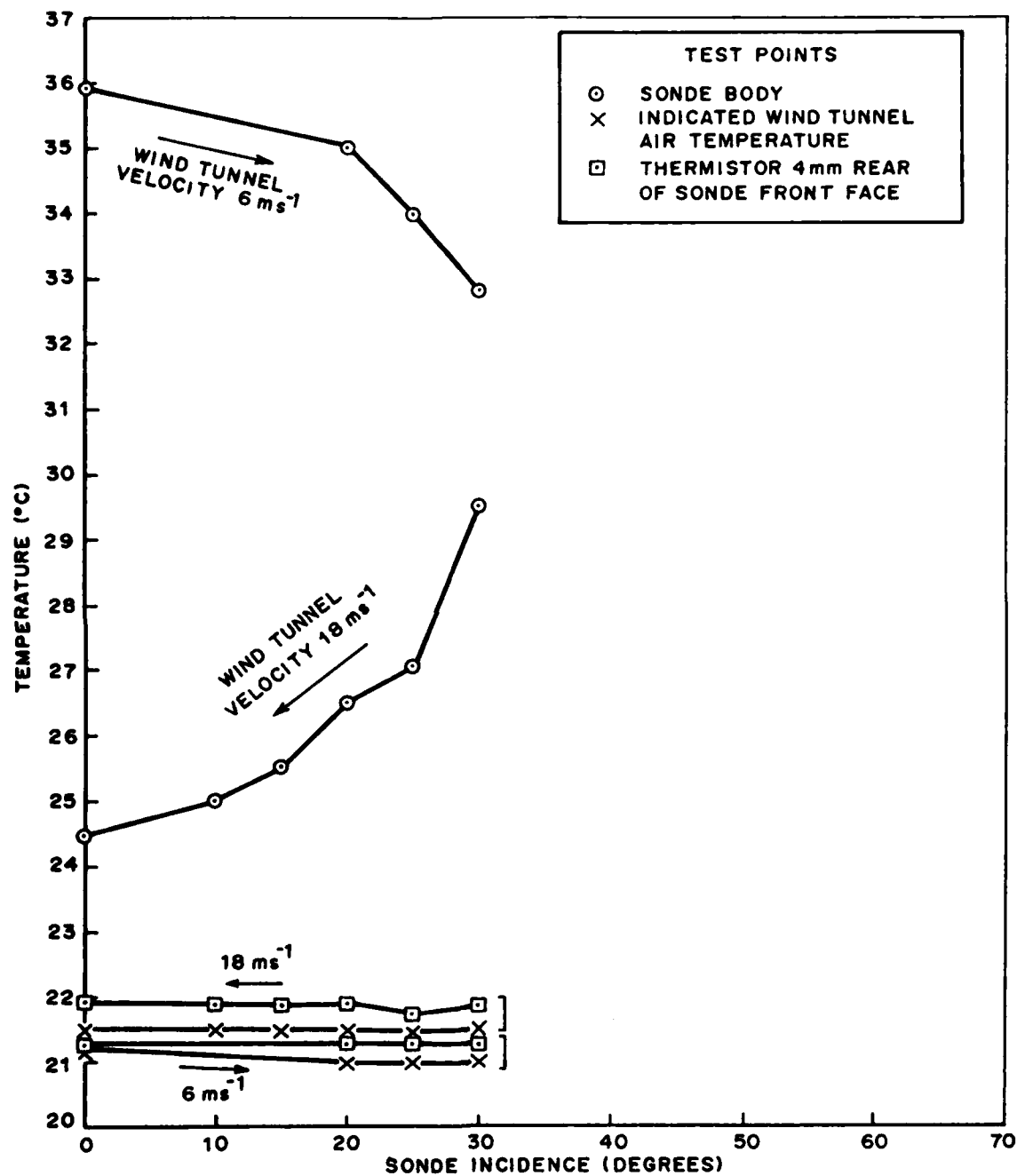


Figure 5. Temperature measurement as a function of sonde incidence (forward thermistor position)

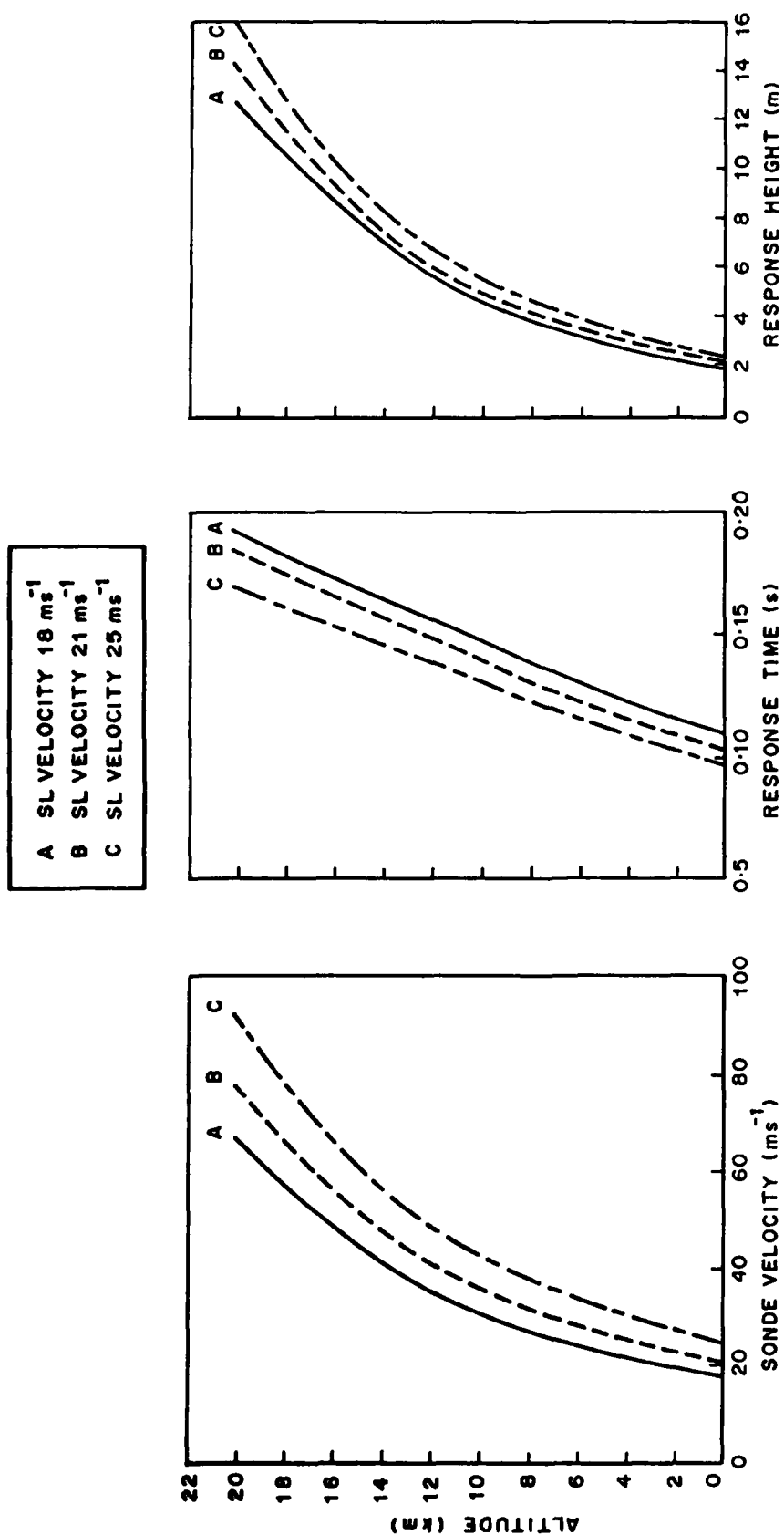


Figure 6. Theoretical sonde velocity, response time and response height as a function of altitude

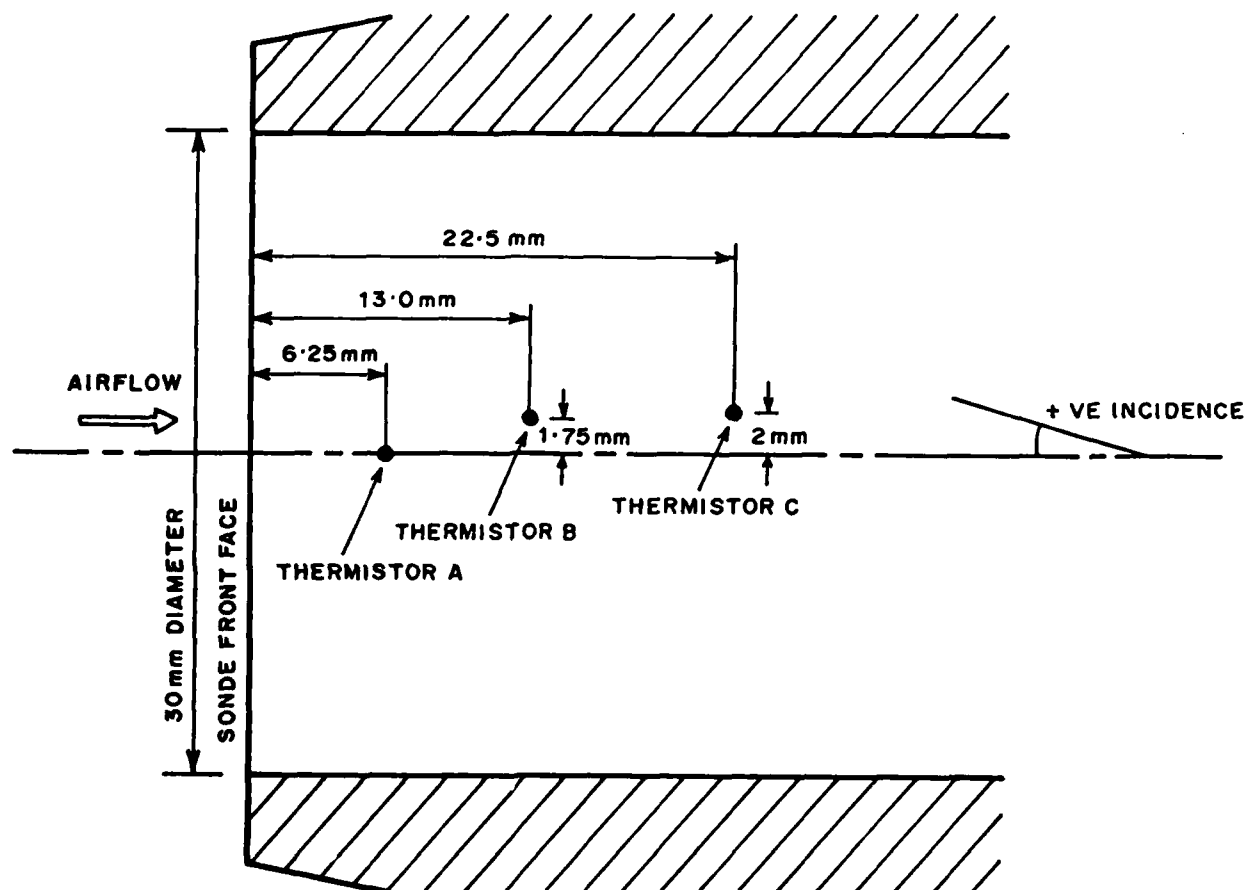


Figure 7. Thermistor position for incidence detecting tests

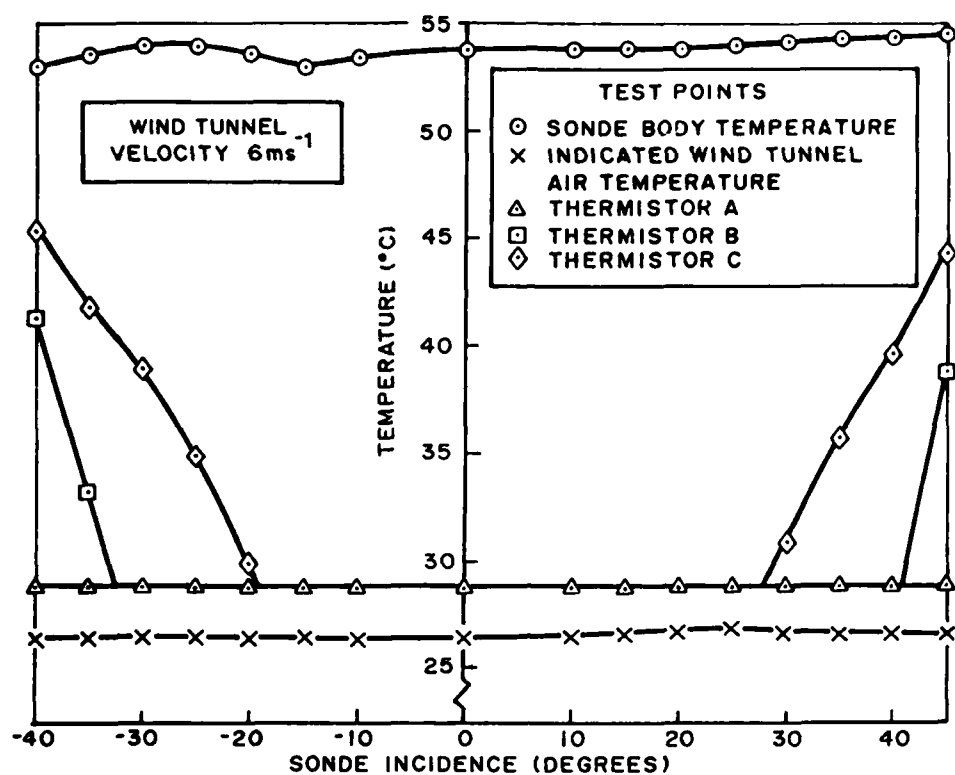


Figure 8. Sonde temperature as a function of incidence for wind tunnel velocity of 6 ms^{-1}

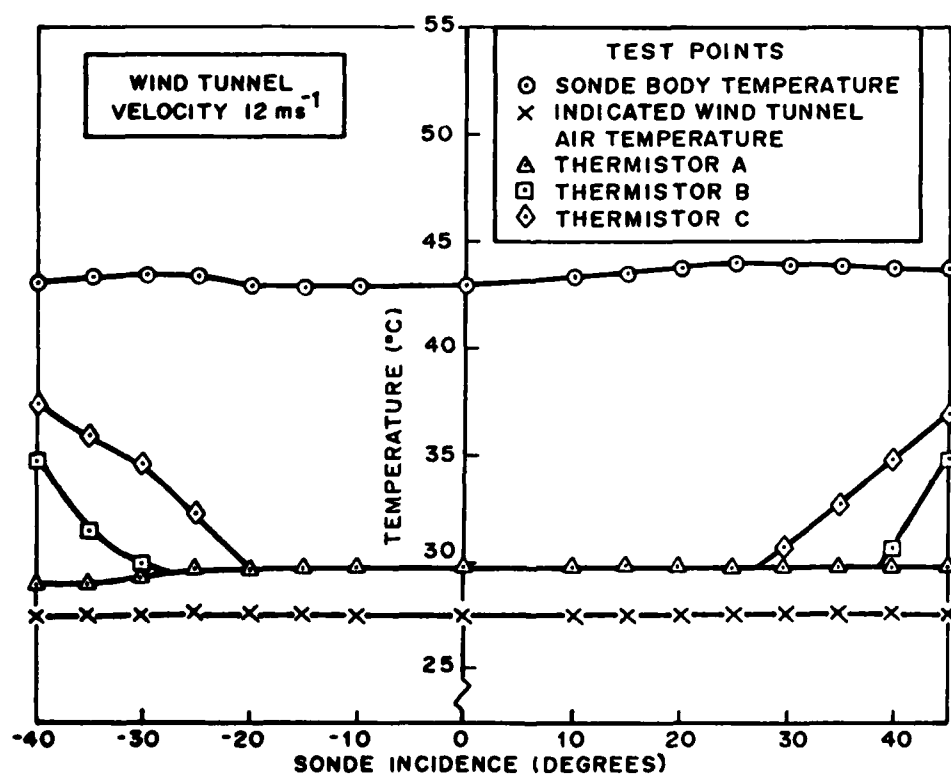


Figure 9. Sonde temperature as a function of incidence for wind tunnel velocity of 12 ms^{-1}

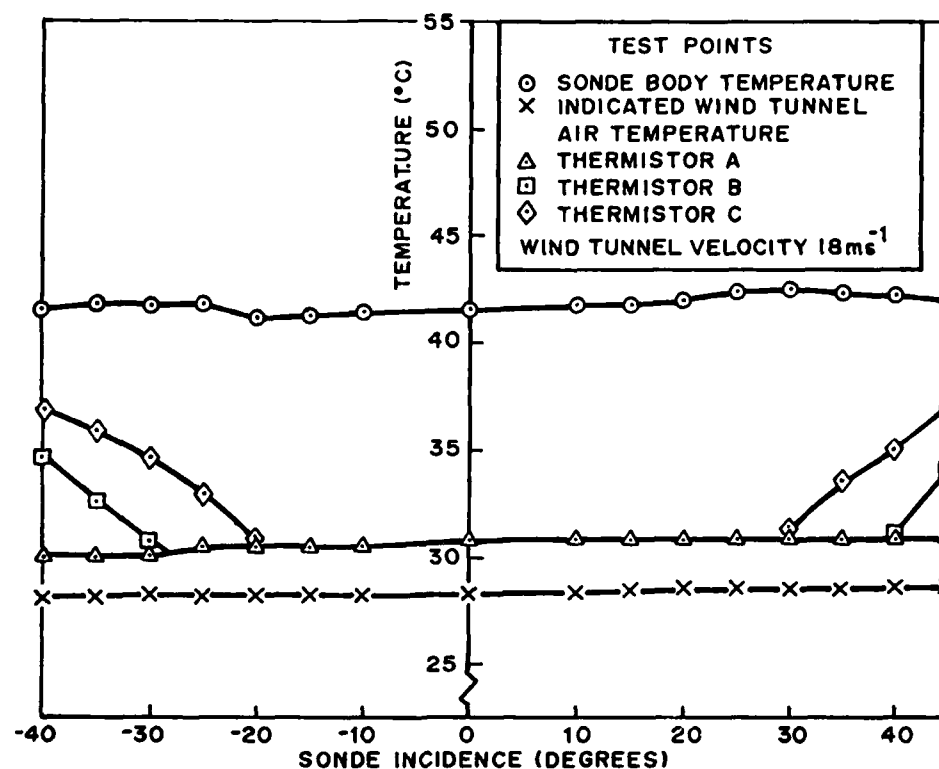


Figure 10. Sonde temperature as a function of incidence for wind tunnel velocity of 18 ms⁻¹

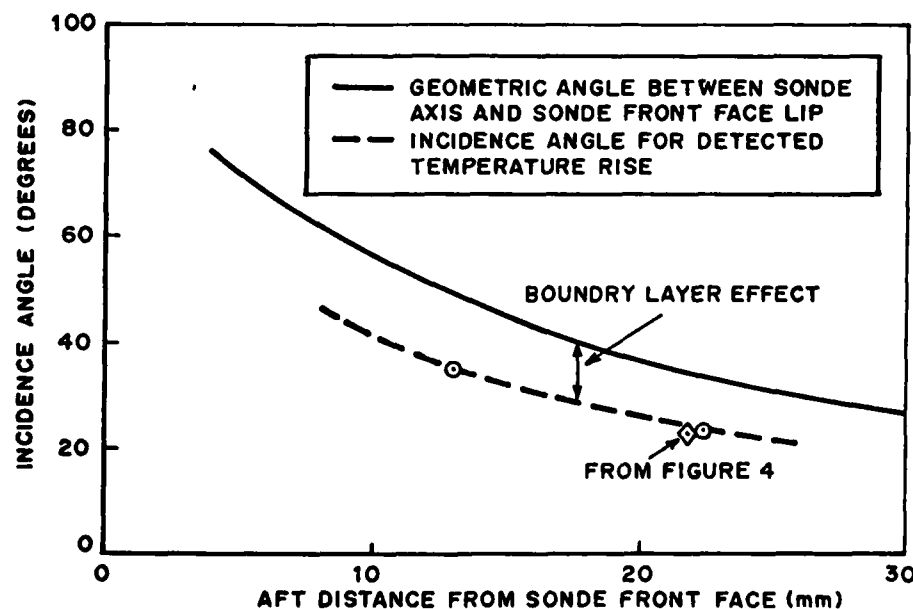


Figure 11. Incidence angle as detected by a thermistor as a function of thermistor position

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16 SUMMARY OR ABSTRACT:

(if this is security classified, the announcement of this report will be similarly classified)

This report investigates aspects of the atmospheric pressure and temperature measuring technique for a fast descent sonde. The sonde, which is drogue stabilised, is released from a rocket vehicle in the vicinity of the apogee which is 20 km. Low speed wind tunnel tests have been conducted to check any errors in the measurement of atmospheric pressure resulting from the positioning of the static tube mounted inside an internally ducted sonde. It shows that no errors occur for the chosen position up to an external airflow incidence of 30° . Errors owing to heat transfer into a centrally mounted thermistor are examined for various thermistor positions and incidence angles and the thermistor response time has been measured and compared with theoretical results. Overall it is shown that the duct design is suitable for a fast descent sonde with errors well below those specified by the Bureau of Meteorology for standard ascending meteorological sondes.

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