AN AMERICAN NATIONAL STANDARD

ANSI/ASME
PTC 11-1984

REAFFIRMED 1995

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Fans

PERFORMANCE
TEST
CODES

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
United Engineering Center
345 East 47th Street New York, N.Y. 10017

FOREWORD

(This Foreword is not part of ANSI/ASME PTC 11-1984.)

PTC 11-1946, entitled Test Code for Fans, was published by the Society in 1946. As noted in its Foreword, the personnel of the committee that developed the Code consisted of members of the American Society of Heating and Ventilating Engineers, the National Association of Fan Manufacturers, and the American Society of Mechanical Engineers. The Code, as written, was basically a laboratory test standard in that it provided instructions for arrangement of test equipment such as ducts, plenum chamber, and flow straighteners, as well as instruments. It even stated that the test could be conducted in the manufacturer's shops, the customer's premises, or elsewhere. This Code was widely distributed and the principles set forth in it undoubtedly provided the basis for many other laboratory standards for testing fans.

Most ASME Power Test Codes (later called Performance Test Codes) provided instructions for testing equipment after it was installed. Since PTC 11-1946 was basically a laboratory standard, it was allowed to go out of print with the expectation that a revised code would be written that would provide directions for site testing of fans.

In July of 1961, a new PTC 11 Committee was formed. Several drafts were prepared, but all of them essentially provided laboratory directions. This Committee still considered field or site testing to be impractical unless laboratory conditions could be duplicated.

The PTC 11 Committee was reorganized in 1971. It initially attempted to resolve the difficulties of site testing by resorting to model testing. This was not acceptable to the Society. Ultimately, procedures were developed that could be used in the field without the need to modify the installation so as to condition the flow for measurement. The Committee performed tests to determine the acceptability of these procedures. These tests included full-scale field tests of two large mechanical-draft fans as well as various laboratory tests of various probes for measuring flow angles and pressures. Subsequent tests (Ref. 19) performed independently of the Committee have demonstrated the practicability of this Code with regard to both manpower and equipment in a large-power-plant situation.

The Committee has also monitored the progress of an International Committee which was writing test codes for fans. While this Committee, ISO 117, had not completed its work, it was obvious that several things they were doing should be incorporated in PTC 11. The major item contributed by ISO 117 is the concept of specific energy (also called work per unit mass) which, when combined with mass flow rate, provides an approach to fan performance that can be used instead of the volume flow rate/pressure approach. ISO also recognizes the distributionality of velocity across the measuring plane and PTC 11 incorporates provisions to account for this.

This Code was approved by the Board on Performance Test Codes on May 19, 1983. It was approved and adopted by the American National Standards Institute, Inc., on March 23, 1984.

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PERSONNEL OF PERFORMANCE TEST CODE COMMITTEE NO. 11 ON FANS

(The following is the roster of the Committee at the time of approval of this Code.)

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BOARD ON PERFORMANCE TEST CODES

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SECTION 1 — INTRODUCTION

1.1 GENERAL

This Code provides standard procedures for conducting and reporting tests on fans, including those of the centrifugal, axial, and mixed flow types. The principal quantities that can be determined are:

(*a*) fan mass flow rate, or alternatively, fan volume flow rate;
(*b*) fan specific energy, or alternatively, fan pressure; and
(*c*) fan input power.

Hereinafter these parameters shall be inclusively covered by the term *performance*. Additional quantities that can be determined are:

(*d*) gas properties at the fan inlet; and
(*e*) fan speed;

hereinafter inclusively covered by the term *operating conditions*. Various other quantities can be determined, including:

(*f*) fan output power;
(*g*) compressibility coefficient; and
(*h*) fan efficiency.

1.2 OBJECTIVES

The objectives of this Code are:

(*a*) to provide the rules for testing fans to determine performance under actual operating conditions; and
(*b*) to provide additional rules for converting measured performance to that which would prevail under specified operating conditions.

1.3 SCOPE

The scope of this Code is limited to the testing of fans after they have been installed in the systems for which they were intended. However, the same directions can be followed in a laboratory test. (The laboratory test performance may not be duplicated by a test after installation because of system effects.) The term *fan* implies that the machine is used primarily for moving air or gas rather than compression. The distinction between fans, blowers, exhausters, and compressors in common practice is rather vague; accordingly, machines that bear any of these names may be tested under the provisions of this Code. (It is conceivable that these machines can also be tested under the provisions of PTC 10, Compressors and Exhausters.)

This Code does not include procedures for determining fan acoustical characteristics.

1.4 APPLICABILITY

A Code test requires a large investment of manpower and equipment. This Code and PTC 1, General Instructions, should be studied thoroughly when preparing procedures for testing a fan. The provisions of this Code are mandatory for a Code test as are the provisions of Part III of PTC 1-1980.

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SECTION 2 — DEFINITIONS AND DESCRIPTION OF TERMS

2.1 SYMBOLS

Symbol	Description	Unit/Value	
		U.S. Customary	**SI**
Symbols and Subscripted Symbols			
A	Cross-sectional area of duct	ft^2	m^2
a	Parameter in Eq. (5.11-20)	dimensionless	dimensionless
b	Parameter in Eq. (5.10-7)	dimensionless	dimensionless
C	Cross-sectional area of calibration jet or wind tunnel	ft^2	m^2
C_1, C_2, etc.	(See pp. 6 and 7)		
C_D	Drag coefficient of probe section	dimensionless	dimensionless
C_ϕ	Pitch pressure coefficient	dimensionless	dimensionless
c_p	Specific heat at constant pressure	Btu/lbm · °F	J/kg · K
c_v	Specific heat at constant volume	Btu/lbm · °F	J/kg · K
D	Duct diameter	ft	m
d	Probe diameter	ft	m
E	Electric potential (voltage)	V	V
e_K	Specific kinetic energy	ft · lb/lbm	J/kg
F_n	Number of points factor	dimensionless	dimensionless
F_{sX}	Steady operation factor for X where $X = m, Q, y, p, \rho$, or N	dimensionless	dimensionless
f	Frequency	Hz	Hz
g	Local acceleration due to gravity	ft/sec^2	m/s^2
g_c	(See p. 7)		
h	Enthalpy	Btu/lbm	J/kg
I	Electric current (amperage)	A	A
J	(See p. 7)		
K_t	Probe total pressure coefficient	dimensionless	dimensionless
K_v	Probe velocity pressure coefficient	dimensionless	dimensionless
K_p	Compressibility coefficient (mass flow — specific energy approach)	dimensionless	dimensionless
K_ρ	Compressibility coefficient (volume flow — pressure approach)	dimensionless	dimensionless

2.1 SYMBOLS (cont'd.)

Symbol	Description	Unit/Value	
		U.S. Customary	SI
Symbols and Subscripted Symbols (cont'd.)			
k	Ratio of specific heats (c_p/c_v)	dimensionless	dimensionless
M	Mach number	dimensionless	dimensionless
$\mathbb{M}$	Molecular weight	lbm/lbm-mol	kg/kg-mol
$\dot{m}$	Mass flow rate	lbm/sec	kg/s
$\dot{m}_f$	Fan mass flow rate	lbm/sec	kg/s
N	Rotational speed	rpm	rev/s
N_s	Specified rotational speed	rpm	rev/s
n	Counts or number	dimensionless	dimensionless
n_p	Number of poles	dimensionless	dimensionless
P_I	Fan input power	hp	kW
P_O	Fan output power	hp	kW
p_b	Barometric pressure	in. Hg	kPa
p_e	Saturated vapor pressure	in. Hg	kPa
p_{Fs}	Fan static pressure	in. wg [Note (1)]	kPa
p_{Ft}	Fan total pressure	in. wg	kPa
p_{Fv}	Fan velocity pressure	in. wg	kPa
p_p	Partial pressure of water vapor	in. Hg	kPa
p_s	Static pressure	in. wg	kPa
p_{sa}	Absolute static pressure	in. wa [Note (2)]	kPa
p_t	Total pressure	in. wg	kPa
p_{ta}	Absolute total pressure	in. wa	kPa
p_v	Velocity pressure	in. wg	kPa
Δ_p	Differential pressure	in. wg	kPa
Q_F	Fan volume flow rate	cfm	m^3/s
$\mathbb{R}_p$	Probe Reynolds Number	dimensionless	dimensionless
R	Specific gas constant	ft · lb/lbm · °R	J/kg · K
R_O	(See p. 7)		
S	Aspect parameter	dimensionless	dimensionless
S_p	Frontal area of probe exposed to calibration stream	ft^2	m^2
s	Specific humidity	lbm vapor/lbm dry gas	kg vapor/kg dry gas
s_w	Specific humidity at saturation	lbm vapor/lbm dry gas	kg vapor/kg dry gas
T_s	Absolute static temperature	°R	K
T_t	Absolute total temperature	°R	K
t_d	Dry-bulb temperature	°F	°C
t_s	Static temperature	°F	°C
t_t	Total temperature	°F	°C
t_w	Wet-bulb temperature	°F	°C

2.1 SYMBOLS (cont'd.)

Symbol	Description	Unit/Value U.S. Customary	Unit/Value SI
Symbols and Subscripted Symbols (cont'd.)			
t	Time	sec	s
U_X	Absolute uncertainty in X	same as X	same as X
u_X	Relative uncertainty in X	per unit	per unit
V	Velocity	fpm	m/s
W	Electrical power input to motor	kW	kW
(X)	Volume fraction of gas constituent whose chemical symbol is X	ft^3/ft^3	m^3/m^3
x	Function used to determine K_p	dimensionless	dimensionless
y_F	Fan specific energy	ft · lb/lbm	J/kg
z	Function used to determine K_p	dimensionless	dimensionless
Greek Symbols			
α	Kinetic energy correction factor	dimensionless	dimensionless
β	Parameter used to correct probe calibration for blockage	dimensionless	dimensionless
η	Fan efficiency	percent or per unit	percent or per unit
η_M	Motor efficiency	percent or per unit	percent or per unit
η_s	Fan static efficiency	percent or per unit	percent or per unit
η_t	Fan total efficiency	percent or per unit	percent or per unit
θ	Power factor	dimensionless	dimensionless
θ_i	Sensitivity coefficient	various	various
μ	Dynamic viscosity	lbm/ft · sec	Pa · s
ρ	Density	lbm/ft^3	kg/m^3
ρ_F	Fan gas density	lbm/ft^3	kg/m^3
ρ_m	Fan mean density	lbm/ft^3	kg/m^3
$\sum_{j=1}^{n}$	Summation of corrected values over n observations	. . .	. . .
τ	Torque	lb · ft	N · m
ϕ	Pitch angle	deg.	deg.
ψ	Yaw angle	deg.	deg.
Subscripts			
c	Converted value	. . .	. . .
dg	Dry gas	. . .	. . .
f	Liquid	. . .	. . .
fg	Liquid to vapor	. . .	. . .
g	Vapor	. . .	. . .

2.1 SYMBOLS (cont'd.)

		Unit/Value	
Symbol	**Description**	**U.S. Customary**	**SI**
Subscripts (cont'd.)			
i	Indicated value at a point	. . .	. . .
j	Corrected value at a point	. . .	. . .
ma	Moist air	. . .	. . .
mg	Moist gas	. . .	. . .
R	Reference measurement	. . .	. . .
ref	Value for calibration reference probe	. . .	. . .
t	Turbine and drive train	. . .	. . .
x	Total value at plane x for A, $\dot{m}$, and Q_f or average value at plane x for c_p, e_K, M, p_s, p_t, T, t_s, V, (X), α, and ρ	. . .	. . .
y	Total value at plane y for A, $\dot{m}$, and Q_f or average value at plane y for c_p, e_K, M, p_s, p_t, T, t_s, V, (X), α, and ρ	. . .	. . .
0	Plane 0 (ambient)	. . .	. . .
1	Plane 1 (fan inlet)	. . .	. . .
2	Plane 2 (fan outlet)	. . .	. . .
3	Plane 3 (alternate velocity transverse station)	. . .	. . .
Superscripts			
R	Random	. . .	. . .
S	Systematic	. . .	. . .
Unit Conversions and Dimensional Constants			
C_1	. . .	459.7°F	273.2°C
C_2	. . .	60 sec/min	1.0 s/s
C_3	. . .	1.0	1.8 °R/K
C_4	. . .	0.672 lbm/ft · sec	1.0 Pa · s
C_5	. . .	1.0 Btu/lbm · °F	4186 J/kg · °C
C_6	. . .	2.96×10^{-4} in. Hg/°F^2	3.25×10^{-3} kPa/°C
C_7	. . .	-1.59×10^{-2} in. Hg/°F	18.6×10^{-3} kPa/°C
C_8	. . .	0.41 in. Hg.	692×10^{-3} kPa
C_9	. . .	2700°F	1500°C
C_{10}	. . .	70.77 lb/ft^2 · in. Hg	10^3 J/m^3 · kPa
C_{11}	. . .	5.193 lb/ft^2 · in. wg	10^3 J/m^3 · kPa
C_{12}	. . .	1097 (lbm/ft · min^2 · in. wg)$^{1/2}$	$\sqrt{2000}$ (m^2/s^2 · kPa)$^{1/2}$
C_{13}	. . .	13.62 in. wg/in. Hg	1.0 kPa/kPa
C_{14}	. . .	745.7 W/hp	10^3 W/kW
C_{15}	. . .	5252 ft · lb · rev/hp · min	($10^3/2\pi$) N · m · rev/kW · s

2.1 SYMBOLS (cont'd.)

Symbol	Description	Unit/Value	
		U.S. Customary	SI
Unit Conversion and Dimensional Constants (cont'd.)			
C_{16}	...	550 ft · lb/hp · sec	N · m/kW · s
C_{17}	...	6354 ft^3 · in. wg/hp · min	1.0 kJ/kW · s
g_c	...	32.17 ft · lbm/lb · sec^2	1.0 kg · m/N · s^2
J	...	778.2 ft · lb/Btu	1.0 J/J
R_o	...	1545 ft · lb/lbm-mol · °R	8314 J/kg-mol · K

NOTES:
(1) in. wg stands for inches water gage
(2) in. wa stands for inches water absolute

2.2 TEMPERATURE

2.2.1 *Absolute temperature* (T) is the value of temperature when the datum is absolute zero. It is measured in kelvins or degrees Rankine. The absolute temperature in degrees Rankine is the temperature in degrees Fahrenheit plus 459.7 and the absolute temperature in kelvins is the temperature in degrees Celsius plus 273.2.

2.2.2 *Static temperature* (t_s, T_s) is the temperature measured in such a way that no effect is produced by the velocity of the flowing fluid. It would be shown by a measuring instrument moving at the same velocity as the moving fluid. Absolute static temperature is used as a property in defining the thermodynamic state of the fluid.

2.2.3 *Total temperature* (t_t, T_t), sometimes called stagnation temperature, is the temperature that would be measured when a moving fluid is brought to rest and its kinetic potential energies are converted to an enthalpy rise by an isoenergetic compression from the flow condition to the stagnation condition. At any point in a stationary body of fluid, the static temperature and the total temperature are numerically equal.

2.2.4 *Dry-bulb temperature* (t_d) is the temperature measured by a dry thermometer or other dry sensor.

2.2.5 *Wet-bulb temperature* (t_w) is the temperature measured by a thermometer or other sensor covered by a water-moistened wick and exposed to gas in motion. When properly measured, it is a close approximation to the temperature of adiabatic saturation.

2.2.6 *Wet-bulb depression* is the difference between the dry-bulb and wet-bulb temperatures at the same location.

2.3 SPECIFIC ENERGY AND PRESSURE

2.3.1 *Specific energy* is energy per unit mass. Specific kinetic energy is kinetic energy per unit mass and is equal to one-half the square of the fluid velocity. Specific potential energy is potential energy per unit mass and is equal to the gravitational acceleration multiplied by the elevation above a specified datum. Fluid pressure divided by density is sometimes called specific pressure energy and is considered a type of specific energy; however, this term is more properly called specific flow work.

2.3.2 *Pressure* is normal force per unit area. Since pressure divided by density may appear in energy balance equations, it is sometimes convenient to consider pressure as a type of energy per unit volume.

2.3.3 *Absolute pressure* is the value of a pressure when the datum is absolute zero. It is always positive.

2.3.4 *Barometric pressure* (p_b) is the absolute pressure exerted by the atmosphere.

2.3.5 *Differential pressure* (Δp) is the difference between any two pressures.

2.3.6 *Gage pressure* is the value of a pressure when the datum is the barometric pressure at the point of measurement. It is the difference between the absolute pressure at a point and the pressure of the ambient atmosphere in which the measuring gage is located. It may be positive or negative.

2.3.7 *Static pressure* (p_s, p_{sa}) is the pressure measured in such a manner that no effect is produced by the velocity of the flowing fluid. Similar to the static temperature, it would be sensed by a measuring instrument moving at the same velocity as the fluid. Static pressure may be expressed as either an absolute or gage pressure. Absolute static pressure is used as a property in defining the thermodynamic state of the fluid.

2.3.8 *Total pressure* (p_t, p_{ta}), sometimes called the stagnation pressure, would be measured when a moving fluid is brought to rest and its kinetic and potential energies are converted to an enthalpy rise by an isentropic compression from the flow condition to the stagnation condition. It is the pressure sensed by an impact tube or by the impact hole of a Pitot-static tube when the tube is aligned with the local velocity vector. Total pressure may be expressed as either an absolute or gage pressure. In a stationary body of fluid, the static and total pressures are numerically equal.

2.3.9 *Velocity pressure* (p_v), sometimes called dynamic pressure, is defined as the product of fluid density and specific kinetic energy. Hence, velocity pressure is kinetic energy per unit volume. If compressibility can be neglected, it is equal to the difference of the total pressure and the static pressure at the same point in a fluid and is the differential pressure which would be sensed by a properly aligned Pitot-static tube. In this Code the indicated velocity pressure (p_{vi}) shall be corrected for probe calibration, probe blockage, and compressibility before it can be called velocity pressure.

2.4 DENSITY

2.4.1 The *density* (ρ) of a fluid is its mass per unit volume. The density can be given static and total values in a fashion similar to pressure and temperature. If the gas is at rest, static and total densities are equal.

2.4.2 *Specific humidity* (s) is the mass of water vapor per unit mass of dry gas.

2.5 FAN BOUNDARIES

The fan boundaries are defined as the interface between the fan and the remainder of the system. These boundaries may differ slightly from fan to fan. The fan accepts power at its input power boundary and moves a quantity of gas from its inlet boundary to its outlet boundary and in the process increases the specific energy and pressure of this gas. The inlet boundary may be specified to include inlet boxes, silencers, rain hoods, or debris screens as a part of the fan. The outlet boundary may be specified to include dampers or a diffuser as a part of the fan. The input power boundary may be specified to include the fan-to-motor coupling or a speed reducer as part of the fan. See Figs. 2.1 and 2.2.

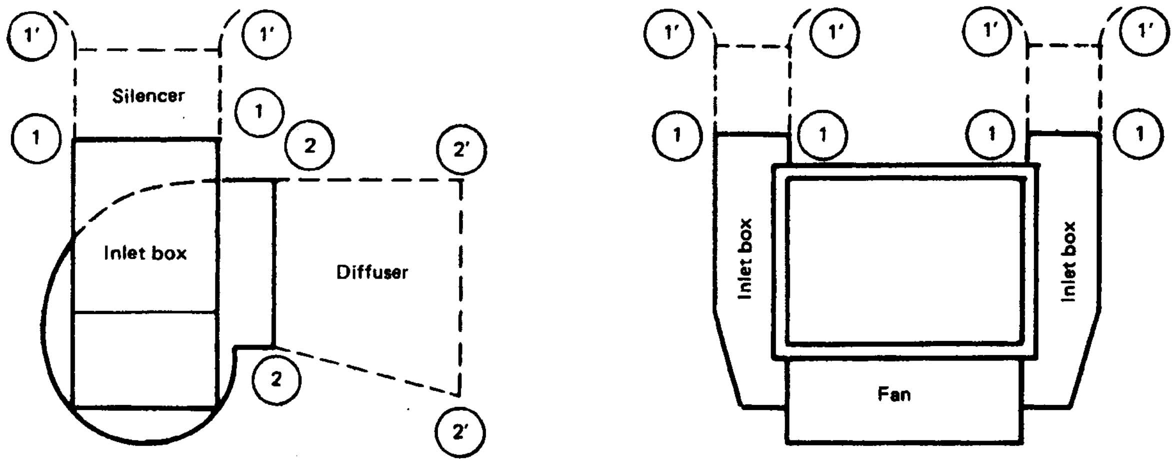
2.6 FAN PERFORMANCE

2.6.1 General. Fan performance can be expressed in terms of different sets of parameters. This Code provides the user with two choices. One set uses mass flow rate and specific energy. The other uses volume flow rate and pressure. The product of mass flow rate and specific energy and the product of volume flow rate, pressure, and a compressibility coefficient are each designated *fan output power*. However, values of output power calculated by the two methods are slightly different [Appendix F, Ref. (1)].

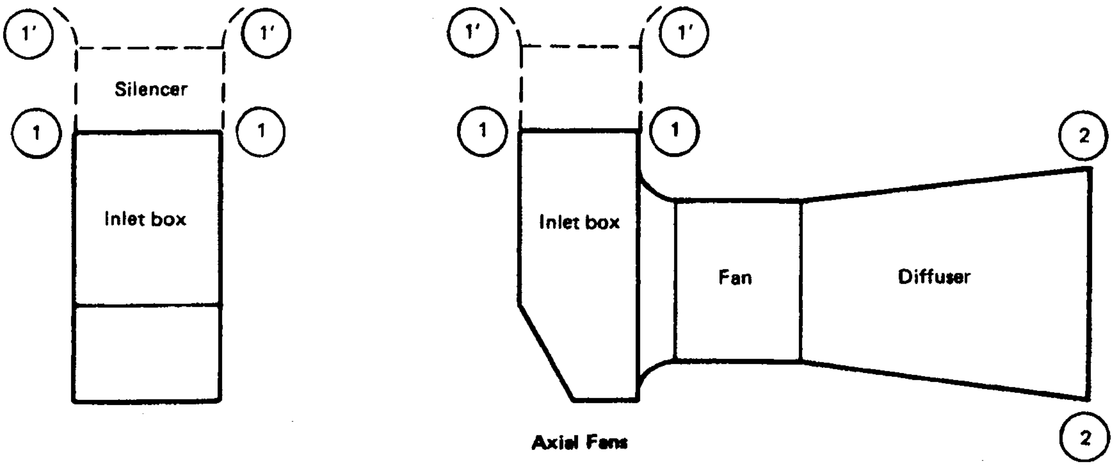
2.6.2 The Mass Flow Rate — Specific Energy Approach. The fan performance parameters that are associated with this approach are defined as follows.

(*a*) *Fan mass flow rate* ($\dot{m}_F$) is the mass of fluid passing through the fan per unit time.

(*b*) *Fan specific energy* (y_F) is the work per unit mass which would be done on the gas in an ideal (frictionless) transition between the actual inlet and outlet states. The ideal work done on a unit mass of fluid is equal to the integral of the differential of the static pressure divided by the fluid density for the fan flow process plus changes of specific kinetic energy and specific potential energy across the fan.



Centrifugal Fans



Axial Fans

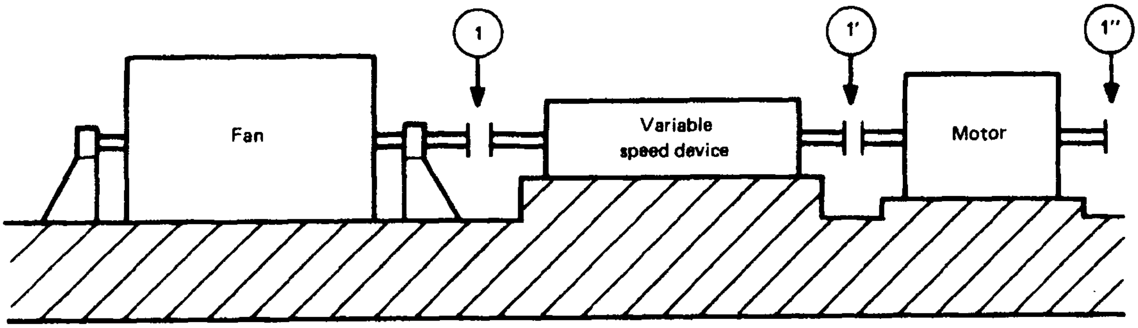
GENERAL NOTES:

The inlet boundary is at ① ① for a centrifugal or axial fan furnished with an inlet box or at (1') (1') if a silencer is considered a part of the fan.

The outlet boundary is at ② ② for a centrifugal fan without a diffuser or at (2') (2') if a diffuser is part of the fan.

An axial fan is usually furnished with a diffuser.

FIG. 2.1 TYPICAL INLET AND OUTLET BOUNDARIES



GENERAL NOTES:

The input power boundary is normally at ①—the point of coupling between the drive train and the fan.

The input power boundary may be at (1')—the point of coupling between the motor and an intermediate drive element, e.g., a variable-speed coupling, the drive element is considered to be a part of the fan.

The input power boundary may be at (1'')—the electrical interface if the entire drive train is considered to be a part of the fan.

FIG. 2.2 TYPICAL INPUT POWER BOUNDARIES

The fan specific energy is the average of the ideal work for all fluid particles passing through the fan. Refer to Par. 5.7 for appropriate averages.

Only the component of velocity in the nominal direction of flow shall be taken into account when determining the specific kinetic energy. It is customary to assume that changes in potential energy are negligible in fans.

$$\left(y_F = \int_1^2 \frac{dp}{\rho} + e_{K2} - e_{K1}\right)$$

For an incompressible flow process, the product of fan specific energy and fluid density is equal to the fan total pressure. For a nonconstant density process, fan specific energy can be approximated by assuming some thermodynamic process within the fan in order to perform the pressure-density integration.

(c) *Kinetic energy correction factor* (α) is a dimensionless factor used to account for the difference between the true average kinetic energy of the fluid and the kinetic energy calculated as one-half the square of the average velocity.

(d) *Fan mean density* (ρ_m) is the ratio of the pressure change across the fan to the thermodynamic path integral of the differential of the pressure divided by the density.

$$\left(\rho_m \equiv (p_2 - p_1) \bigg/ \int_1^2 \frac{dp}{\rho}\right)$$

In this approach, mean density is approximated by the arithmetic mean of inlet and outlet densities.

$$(\rho_m \approx (\rho_1 + \rho_2)/2)$$

(e) *Fan output power* (P_O) is equal to the product of fan mass flow rate and fan specific energy. Since mass flow rate equals the product of volume flow rate and density at a particular plane, fan output power can also be expressed as the product of fan inlet density, fan inlet volume flow rate, and fan specific energy.

(*f*) The *compressibility coefficient* (K_p), defined as the ratio of the fan inlet density to the fan mean density, is useful in this approach.

(*g*) *Fan efficiency* (η) is the ratio of the fan output power to the fan input power. In this approach there is only one definition of fan output power so there is only one definition of fan efficiency.

2.6.3 The Volume Flow Rate — Pressure Approach. The fan performance parameters associated with this approach are defined as follows.

(*a*) *Fan volume flow rate* (Q_F) is the fan mass flow rate divided by the fan gas density.

(*b*) *Fan pressure.* In this approach, three fan pressures are defined:

(*1*) *Fan total pressure* (p_{Ft}) is the difference between the average total pressure at the fan outlet and the average total pressure at the fan inlet. Only the component of velocity in the nominal direction of flow shall be taken into account when determining fan total pressure. Refer to Par. 5.7 for appropriate averages. It is customary to assume that pressure changes due to elevation changes are negligible in fans.

(*2*) *Fan velocity pressure* (p_{Fv}) is the product of the average density and average specific kinetic energy at the fan outlet. Refer to Par. 5.7 for the appropriate averages.

(*3*) *Fan static pressure* (p_{Fs}) is the difference between the fan total pressure and the fan velocity pressure. Therefore, fan static pressure is the difference between the average static pressure at the fan outlet and the average total pressure at the fan inlet. Refer to Par. 5.7 for appropriate averages.

(*c*) *Fan gas density* (ρ_F) is the total density of the gas at fan inlet conditions.

(*d*) *Fan output power* (P_O) equals the product of fan volume flow rate, fan total pressure, and compressibility coefficient K_p.

(*e*) The *compressibility coefficient* (K_p) is a dimensionless coefficient employed to account for compressibility effects [Ref. (4)] and is calculated according to the procedure given in Par. 5.11.4 [Ref. (19)].

(*f*) *Fan efficiency.* In this approach, fan efficiency is expressed as either fan total efficiency or fan static efficiency.

(*1*) *Fan total efficiency* (η_t) is the ratio of fan output power to fan input power. This may also be called total-to-total efficiency.

(*2*) *Fan static efficiency* (η_s) is the ratio of fan output power to fan input power, in which the fan output power is modified by deleting the fan velocity pressure. This may also be called total-to-static efficiency.

2.6.4 *Fan input power* (P_I) is the power required to drive the fan and any elements in the drive train that are considered to be within the fan boundaries.

2.7 FAN OPERATING CONDITIONS

Fan operating conditions are specified by the speed of rotation of the fan, and sufficient information to determine the average gas properties including pressure, temperature, density, viscosity, gas constants, and specific heats at the fan inlet.

2.8 ERRORS AND UNCERTAINTIES

2.8.1 *Error* is the difference between the true value of a quantity and the measured value. The true value of an error cannot be determined.

2.8.2 *Uncertainty* is a possible value for the error [Ref. (2)]. It is also the interval within which the true value can be expected to lie with a stated probability [Ref. (3)]. The uncertainty is used to estimate the error. *Absolute uncertainty* (U) has the same units as the variable in question. *Relative uncertainty* (u), also called *per unit uncertainty,* is absolute uncertainty divided by the magnitude of the variable and is dimensionless.

2.8.3 *Random uncertainty* (U^R, u^R) is uncertainty due to numerous small independent influences that prevent a measurement system from delivering the same reading when supplied with the same input. Random uncertainties can be reduced by replication and averaging [Ref. (3)].

2.8.4 *Systematic uncertainty* (U^S, u^S) is uncertainty due to such things as instrument and operator bias and changes in ambient conditions for the instruments. Systematic uncertainty cannot be reduced by increasing the number of measurements if the equipment and the conditions of measurements remain unchanged [Ref. (3)].

2.8.5 *Confidence level* (ℓ_C) is a percentage value such that, if a very large number of determinations of a variable are made, there is an ℓ_C percent probability that the true value will fall within the interval defined by the mean plus or minus the uncertainty. A value for uncertainty is meaningful only if it is associated with a specific confidence level. As used in this Code, all uncertainties are assumed to be at the 95% confidence level. If the number of determinations of a variable is large and if the values are normally distributed, the uncertainty at the 95% confidence level is approximately twice the standard deviation of the values.

SECTION 3 — GUIDING PRINCIPLES

3.1 INTRODUCTION

In applying this Code to a specific fan test, various decisions must be made. This Section explains what decisions shall be made and gives general guidelines for performing a Code test.

Any test shall be performed only after the fan has been found by inspection to be in a satisfactory condition to undergo the test. The owner and vendor shall mutually decide when the test is to be performed.

The parties to the test shall be entitled to have present such representatives as are required for them to be assured that the test is conducted in accordance with this Code and with any written agreements made prior to the test.

3.2 PRIOR AGREEMENTS

Prior to conducting a Code test, written agreement shall be reached by the parties to the test on the following items:

(*a*) object of test
(*b*) duration of operation under test conditions
(*c*) test personnel and assignments
(*d*) person in charge of test
(*e*) test methods to be used
(*f*) test instrumentation and methods of calibration
(*g*) locations for taking measurements and orientation of traverse ports
(*h*) number and frequency of observations
(*i*) method of computing results
(*j*) values of primary uncertainties
(*k*) arbitrator to be used if one becomes desirable
(*l*) applicable contract performance curves and/or the specified performance and operating conditions
(*m*) fan boundaries
(*n*) number of test runs

3.3 CODE PHILOSOPHY

3.3.1 This Code offers the user the choice of expressing fan performance in terms of mass flow rate and specific energy or volume flow rate and pressure. After reviewing both methods, the parties to the test shall decide which method they intend to use. Once a method is selected then the principles and procedures for only that method shall be adhered to throughout the test, rather than commingling the various aspects of the two methods [Ref. (1)].

3.3.2 The methods of this Code are based on the assumption that fan pressures or specific energies are measured sufficiently close to the fan boundaries that corrections for losses between the measurement planes and the fan boundaries are not required. It is not feasible to include methods for such corrections in this Code; therefore, if such corrections are necessary, the test cannot be a Code test.

For the purpose of determining proper average values of pressure, temperature, and density, it is always necessary to measure point velocities at the fan boundaries. However, only the point velocities measured at traverse planes conforming to the requirements of this Code (see Par. 4.2.3) shall be used for fan flow rate. If the conditions at the fan boundaries do not meet the criteria given in this Code for a suitable flow traverse, then point velocity measurements made at the fan boundaries shall be used only for determining average values of pressure, temperature, density, and specific kinetic energy and not for fan flow rate. If this condition exists, then the fan flow rate may be determined at a plane other than the fan boundary provided that no fluid enters or leaves the duct between the fan boundary and the measurement plane. Although the point velocities measured at the fan boundaries may not conform to the requirements for a valid flow traverse, they can provide a useful statistical basis for substantiating the fan flow rate.

3.3.3 For large ducts handling gas flows, often the only practicable method of gas flow measurement is the velocity traverse method. This method shall be considered the primary method for measuring flows of the type addressed by this Code. Other methods of determining flow, including but not limited to, stoichiometric methods (where applicable), ultrasonic methods, and methods using such devices as flow nozzles, may be permitted if it can be shown that the accuracy of the proposed method is at least equal to that of the primary method.

In the velocity traverse method, the duct is subdivided into a number of elemental areas and, using a suitable probe, the velocity is measured at a point in each elemental area. The total flow is then obtained by summing the contributions of each elemental area. Within the framework of the velocity traverse method, many different techniques have been proposed for selecting the number of points at which velocity is measured, for establishing the elemental areas, and for summing (theoretically integrating) the contributions of each elemental area. Options that have been proposed include the placing of points based on an assumed (usually log-linear) velocity distribution [Refs. (4), (5)], the use of graphical or numerical techniques to integrate the velocity distribution over the duct cross section [Refs. (5), (6)], the use of equal elemental areas with simple arithmetic summing of the contribution of each area to the total flow [Refs. (5), (7), (8)], and the use of boundary layer corrections to account for the thin layer of slow-moving fluid near a wall. As a general rule, accuracy of flow measurement can be increased by either increasing the number of points in the traverse plane or by using more sophisticated mathematical techniques (e.g., interpolation polynomials, boundary layer corrections) [Refs. (5), (7)]. It is more in line with the requirements of field testing as well as more realistic in light of the varied distributions of velocity that may actually occur in the field, to obtain the desired accuracy of flow measurement by specifying measurements at a relatively large number of points rather than by relying on assumed velocity distributions or unsubstantiated assumptions regarding such things as boundary layer effects. For these reasons, this Code has elected to specify measurements at the centroids of equal elemental areas and simple arithmetic summing of the contribution of each elemental area to the total flow. Investigations of flow measurement under conditions similar to those expected in application of this Code have demonstrated the validity of this approach [Refs. (7), (8), (9)].

3.3.4 Due to the highly disturbed flow at the fan boundaries and the errors obtained when making measurements with probes unable to distinguish directionality, probes capable of indicating gas direction and speed, hereinafter referred to as *directional probes,* are generally required. Only the component of velocity normal to the elemental area is pertinent to the calculation of flow. Measurement of this component cannot be accomplished by simply aligning a nondirectional probe parallel to the duct axis, since such probes only indicate the correct velocity pressure when aligned with the velocity vector. Errors are generally due to undeterminable effects on the static (and to a lesser degree, total) pressure sensing holes. Therefore, adequate flow measurements in a highly disturbed region can only be made by measuring speed and direction at each point and then calculating the component of velocity parallel to the duct axis. Only in some circumstances (see Par. 4.7) may nondirectional probes be used.

3.3.5 Various methods of averaging are required to calculate the appropriate values of the parameters that determine fan performance. These methods, along with the large number of traverse points, the directional probe, and requirements for measurements at the fan boundaries make it possible to conduct an accurate field test for most fan installations [Refs. (8), (9), (10)].

3.3.6 The instruments and methods of measurement specified in this Code are selected on the premise that only mild compressibility effects are present in the flow. The velocity, pressure, and temperature determinations provided for in this Code are limited to situations in which the gas is moving with a Mach number less than 0.4. This corresponds to a value of $(K_j\, p_{vi}/p_{saj})$ of approximately 0.1 (see Par. 5.2.1).

3.3.7 Although this Code provides methods for conversion of measured fan performance variables to specified operating conditions, such conversions shall not be permitted if the test speed differs by more than 10% from the specified speed or if the test values of the fan inlet density (ρ_1) or fan gas density (ρ_F) differ by more than 20% from specified values.

3.3.8 A question that invariably arises in connection with any test is "how accurate are the results?" [Ref. (2)]. This question is addressed in this Code by the inclusion of a complete procedure for the evaluation of uncertainties. It is believed that all significant sources of error in a fan test have been identified and addressed in this procedure. Since in fact any results based on measurements are of little value without an accompanying statement of their expected accuracy, uncertainty evaluation is made a mandatory part of this Code.

3.3.9 Commercially quoted fan performance is usually based on measurements made under laboratory conditions. In a laboratory test, a fan is operated in a system specifically designed to facilitate accurate measurement of fan performance parameters and to minimize those system effects that can degrade fan performance [Refs. (4), (17)]. Comparative fan tests conducted according to a laboratory standard [Ref. (4)] and according to procedures of this Code have demonstrated that similar performance ratings can be obtained if the fan is operated under laboratory conditions [Ref. (18)].

The user of this Code should be aware that application of the procedures contained herein will reveal the performance of the test fan as it is affected by the system in which it is installed. These in-situ performance ratings and ratings of the same fan based on laboratory tests or ratings of a model fan based on laboratory tests may not be the same due to various effects generally called *system effects* [Ref. (17)]. Any methods for reconciliation of in-situ performance ratings and laboratory based ratings are beyond the scope of this Code.

3.4 SYSTEM DESIGN CONSIDERATIONS

There are field situations where it is not possible to obtain sufficiently accurate measurements to conform with this Code. Consideration of a few simple concepts when a new system is designed will facilitate fan testing as well as improve the fan system performance.

3.4.1 Generally the most difficult parameter to determine during a field test is the fan flow rate. If the following considerations can be made during the design of the fan and duct system, fan flow rates will be easier to determine.

(*a*) Design of inlet and outlet ducts should avoid internal stiffeners for three equivalent diameters both upstream and downstream of the fan boundaries.

(*b*) Abrupt changes in direction should not be located at the fan boundaries.

(*c*) All transitions in duct size should be smooth.

(*d*) A duct length of approximately 3 ft (1 m) should be allowed at the fan boundaries for inserting probes. This section should be free of internal obstructions which would affect the flow measurement and external obstructions which would impede probe maneuverability such as structural steel, walkways, handrails, etc.

3.4.2 Considerations that can be observed that will aid the determination of fan input power are:

(*a*) installing a calibrated drive train; or

(*b*) allowing sufficient shaft length at the fan for the installation of a torque meter.

3.5 INTERNAL INSPECTION AND MEASUREMENT OF CROSS SECTION

An internal inspection of the ductwork at planes where velocity and/or pressure measurements are to be made shall be conducted by the parties to the test to insure that no obstructions will affect the measurements. Areas where there is an accumulation of dust such that the duct area is significantly reduced shall be avoided as this indicates that the velocities are inadequate to prevent entrained dust from settling. This dust settlement will in effect cause the duct cross-sectional area to decrease during the test. Where this situation exists, it is recommended that velocity measurements be made in vertical runs.

The internal cross-sectional area shall be based on the average of at least four equally spaced measurements across each duct dimension for nominally rectangular ducts, and on the basis of the average of at least four equally spaced diametral measurements for nominally circular ducts. Sufficient equally spaced measurements shall be used to limit the uncertainty in the area to 0.3%. If the duct area is measured under conditions different from operating conditions, suitable expansion or contraction corrections for temperature and pressure shall be made.

3.6 TEST PERSONNEL

3.6.1 A test team shall be selected that includes a sufficient number of test personnel to record the various readings in the allotted time. Test personnel shall have the experience and training necessary to obtain accurate and reliable records. All data sheets shall be signed by the observers. The use of automatic data recording systems can reduce the number of people required.

3.6.2 The person in charge of the test shall direct the test and shall exercise authority over all observers. This person shall certify that the test is conducted in accordance with this Code and with all written agreements made prior to the test. This person may be required to be a registered professional engineer.

3.7 POINT OF OPERATION

This Code describes a method for determining the performance of a fan at a single point of operation. If more than one point of operation is required, a test shall be made for each. The parties to the test must agree prior to the tests on the method of varying the system resistance to obtain the various points of operation. If performance curves are desired, then the parties to the test shall agree beforehand as to the number and location of points required to construct the curves.

3.8 METHOD OF OPERATION DURING TEST

3.8.1 When a system contains fans operating in parallel, the fan to be tested shall be operated in the manual mode during the test and the remaining fans in the system used to follow load variations. The fan to be tested shall be operated at a constant speed with constant damper and vane positions. Various positions may be required for part-load tests.

3.8.2 The system shall be operated to maintain constant gas flows and other operating conditions. For example, for draft fans the boiler load should be steady. Soot blowers should not be cycled on and off during the test. If soot blowing is necessary, it should be used throughout the test. The operation of pulverizers, stokers, baghouses, scrubbers, air heaters, etc., shall not be allowed to affect the results of the test.

3.8.3 Adequate records of the position of variable vanes, variable blades, dampers, or other control devices shall be maintained.

3.9 INSPECTION, ALTERATIONS, ADJUSTMENTS

Prior to the test, the manufacturer or supplier shall have reasonable opportunity to inspect the fan and appurtenances for correction of noted defects, for normal adjustments to meet specifications and contract agreements, and to otherwise place the equipment in condition to undergo further operation and testing. The parties to the test shall not alter or change the equipment or appurtenances in such a manner as to modify or void specifications or contract agreements or prevent continuous and reliable operation of the equipment at all capacities and outputs under all specified operating conditions. Adjustments to the fan that may affect test results are not permitted once the test has started. Should such adjustments be deemed necessary, prior test runs shall be voided and the test restarted. Any readjustments and reruns shall be agreed to by the parties to the test.

3.10 INCONSISTENCIES

If inconsistencies in the measurements are observed during the conduct of the test, the person in charge of the test shall be permitted to take steps to remedy the inconsistency and to continue the test. Any actions in this regard must be noted and are subject to approval by the parties to the test. Any such action shall be fully documented in the test report.

3.11 MULTIPLE INLETS OR DUCTS

If there is more than one fan inlet, measurements shall be obtained at each inlet or in each inlet duct. It is not permissible to measure the conditions at one inlet and assume the conditions are the same for all the inlets. Similarly, if the discharge duct from a fan splits into two or more ducts and it is more practical to measure the conditions downstream of the split, then the conditions in each branch of the duct shall be measured to determine the total flow.

3.12 PRELIMINARY TEST

Prior to performing a Code test, a preliminary test shall be made. The purpose of the preliminary test is to train the observers, to determine if all instruments are functioning properly, and to verify that the system and fan are in proper order to permit a valid Code test. The preliminary test can be considered a Code test if agreed to by the parties to the test and all requirements of this Code are met.

3.13 REFERENCE MEASUREMENTS

For the purposes of determining that the system has reached steady state, verifying the constancy of operating conditions, and verifying that the fan performs at a constant point of operation during the test, the following reference measurements shall be made.

(*a*) speed (N_R)

(*b*) driver power, or some quantity proportional to driver power (e.g., I_R, T_R, W_R, etc.)

(*c*) fan inlet static pressure (p_{1sR})

(*d*) fan outlet static pressure (p_{2sR})

(*e*) fan inlet temperature (T_{1R})

(*f*) fan outlet temperature (T_{2R})

(*g*) total pressure rise across the fan (p_{tR})

(*h*) velocity pressure in either inlet or outlet plane (p_{vR})

The measurement of speed and power made in accordance with the requirements of Section 4 for determining fan performance shall be used for reference purposes. The reference measurements for pressure and temperature shall be in accordance with Section 4 except a single point measurement shall be used for each parameter instead of the sampling grid. For purposes of reference measurements, probes capable of sensing total pressure, static pressure, velocity pressure, and temperature connected to appropriate indicators shall be permanently fixed at central locations in the inlet and outlet planes. These need not be directional probes nor do they have to be calibrated since measurements taken from these probes are for reference purposes only. At 15 min intervals, the reference measurements of temperature and pressure shall be averaged over a 2 min window of time and recorded, preferably on a graph. This may be done manually or automatically.

If the reference measurements indicate a departure from steady conditions at a fixed point of operation which will cause an uncertainty u_{FsX} in excess of 1%, then the test shall be invalidated.

The person in charge of the test shall be solely responsible for deciding when operating conditions are sufficiently constant to begin the test and continue the test.

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SECTION 4 — INSTRUMENTS AND METHODS OF MEASUREMENT

4.1 GENERAL CONSIDERATIONS

4.1.1 Accuracy. The specifications for the selection and calibration of instruments that follow include accuracy requirements. Unless otherwise stated, the specified accuracies are expressed in terms of the maximum uncertainty in any reading due to the instrument based on a minimum confidence level of 95%.

It is a requirement of this Code that the parties to the test agree in advance on the limits of possible measurement errors and test uncertainties. The parties should base their judgments of possible error on the references cited for each instrument, any records pertaining to the instrument to be used, and their collective experience with similar measurements.

4.1.2 Instrument Calibration. All instruments used in a Code test shall be calibrated. It is not necessary to calibrate all instruments specifically for the test if the parties to the test agree on the validity of previous calibrations.

The calibration data for an instrument shall be represented as a continuous function which may be determined by graphically fairing a smooth curve among the calibration points, or by fitting, using the least squares methods, a mathematical curve which has a number of fitting parameters less than or equal to one-half of the number of calibration points. In a polynomial, the fitting parameters are the undetermined coefficients. In a power law formula, e.g., ax^b, a and b are the fitting parameters. The fitting parameters for other cases may be determined in a similar manner.

Where the physical facts dictate, the calibration function may be extrapolated to the origin. Calibration data should cover the entire range of instrument readings, except where extrapolation to zero is indicated. Any other extrapolation requires agreement among the parties.

4.1.3 Monitoring Operational Steadiness. It is a requirement of this Code (see Par. 3.13) that operating conditions and point of operation be held steady during the test. Readings for some of the test parameters, such as rotational speed and input power, can be monitored for operational steadiness. Other test variables, such as velocity and pressure, are not uniformly distributed; therefore, test readings should not be used to monitor operational steadiness. Separate instruments shall, therefore, be used if these variables are to be monitored. Such monitoring instruments shall be held in a fixed position rather than used to traverse the plane.

Monitoring instruments shall be sensitive to changes in the monitored variables that would affect results. However, the accuracy and calibration requirements for the measuring instruments that follow can be relaxed or eliminated for instruments used only for monitoring purposes. It may even be desirable to use instruments with appreciably more damping than would be acceptable for measuring instruments as long as the response is fast enough to adequately indicate departures from operational steadiness.

4.2 TRAVERSE SPECIFICATIONS

4.2.1 Quantities Measured by Traverse. Because the distributions of velocity, pressure, temperature, gas composition, and moisture across the duct cross section are nonuniform, each quantity shall be measured at a sufficient number of points to facilitate the calibration of a proper average value. Point values of all of these quantities are theoretically required at every traverse plane, but this

Code recognizes that the distributions of gas composition and moisture are generally much more uniform than the distributions of velocity, pressure, and temperature. Accordingly, the Code does not require that gas composition and moisture be measured at every point in a traverse plane. Similarly, the Code does not require that these quantities be measured at all traverse planes if there are sound reasons to believe that there will be no change between planes. There may also be cases where the distribution of temperature is quite uniform. The parties may, therefore, agree to relax the requirement for temperature measurements if they are convinced this will have a negligible effect on the results.

4.2.2 Number of Traverse Planes. Two traverse planes are required to determine specific output (fan pressure or fan specific energy), except for the case listed below. The preferred locations for the traverse planes are at the fan inlet and outlet boundaries. However, a slight offset, upstream or downstream, is usually required so that heavy flanges or stiffeners do not have to be penetrated. Similarly, when dampers are located at the fan boundaries, it is more desirable to traverse slightly upstream of these dampers than downstream of them.

Only one traverse plane is required to determine flow rate, but if both the inlet plane and the outlet plane qualify, each should be used. If neither the inlet plane nor the outlet plane qualifies, a third plane will be required for the velocity traverse to determine flow rate.

If at its inlet boundary the fan draws gas from an essentially quiescent region of large volume and the inlet flow path is free from obstructions (e.g., a fan drawing air from the atmosphere or a fan located inside a large room), it is not necessary to traverse the inlet to determine specific output. The inlet total pressure, inlet static pressure, and inlet velocity pressure are all zero if the inlet region pressure is selected as the datum. If the inlet region pressure is not the datum, then the inlet velocity pressure is zero and the inlet total and inlet static pressures are each equal to the inlet region pressure (see Fig. 4.4). However, if such fans are equipped with inlet boxes, the flow can be expected to be quite uniform at the entrance to the inlet box, particularly if equipped with an inlet bell, and this may be the optimum location for a velocity traverse to determine the flow rate.

4.2.3 Qualified Velocity Traverse Planes. To qualify for a velocity traverse for purposes of determining fan flow rate (see Par. 3.3.2), a plane shall meet the following specifications.

(*a*) There shall be no internal stiffeners or other internal obstructions.

(*b*) There shall be no accumulation of dust or debris.

(*c*) The traverse plane shall be at least one damper blade width upstream or ten damper blade widths downstream of a damper.

(*d*) A preliminary velocity traverse shall show that the flow is reversed or essentially stagnant at no more than 20% (preferably 0%) of the elemental areas.

(*e*) There shall be no sudden change in either cross-sectional area or duct direction.

4.2.4 Determination of Sampling Grid. Measurements shall be taken at centroids of equal elemental areas. However, allowing for probe stem droop and the need to avoid outside duct bracing, the probe tip shall be located within a central area the sides of which are no more than 30% of the corresponding dimensions of the elemental area. Similarly, the probe tip may be outside the traverse plane by no more than 30% of the largest elemental area dimension, and then only if the duct area is the same as at the traverse plane. Refer to Figs. 4.1 and 4.2.

The number of test points shall be the larger of the following:

(*a*) 24 points, or

(*b*) not less than one point for every 2 ft^2 (0.2 m^2)

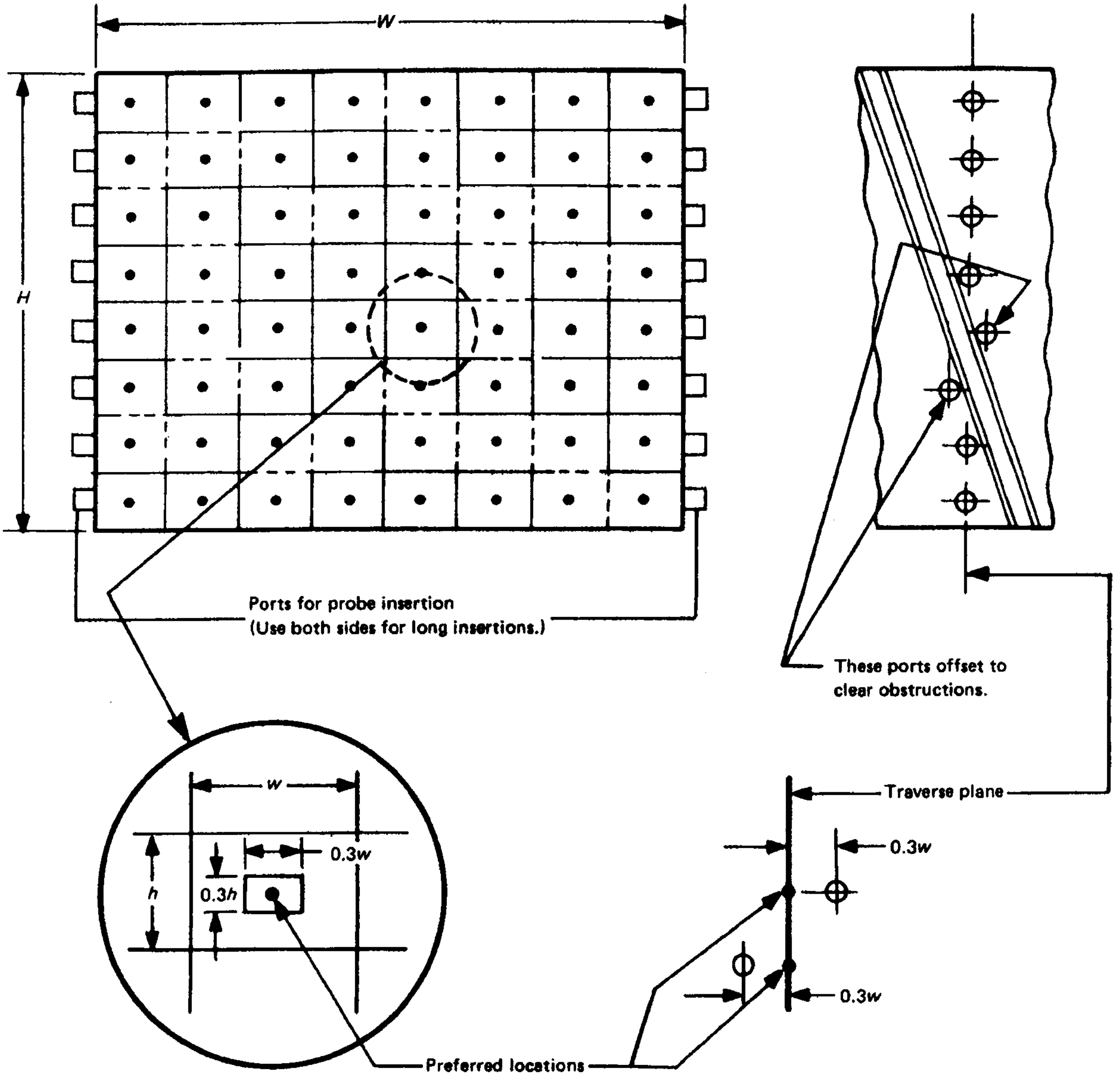
For measurement planes of rectangular and square cross section, the aspect parameter S shall be between ⅔ and ⁴⁄₃ where

$$S = \frac{\text{aspect ratio of elemental area}}{\text{aspect ratio of duct cross section}}$$

The long dimension of the elemental area shall align with the long dimension of the duct cross section.

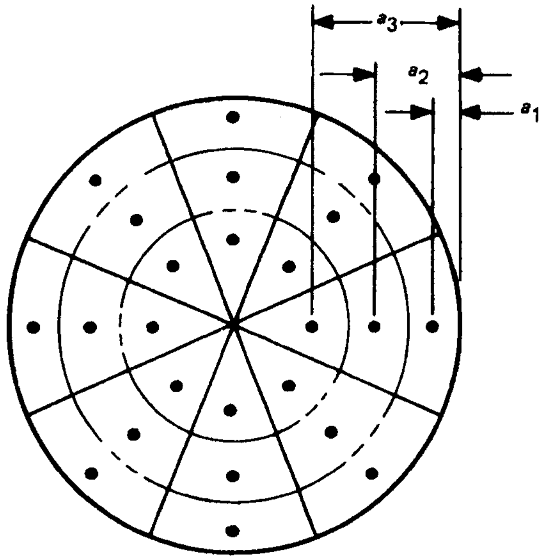
The intent of this specification is to make the elemental areas closely geometrically similar to the duct cross section. [See Ref. (7) and Fig. 4.1.]

For measurement planes of circular cross section, there shall be a minimum of eight equally spaced radial traverse lines (8 radii or 4 diameters), and the distance between adjacent points on any radial line



GENERAL NOTE:
See Par. 4.2.4 for specifications.

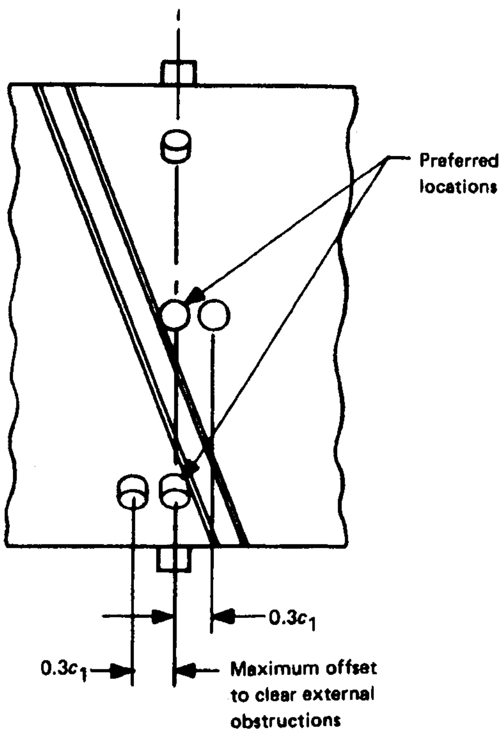
FIG. 4.1 SAMPLING POINT DETAILS (RECTANGULAR DUCT)



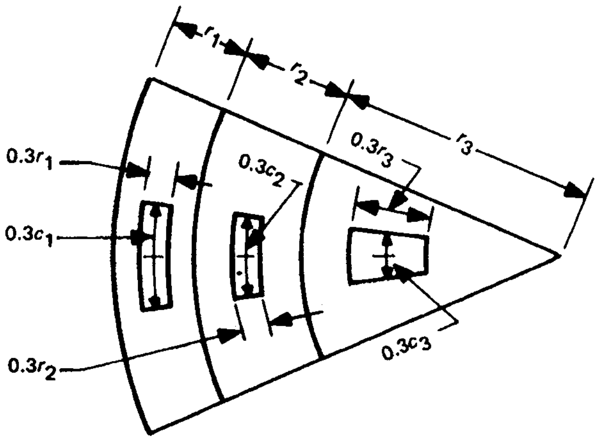
Location of Traverse Points in a Circular Duct

From: $a_n = \frac{D}{2}\left[1 - \sqrt{1 - \left(\frac{2n-1}{2u}\right)}\right]$

where
a = probe penetration
u = number of traverse points each radius
n = point number



Maximum offset to clear external obstructions



Preferred Traverse Zones Along Each Radius

where
r_n = depth in radial direction
d_n = $D - 2a_n$
e = number of radial traverse lines

FIG. 4.2 SAMPLING POINT DETAILS (CIRCULAR DUCT) shall not be less than 0.5 ft (0.15 m). (It may be necessary to increase the number of radial lines to meet this requirement.) Refer to Fig. 4.2.

4.2.5 Orientation of Traverse Ports. Yaw and pitch are the two angles necessary to orient the velocity vector with respect to the nominal direction of flow (normal to the measurement plane). It is desirable, when measuring both yaw and pitch, to measure the larger angle by rotating the probe as explained in Par. 4.9.5. For this reason, the traverse ports should be located in the duct wall or walls which will orient the probes accordingly.

For measurement planes of circular cross section, the traverse ports should be oriented so that the probe stem will be inserted radially.

For measurement planes of rectangular cross section, the traverse ports should generally be oriented so that the probe stem is parallel to the fan shaft. This is particularly appropriate for inlet measurements on either axial or centrifugal fans with inlet boxes. It is also appropriate for outlet measurements on centrifugal fans unless the geometry of the diffuser would suggest otherwise. In any case, the parties should agree in advance to the orientation of the traverse ports. Refer to Figs. 4.3(a) and 4.3(b).

4.3 ATMOSPHERIC PRESSURE

4.3.1 Instruments. The atmospheric pressure shall be measured with a barometer. A Fortin type barometer is generally preferred, but an aneroid type can be acceptable.

4.3.2 Accuracy. The barometer shall have a demonstrated accuracy of plus or minus 0.05 in. Hg (170 Pa).

Readings shall be corrected for temperature and gravity according to the procedures given in PTC 19.2 in the section on barometers.

4.3.3 Calibration. The barometer shall be calibrated in accordance with the section on barometer calibration in PTC 19.2.

4.3.4 Number of Readings. Measurements shall be made in the test vicinity at the beginning of the test and repeated every 15 min until the test is completed. These readings shall be used not only for calculation of results, but for monitoring operational steadiness.

Note that the absolute pressure may vary significantly between two locations, both of which are in the vicinity of the test. For instance, if the fan is installed in a room and the air is drawn through silencers or heaters, the pressure in the room will be lower than that outside. See Fig. 4.4.

4.3.5 Operation. The method of using a barometer is amply covered in the section of barometers in PTC 19.2.

4.4 TEMPERATURE

4.4.1 Instruments. Gas temperatures shall be measured using thermometers or other temperature measuring systems as appropriate. Ordinary liquid-in-glass thermometers are generally preferred for ambient air measurements. Thermocouple systems are generally preferred for measurements in ducts.

4.4.2 Accuracy. The temperature measuring system shall have a demonstrated accuracy of ±2.0°F (±1.0°C). Readings shall be corrected for emergent stem, reference junction temperature, and any other condition which might affect the reading as noted in the appropriate paragraphs of PTC 19.3.

4.4.3 Calibration. Instruments shall be calibrated in accordance with the chapter on calibration of instruments in PTC 19.3.

4.4.4 Number of Readings. Temperature measurements shall be made at each traverse point for each traverse plane. Temperatures can be measured simultaneously with pressures if the thermocouple is attached to the pressure probe so that it does not interfere with other measurements.

If the fan handles ambient air, the air temperature shall be measured in the test vicinity at the beginning of the test and every 15 min until the test is completed. These measurements are used to monitor the operational steadiness and to calculate the results.

4.4.5 Operation. The operation of various temperature measuring systems shall conform to PTC 19.3.

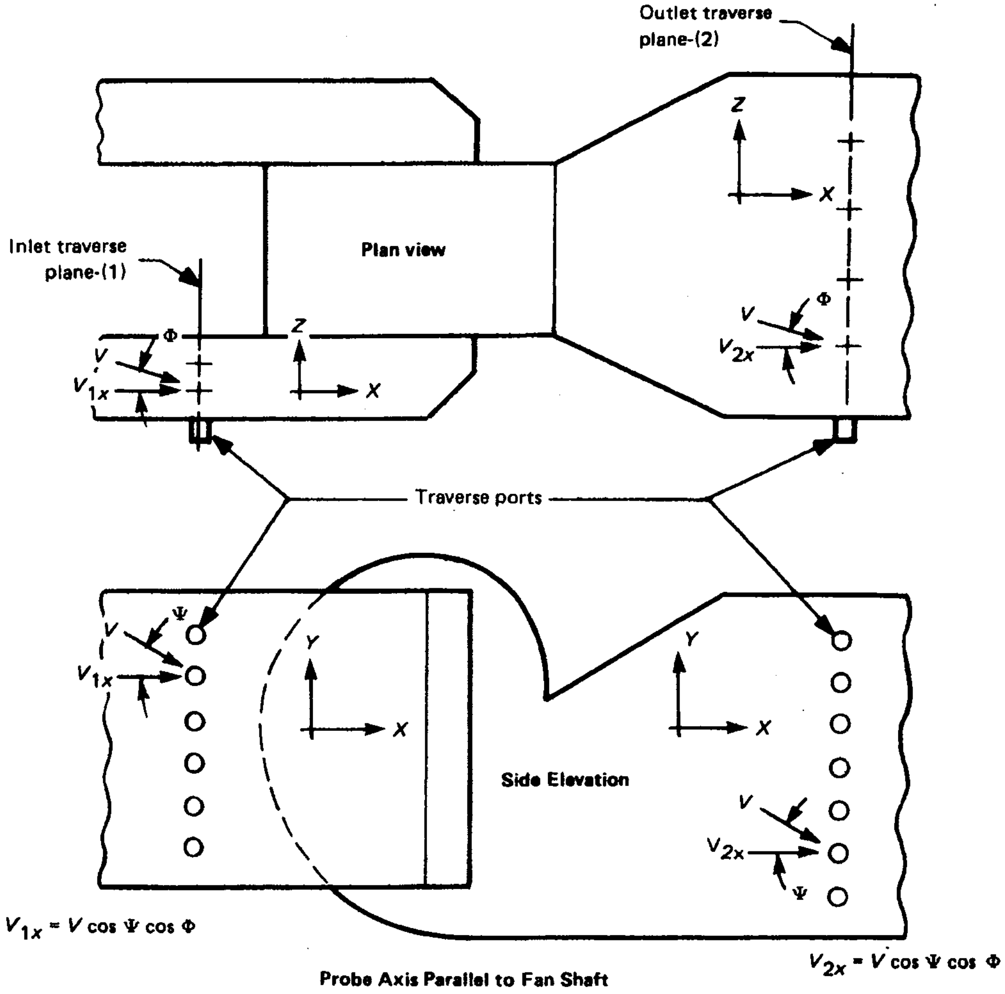


FIG. 4.3(a) PROBE ORIENTATION — CENTRIFUGAL FANS

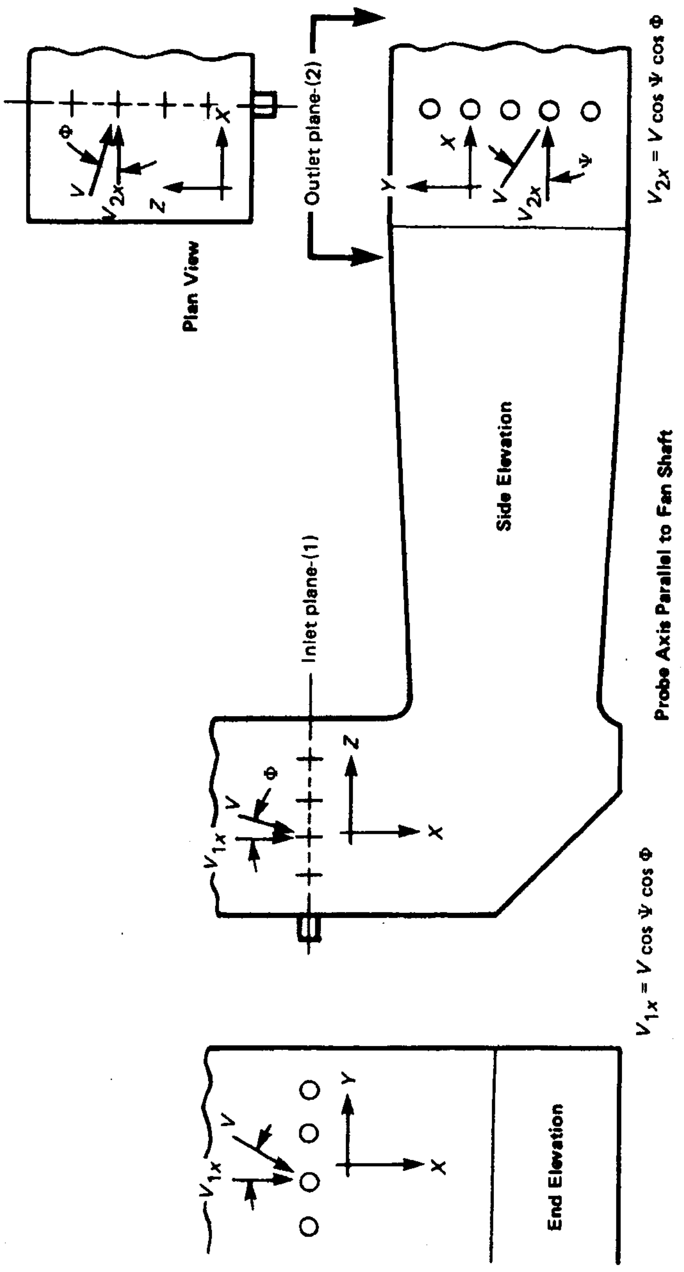


FIG. 4.3(b) PROBE ORIENTATION — AXIAL FANS

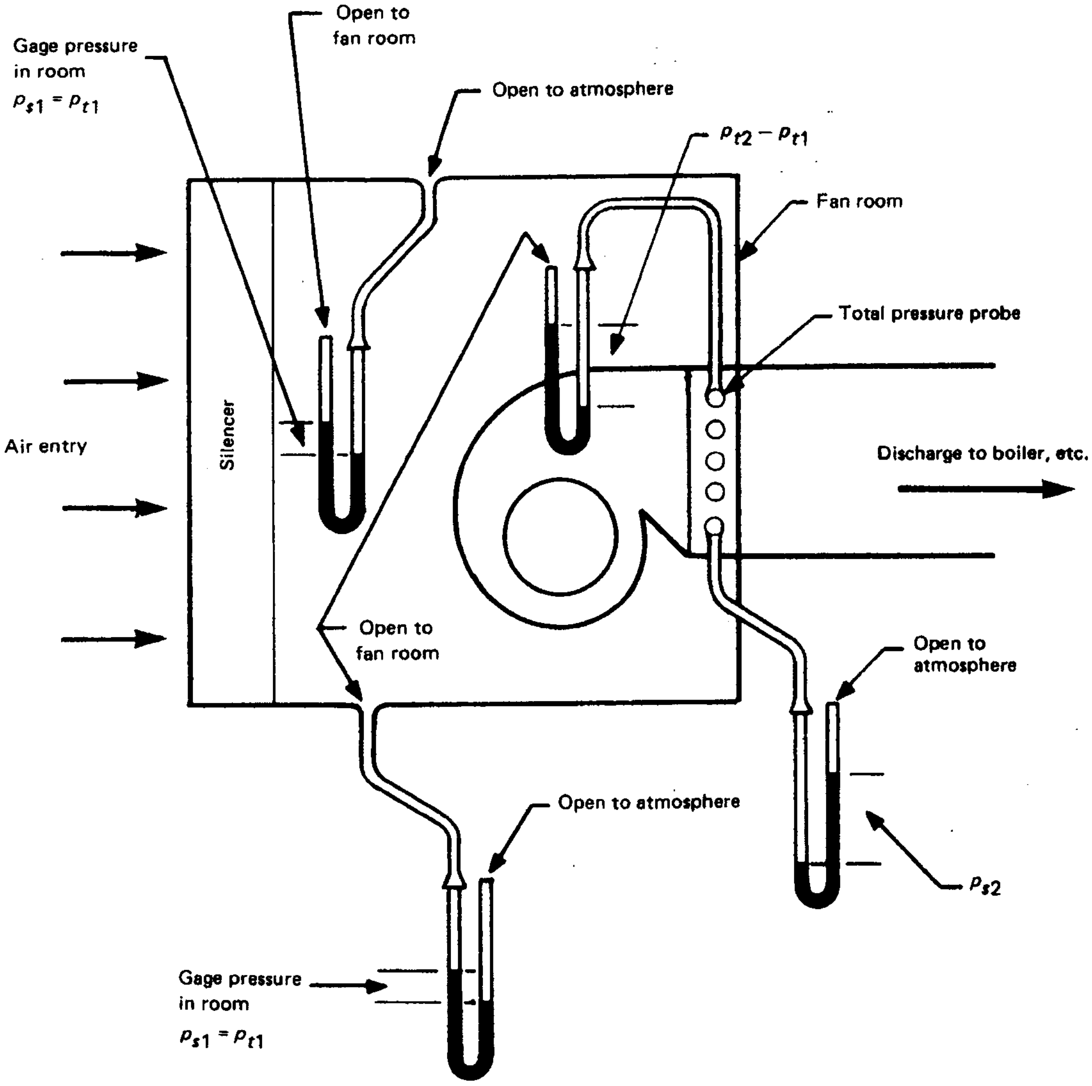


FIG. 4.4 FAN ROOM PRESSURE

4.5 MOISTURE

4.5.1 Instruments. The moisture content of ambient air shall be measured using a psychrometer or other humidity measuring system. A simple sling psychrometer is generally preferred.

The moisture content of other gases shall be measured using a condensation/desiccation sampling train or other moisture measuring system. Stoichiometric methods can also be used in some cases. The condensation/desiccation method is generally preferred because it does not require fuel sampling and analysis.

4.5.2 Accuracy. The humidity measuring system shall have a demonstrated accuracy of 0.001 mass units of water vapor per unit mass of dry gas.

4.5.3 Calibration. The various elements in the moisture measuring system shall each be calibrated according to the procedure for that element in the appropriate PTC 19 Supplement.

4.5.4 Number of Readings. If the fan handles ambient air, the ambient air measurements shall be made in the test vicinity at the beginning of the test and repeated every 15 min until the test is completed. These readings shall be used to monitor operational steadiness and to calculate results. Moisture measurements in other gases shall be made at every other point using every other port for at least one traverse plane. The samples from any port can be mixed before measurement. Even this requirement can be reduced to a single point sample if the parties agree that the preliminary test shows the distribution of moisture is sufficiently uniform.

4.5.5 Operation. The operation of a moisture sampling train shall conform to the Federal Register, Vol. 42, No. 160, August 18, 1977.

4.6 GAS COMPOSITION

4.6.1 Instruments. The composition of air can generally be assumed to be that of normal atmospheric air and measurements need not be made.

The composition of other gases shall be measured by using a sampling train containing a gas analysis system. The Orsat apparatus is generally preferred for flue gas measurements.

4.6.2 Accuracy. The gas composition measuring system shall have a demonstrated accuracy of 0.1% by volume for each major constituent (e.g., 5% ±0.1% for oxygen).

4.6.3 Calibration. The various elements of the gas composition measuring system shall be calibrated against appropriate standards. Certified standard gas samples are available commercially.

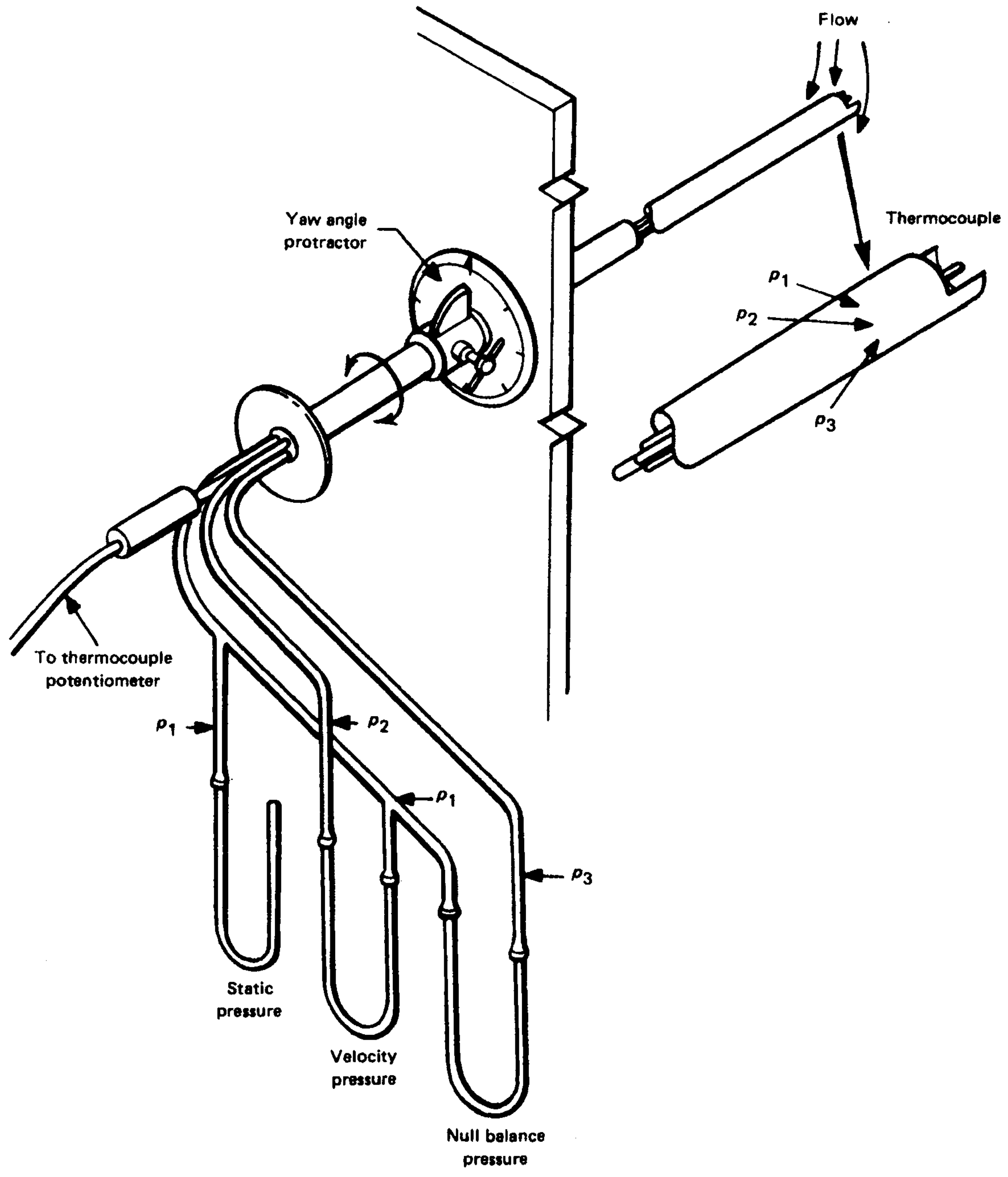
4.6.4 Number of Readings. Gas composition measurements shall be made at every other point using every other port for at least one traverse plane. The samples for any port can be mixed before measurement. Even this requirement can be reduced to a single point sample if the parties agree that the preliminary test shows the distribution of gas composition is sufficiently uniform.

4.6.5 Operation. Operation of flue and exhaust gas analysis systems shall conform to PTC 19.10.

4.7 PRESSURE SENSING

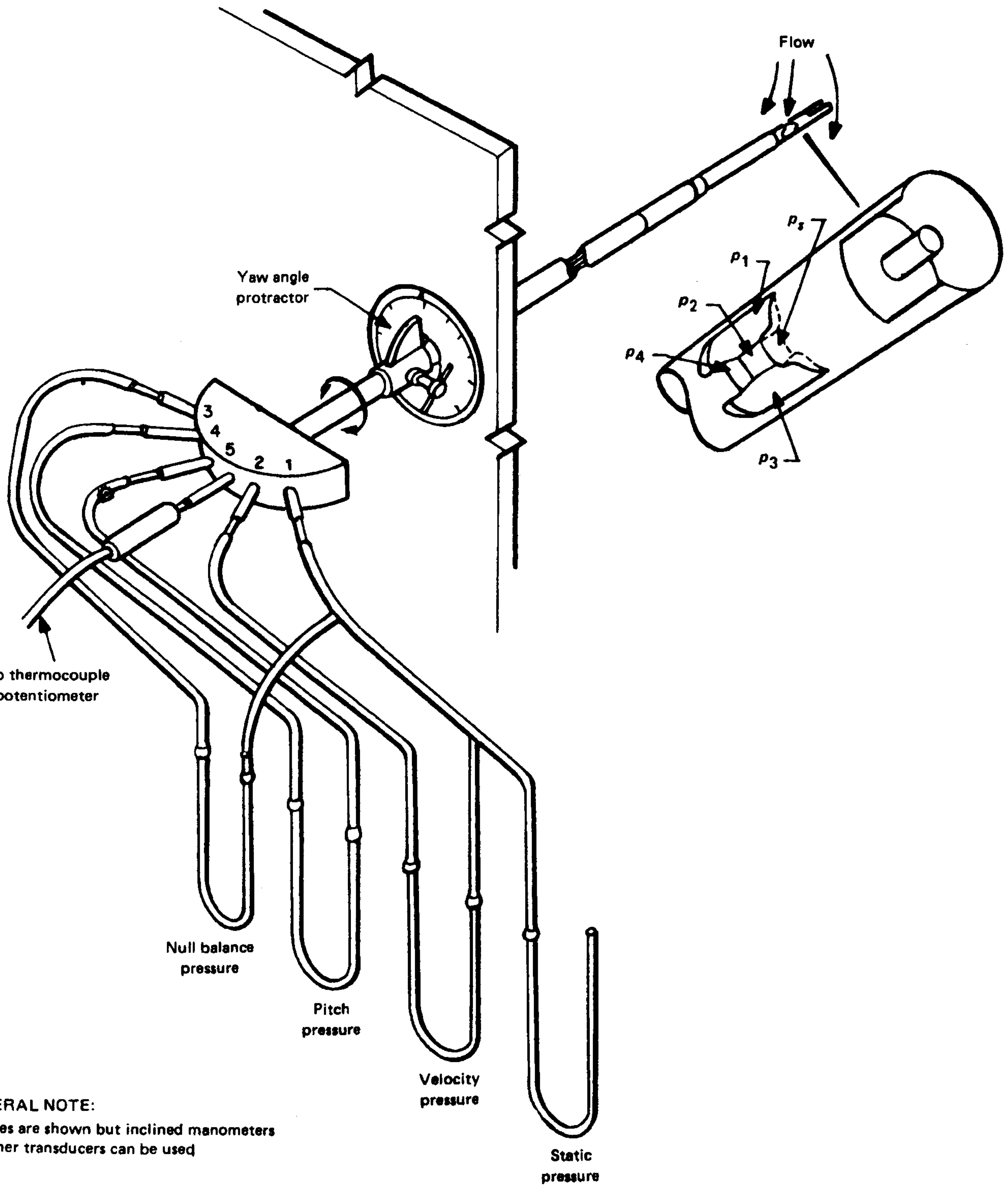
Point values of pressure (velocity, and total or static pressure) shall be measured using a probe that can be positioned at the appropriate points by insertion through one or more ports as required. A probe capable of measuring static pressure, total pressure, their differential, yaw, and pitch is preferred. A probe with only yaw measuring capability can only be used if a preliminary test gives good evidence that pitch does not exceed 5 deg. A nondirectional probe may only be used where the preliminary test gives good evidence that neither yaw nor pitch exceeds 5 deg.

4.7.1 Instruments. Nondirectional probes include Pitot-static tubes and Stauschiebe tubes. The latter are also called type S or forward-reverse tubes. Direction finding probes include the Fechheimer probe which has two holes and is capable of determining yaw angles and static pressure only. A three-hole version of the Fechheimer probe, also called a three-hole cylindrical yaw probe, can be used to determine total pressure (and therefore indicated velocity pressure) as well as the static pressure and yaw. See Fig. 4.5. A five-hole probe is generally required to determine pitch angles as well as the various pressures and yaw angles. See



GENERAL NOTE:
U-tubes are shown but inclined manometers or other transducers can be used.

FIG. 4.5 FECHHEIMER PROBE



GENERAL NOTE:
U-tubes are shown but inclined manometers or other transducers can be used

FIG. 4.6 FIVE-HOLE PROBE

Fig. 4.6. Probes with wedge shapes where the holes are located are slightly preferred over probes with cylindrical shapes throughout, because they are easier to null-balance. See Par. 4.9.5. If more than one probe is present in the measuring plane, the total blockage of all probes shall not exceed 5% of the duct cross-sectional area.

4.7.2 Accuracy. Refer to Par. 4.8 for accuracy of pressure readings and to Par. 4.9 for accuracy of angularity readings.

4.7.3 Probe Calibration. All probes except Pitot-static tubes shall be calibrated. Pitot-static tubes are considered primary instruments and need not be calibrated provided they are maintained in the specified condition described in Ref. (4). The calibration procedures specified in this paragraph apply to pressure measurement only. Calibration of probes for direction sensing is usually carried out simultaneously with calibration for pressure. See Par. 4.9.3 for calibration procedures for direction sensing.

Probe calibration may be carried out in a free stream nozzle jet (see Fig. 4.7) or a closed wind tunnel. In either case, the probe blockage shall be less than 5% of the cross-sectional area. Preferably, the probe blockage should be as small as possible. The flow should be adjusted to produce at least eight equally spaced calibration points.

The calibration reference may be a standard Pitot-static tube (preferred) or a previously calibrated reference probe of another type. The blockage of the reference probe should be as small as possible. In no case shall the blockage of the reference probe exceed 5% of the cross-sectional area.

The reference probe and the test probe shall each be mounted so that they can be placed in the stream alternately and their positions in the stream will be the same and firmly held. When calibrating directional probes, the probe shall be aligned with the stream in order to eliminate yaw according to the null-balance principle described in Par. 4.9.5. Static pressure indication shall be from the appropriate static pressure hole(s) of the reference probe and test probe and not from wall taps (wind tunnel) nor shall it be assumed equal to ambient pressure (free jet). The test probe and reference probe shall be connected to appropriate indicators so that the indicated static pressure p_{si}, indicated total pressure p_{ti}, and their differential, the indicated velocity pressure p_{vi}, can each be recorded for each probe. When calibrating directional probes, the static pressure from each static pressure hole should be observed and any differences noted. The static pressure hole that is used to obtain indicated velocity pressure during the calibration should be noted and the same hole used for subsequent tests.

Probe calibration shall be expressed in terms of a probe total pressure coefficient K_t and a probe velocity pressure coefficient K_v. The probe total pressure coefficient is calculated from the test data by

$$K_t = \frac{(p_{ti})_{\text{ref}}}{(p_{ti})_{\text{test}}}$$

The probe velocity pressure coefficient is calculated from the test data by

$$K_v = \frac{\left(\dfrac{K_{v,\,\text{ref}}}{1 + K_{v,\,\text{ref}}\beta_{\text{ref}}}\right)\left(\dfrac{(p_{vi})_{\text{ref}}}{(p_{vi})_{\text{test}}}\right)}{1 - \dfrac{\beta_{\text{test}}K_{v,\,\text{ref}}}{1 + K_{v,\,\text{ref}}\,\beta_{\text{ref}}}\left(\dfrac{(p_{vi})_{\text{ref}}}{(p_{vi})_{\text{test}}}\right)}$$

where

$$\beta = \pm\frac{(1 - \epsilon_p)}{4(1 - \epsilon_p) - 3}\,(C_D)\left(\frac{S_p}{C}\right)$$

and

$$(1 - \epsilon_p) = 1 - \frac{K_{v,\,\text{ref}}}{2k}\,\frac{(p_{vi})_{\text{ref}}}{(p_{sa})_{\text{ref}}}$$

NOTE: It is recognized that C_D is usually not known to a high degree of accuracy. Lacking specific information, $C_D \approx 1.2$ for probes of cylindrical shape. For a closed wind tunnel, β will be positive; for a free jet, β will be negative.

The equation for K_v includes a correction for probe blockage derived from the analysis presented in Refs. (11) and (12). If the reference probe is a Pitot-static tube, $K_{v,\,\text{ref}} = 1$ and the blockage of both the reference probe and the test probe is negligible ($S_p/C < 0.0005$), the equation for K_v assumes the simplified form

$$K_v = \frac{(p_{vi})_{\text{ref}}}{(p_{vi})_{\text{test}}}$$

The probe total pressure coefficient and the probe velocity pressure coefficient shall be repre-

FIG. 4.7 FREE STREAM NOZZLE JET
(Courtesy of Babcock & Wilcox)

sented as functions of Reynolds Number for nondirectional and three-hole probes and as functions of pitch pressure coefficient, C_ϕ, and Reynolds Number for five-hole probes. See Par. 4.1.2 regarding calibration function.

Calibrated probes should be handled with care because large scratches or nicks near the pressure taps will invalidate the calibration.

4.7.4 Number of Readings. Pressure measurements shall be made at each traverse point for each traverse plane. The indicated velocity pressure and either the total pressure or the static pressure shall be measured. The remaining pressure can be determined arithmetically.

Pressures can be obtained at two or more locations, simultaneously, by using two or more probes as appropriate. It may be desirable to traverse both inlet boxes of a double inlet fan and to traverse from both sides of the outlet, all simultaneously. This would require four probes and four probe crews, but it would significantly reduce the total elapsed time required for the test.

4.7.5 Operation. Refer to Pars. 4.8.5 and 4.9.5.

4.8 PRESSURE INDICATING

4.8.1 Instruments. Manometers or other pressure indicating systems shall be connected to the appropriate taps of the pressure sensing probes to measure point values of pressure. A five-hole probe requires one indicator for velocity pressure, one indicator for static pressure or total pressure, and additional indicators for nulling and pitch determination. (See Par. 4.9 for the latter.) A three-hole probe requires the same indicators, except that for pitch determination. A nondirectional probe requires indicators only for velocity pressure and either static or total pressure. Inclined manometers are generally preferred, but U-tube manometers and other indicators are acceptable if they meet the following specifications.

4.8.2 Accuracy. Pressure measuring systems including the sensor and the indicator shall have a demonstrated accuracy of ±1% of the reading or 0.01 in. wg (2.5 Pa), whichever is larger. Readings shall be corrected for any difference from calibration conditions in specific weight of manometer fluid, gas column balancing effect, or any change in length of the graduated scale due to temperature. However, corrections may be omitted for temperature changes less than 10°F (5°C) from calibration and elevation changes less than 5000 ft (1500 m).

4.8.3 Calibration. Pressure indicating instruments shall be calibrated against a suitable standard. For pressures from 0 to 10 in. wg (0 to 2.5 kPa), calibration shall be against a water-filled hook gage of the micrometer type or a precision micromanometer. When the pressure is above 10 in. wg (2.5 kPa), calibration shall be against a water-filled hook gage of the micrometer type, a precision micromanometer, or water-filled U-tube. Pressure indicating instruments should preferably be calibrated in place, but the parties may agree to a remote calibration in a more suitable laboratory environment. In the latter case, extreme care should be taken to mount the pressure indicating instrument in exactly the same manner for calibration as it is mounted for the test. Calibration points shall be selected to fall at both ends of the expected range and at sufficient intermediate points so that no reading will be more than 0.25 in. wg (60 Pa) removed from a calibration point for inclined manometers or more than 1 in. wg (250 Pa) removed for U-tube manometers.

4.8.4 Number of Readings. Pressure measuring instruments shall be read at each position of the probe as outlined in Par. 4.7.4. Since pressures are seldom strictly steady, the pressure indicated on any instrument will fluctuate with time. In order to obtain a reading, either the instrument shall be damped or the readings shall be averaged in a suitable manner. Averaging can be accomplished mentally, if the fluctuations are small and regular. If the fluctuations are large and irregular, more sophisticated methods shall be used. It is possible to obtain a temporal average electronically when an electrical pressure transducer is the primary element. Even though the spatial average velocity is obtained from the square roots of the temporal average velocity pressures, it is not proper to take the square root of the raw data before temporal averaging as this may introduce a bias into the average values [Ref. (9)].

4.8.5 Operation. For many of the principles of operation, refer to PTC 19.2. Refer to Figs. 4.5 and

4.6 for the proper hose connecting arrangements for probes and indicators. Precautions should be taken to protect the indicator from the effects of wind, sun, and boiler radiant heat. Periodically during the test, probes, hoses, and indicators should be checked for leaks or plugging. Plugging can result from either particulate buildup in the probe or condensation in a portion of the system.

Indicators used for static or total pressure measurement have one tap open to atmosphere. If the indicator is not located in the same atmosphere as the barometer, an additional measurement to determine the difference in pressure is required. See Fig. 4.4.

4.9 YAW AND PITCH

4.9.1 Instruments. Yaw and pitch angles shall be measured using a directional probe equipped with suitable indicating devices. A five-hole probe is preferred as noted in Par. 4.7.1. A three-hole probe may be suitable in some cases. See Figs. 4.5 and 4.6.

4.9.2 Accuracy. The yaw and pitch measuring system shall have a demonstrated accuracy of ±2 deg. each.

4.9.3 Calibration. A reference line shall be scribed on the probe at the time of calibration for pressure response. The protractor scale with which the probe is then equipped can be checked against any high-quality protractor used as a reference. As noted below, the protractor arrangement is only used to measure yaw.

Pitch angles are determined from a pressure measurement obtained with a pressure indicator connected across the fourth and fifth holes of a five-hole probe. Calibration for pitch can be performed in a free stream nozzle jet or in a wind tunnel. The probe shall be precision aligned at various pitch angles and the pressure difference across the taps for the fourth and fifth holes recorded. The flow should be set at several values for each position of the probe and each time the pressure difference across the yaw taps should be nulled.

A calibration function which represents pitch angle as a function of pitch pressure coefficient, C_ϕ ($\equiv$ pitch pressure difference/indicated velocity pressure) and Reynolds Number is derived. See Fig. 4.8.

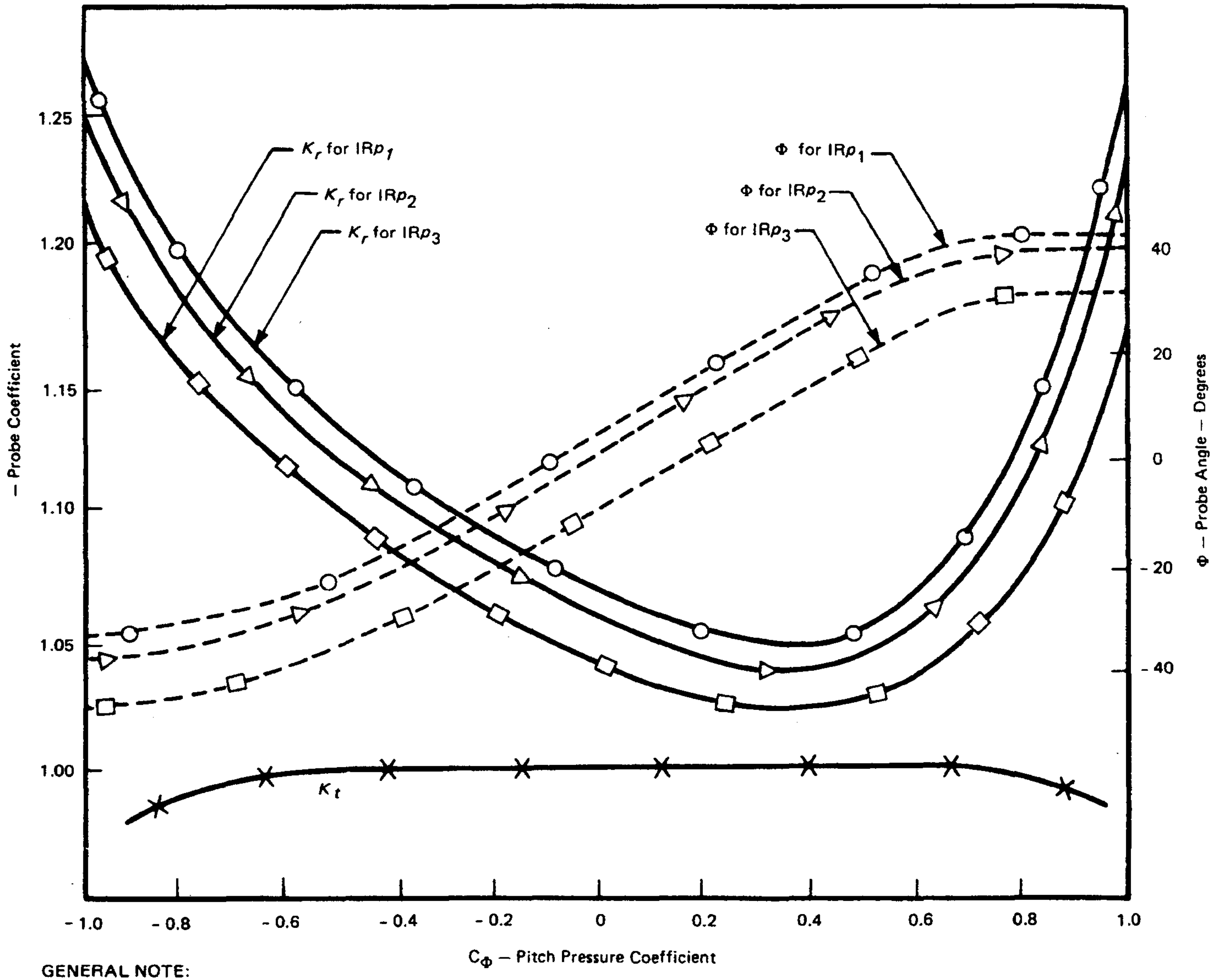
4.9.4 Number of Readings. Yaw and pitch angles shall be measured at each traverse point for each traverse plane. This is the same requirement as for pressures which should be measured simultaneously.

4.9.5 Operation. In operation, a five-hole probe is inserted in the proper port to the proper depth for each traverse point. The probe should be rigid enough over its inserted length to avoid any droop beyond the permissible amount as noted in Par. 4.2.4. The reference line on the probe should be used to orient the probe in such a way that when the total pressure hole is pointing upstream perpendicular to the measuring plane, the indicated yaw angle is zero. The probe is then rotated about its own axis until a null balance is obtained across the taps of the static pressure holes. The angle of probe rotation from the zero yaw reference direction is measured with an appropriate indicator and is reported as the yaw angle. Without changing the angularity of the probe, the pressure difference across the taps for the fourth and fifth holes shall also be recorded and used with the indicated velocity pressure and the pitch pressure coefficient to determine pitch angle. Measurements of indicated velocity pressure and static pressure or indicated velocity pressure and total pressure as outlined in Par. 4.7.4 shall be recorded with the probe in the proper null-balance position. (Note that a null balance can be obtained at four different positions but only one is correct. Incorrect null positions usually correspond to negative velocity pressures.)

A three-hole probe is operated in a similar manner except that the pitch pressure difference is omitted.

4.10 ROTATIONAL SPEED

4.10.1 Instruments. The speed of the fan shall be measured with a speed-measuring system. An electronic counter actuated by a magnetic pulse generator or photoelectric pickup is preferred. Slip counting with stroboscopic light may be acceptable for speeds close to line frequency synchronous speeds. Hand tachometers, mechanical revolution counters, and vibrating-reed tachometers are unacceptable.



GENERAL NOTE:
Actual calibration curves may exhibit discontinuities.

FIG. 4.8 TYPICAL CALIBRATION CURVES FOR A FIVE-HOLE PROBE

4.10.2 Accuracy. The speed-measuring system shall have a demonstrated accuracy of ±0.1% or ±1 rpm, whichever is smaller.

4.10.3 Calibration. Speed-measuring instruments shall be calibrated against the line frequency of a suitable major power circuit or other frequency standard.

4.10.4 Number of Readings. Fan speed shall be measured at the beginning of the test and every 15 min until the conclusion of the test. These readings shall be used to monitor operational steadiness as well as for calculations.

4.10.5 Operation. The electronic counter should be equipped with a digital readout and may be equipped with a recorder and an automatic averager.

With the slip method, the shaft must be marked with a reference line or other mark that is easily visible under stroboscopic light flashing at line frequency. The mark will appear to slowly rotate opposite shaft rotation and permit visual observation of the slip frequency. A stopwatch shall be used to measure the time for at least ten rotations of the mark. Average slip frequency is derived by dividing the total number of mark rotations by the measured time interval for which the counts were made.

See PTC 19.13 for further information on the measurement of rotary speed.

4.11 INPUT POWER

4.11.1 Instruments. The fan input power shall be derived from measurements of torque with a torque meter, or measurements of electrical input when a calibrated electric motor is used, or other suitable measurements if the fan is driven by some other calibrated prime mover and drive train. Both the torque meter and the calibrated prime mover measurements qualify as preferred methods. If a torque meter cannot be used and if the drive train is not calibrated prior to installation, the parties to the test must agree upon a method of estimating the drive train losses. Also, it must be noted that various methods and procedures for calibrating the drive train may result in accuracies which are unacceptable for this Code. The parties to the test and the party responsible for the calibration must agree beforehand to the method of calibration and the expected accuracy. (See Section 5 of PTC 19.7-1980.)

Since the temperature rise through a fan is generally not large enough to permit accurate measurement and since heat transfer losses through the casing are indeterminate, the heat balance method is not acceptable for determining fan input power.

4.11.2 Accuracy. The input-power-measuring system shall have a demonstrated accuracy of ±1%.

4.11.3 Calibration. A torque meter shall be calibrated in accordance with the provisions of PTC 19.7.

The drive train in the context of this Code includes the driver, whether it be electric motor or steam turbine or other prime mover, and any intermediate elements, such as gear boxes and variable speed drives. The drive train may be calibrated as a unit or the driver and any intermediate elements may be separately calibrated. Calibration procedures as given in the following documents shall be followed as appropriate.

ANSI/IEEE 112-78	Test Procedure for Polyphase Induction Motors and Generators
IEEE 115-65	Test Procedure For Synchronous Machines
IEEE 113-72	Test Code for Direct Current Machines With Supplement 113A-76
ASME PTC 6S	Simplified Procedures for Routine Performance Tests of Steam Turbines
ASME PTC 17	Reciprocating Internal Combustion Engines
ASME PTC 18	Hydraulic Prime Movers
ASME PTC 19.7	Measurement of Shaft Power
ASME PTC 22	Gas Turbine Power Plants

Calibration shall be performed under specified operating conditions and a range of loads sufficient to cover the anticipated test conditions.

4.11.4 Number of Readings. Torque or electrical input shall be measured at the start of the test and at least every 15 min until the conclusion of the test. These readings shall be used to monitor operational steadiness as well as for calculations.

TABLE 4.1 SUMMARY OF INSTRUMENTATION REQUIREMENTS

Measurement	Instrument	Accuracy	Frequency of Readings	Reference	Paragraph No.
Atmospheric pressure	Barometer	±0.05 in. Hg ±170 Pa	15 min	PTC 19.2	4.3
Temperature	Thermometer or thermocouple	±2.0°F ±1.0°C	Each traverse point	PTC 19.3	4.4
Moisture	Psychrometer or condensation/ desiccation	0.001 lbm/lbm gas 0.001 kg/kg gas	Air 15 min Gas alternate traverse points	PTC 19.10 PTC 38	4.5 4.5
Gas analysis	Orsat or electronic analyzers	0.1% by volume	Alternate traverse points	PTC 19.10	4.6
Pressure	Manometer or pressure indicator	Larger of ±1.0% or ±0.1 in. wg ±2.5 Pa	Each traverse point	PTC 19.2	4.8
Yaw angle	Protractor	±2.0 degree	Each traverse point	. . .	4.9
Pitch angle	(See Pressure)	. . .	Each traverse point	. . .	4.8 and 4.9
Speed	Magnetic pulse Fiber optic or slip	Smaller of ±0.1% or ±1 rpm	15 min	PTC 19.13	4.10
Power	Torque meter or calibrated drive	±1.0%	15 min	PTC 19.7 PTC 19.6	4.11

4.11.5 Operation. Operation of prime movers is covered in the various Standards listed in Par. 4.11.3. Operation of the instruments for measuring the output of these prime movers is covered in various supplements on instruments and apparatus. Electrical instruments shall conform to ANSI C 39.1, Requirements for Analog Indicating Instruments. A wattmeter and voltmeter or an ammeter, voltmeter, and power factor meter may be used together with the necessary instrument transformers. Refer to PTC 19.6, Electrical Measurements in Power Circuits, for instructions. Meter ranges and transformer ratio shall be such as to produce readings above ⅓ full scale. Instruments shall have full-scale accuracy of 0.5% or better. They shall be used in the same position as rated (usually horizontal). Care should be taken to maintain instruments at a uniform and constant temperature near the calibration temperature; otherwise, corrections shall be made according to manufacturer's instructions regarding lead wires, waveform, etc.

The preferred location for taking electrical measurements is at the terminals of the motor. If this is not possible, then allowance shall be made for the drop in potential between the point of measurement and the motor terminals. Care shall be taken to measure motor power only and not include any auxiliary's power.

SECTION 5 — CALCULATIONS

5.1 GENERAL CONSIDERATIONS

The results of the test shall be calculated in accordance with the appropriate paragraphs of this Section and any prior agreement reached by the parties regarding computation of results. The following paragraphs are intended to cover all possible cases but it is not necessary to use every paragraph for any particular case. For instance, it is not necessary to refer to the paragraphs on products of combustion if the test gas is air. Similarly, only the paragraph on computing power which corresponds to the method of power measurement shall be used. Various other calculations may be omitted depending on whether mass flow rate and specific energy or volume flow rate and fan total pressure are used to express fan performance. The data to be used in the calculations are the measured values of pressure and temperature at various planes, the fan input power measurements, various geometric information (primarily duct areas at measurement planes), and information used to determine gas composition.

5.1.1 Calibration Corrections. Temporal averaging shall be performed prior to correcting for calibrations. Calibration corrections shall be applied to individual readings before spatial averaging or other calculations.

5.1.2 Average Values. Recognizing that nonuniform velocity distribution and temperature or composition stratification are normal on large fans, the appropriate volume-flow-weighted or mass-flow-weighted average values at the traverse planes must be used for determinations of fan performance [Ref. (10)].

5.2 CORRECTION OF TRAVERSE DATA

Difficulties arise in employing traverse data in calculations as these data usually must be corrected for probe calibration and possibly for blockage and compressibility as well. The probe calibration coefficients K_t and K_v are generally functions of the probe Reynolds Number $\mathbb{R}_p$, which is determined by actual gas velocity V, density ρ, and viscosity μ at the probe location. They are also slightly dependent upon specific heat ratio k. As these four quantities are determined only from the measurements themselves, an iteration procedure may be necessary. Such a procedure would be as follows.

(*a*) Select provisional values of K_{tj}, K_{vj} and k (see Par. 5.2.1).

(*b*) Correct the traverse readings for calibration and, if necessary, probe blockage and compressibility (see Par. 5.2.2).

(*c*) Proceed with calculations.

(*d*) After determining gas composition (see Par. 5.3), densities (see Par. 5.4), and velocities (see Par. 5.5.1) at all points in a traverse plane, calculate Reynolds Number (see Par. 5.2.2) at all points and determine new values of K_{tj} and K_{vj}.

(e) If new values of K_{tj} and K_{vj} are significantly different from the old values, then the process must be repeated.

The probe calibration coefficients are also a function of pitch pressure coefficient (C_ϕ); however, this dependency does not affect the iteration process.

5.2.1 Guidelines for Initial Estimation of Probe Coefficient. To begin calculations, initial values of K_{tj} and K_{vj} must be selected. The selection of an appropriate value makes the calculation procedure converge more rapidly, often making iteration unnecessary. Following are guidelines to help the initial selection of K_{tj} and K_{vj}.

(*a*) For Pitot-static probe, K_{tj} and $K_{vj} = 1.0$ and need not be changed.

(*b*) For other probes, the K_{tj} and K_{vj} versus $\mathbb{R}_p$ curves should be relatively flat in the range of interest, hence any reasonable first estimates of K_{tj} and K_{vj} should produce satisfactory results. The following ideas are suggested.

(*1*) Select the values of K_{tj} and K_{vj} at the middle of the range of calibration data, or

(*2*) Use an average K_{tj} and K_{vj} value based on the calibration data, or

(*3*) Estimate $\mathbb{R}_p$ from specified fan conditions and use corresponding K_{tj} and K_{vj} values, or

(*4*) Estimate $\mathbb{R}_p$ from a typical point in the traverse data and use the corresponding K_{tj} and K_{vj} values.

5.2.2 Correction for Probe Calibration, Probe Blockage, and/or the Effects of Compressibility. Measured values from traverses are t_i, p_{vi} and p_{si} or p_{ti}. The remaining pressure can be calculated from $p_{ti} = p_{si} + p_{vi}$. Corrected values, (subscript *j*) at each point shall be obtained from the measured values, (subscript *i*) at that point and probe coefficients K_{tj} and K_{vj} using

$$p_{tj} = K_{tj} p_{ti} \tag{5.2-1}$$

$$K_{vjc} = \frac{K_{vj}}{1 + \beta_j K_{vj}} \tag{5.2-2}$$

$$p_{sj} = K_{tj} p_{ti} - K_{vjc} p_{vi} \qquad \text{or}$$

$$p_{sj} = K_{vjc} p_{si} - (K_{vjc} - K_{tj})\, p_{ti} \tag{5.2-3}$$

$$p_{saj} = p_{sj} + C_{13} p_b \tag{5.2-4}$$

$$p_{vj} = K_{vjc}(1 - \epsilon_p)\, p_{vi}$$

$$(p_{vj} = 0 \text{ for reverse flow) and} \tag{5.2-5}$$

$$T_{sj} = T_i/(1 + \epsilon_T) \qquad \text{where } (T_i = t_i + C_1) \tag{5.2-6}$$

β_j is used to correct for probe blockage and is calculated by

$$\beta_j = \frac{C_D(1 - \epsilon_p)}{4(1 - \epsilon_p) - 3}\, \frac{S_{pj}}{A} \tag{5.2-7}$$

In these equations, $(1 - \epsilon_p)$ and $(1 + \epsilon_T)$ are compressibility corrections and are calculated by

$$(1 - \epsilon_p) = 1 - \frac{1}{2k}\left(\frac{K_{vjc} p_{vi}}{p_{saj}}\right) \tag{5.2-8}$$

and

$$(1 + \epsilon_T) = 1 + 0.85\,\frac{k-1}{k}\left(\frac{K_{vjc}p_{vi}}{p_{saj}}\right) \tag{5.2-9}$$

provided that $(K_{vjc}p_{vi}/p_{saj})$ does not exceed 0.1. See Par. 3.3.6.

NOTE: The recovery factor of the temperature sensor is assumed to be 0.85 [Ref. (13)].

5.3 GAS COMPOSITION

For the purposes of this Code, it is sufficient to use a uniform gas composition and uniform values of molecular weight, specific heats, and viscosity to characterize any particular plane. These values shall be determined by arithmetic averaging of gas composition data and the use of arithmetic averages of measured temperatures in the plane in question where temperatures are needed to determine the appropriate gas properties.

5.3.1 Arithmetic Averages of Composition and Property Data. The average volume fraction of constituent $(X)_x$ at plane x shall be calculated from the point value $(X)_j$ using

$$(X)_x = \frac{1}{n}\sum_{j=1}^{n}(X)_j \tag{5.3-1}$$

The average temperature T_x at plane x (to be used only for purposes of defining gas composition and properties) shall be calculated from the point values T_j using

$$T_x = \frac{1}{n}\sum_{j=1}^{n}T_j \tag{5.3-2}$$

5.3.2 Molecular Weight and Specific Humidity. The molecular weight of dry air is 28.965. The molecular weight of dry gas $\mathbb{M}_{dg}$ shall be calculated from the average volume fractions $(X)_x$ using

$$\mathbb{M}_{dg} = 44.01(CO_2) + 28.02(N_2) + 28.01(CO) + 32.00(O_2) + \cdots \tag{5.3-3}$$

The molecular weight of moist gas $\mathbb{M}_x$ at plane x shall be calculated from

$$\mathbb{M}_x = \frac{1}{\dfrac{s}{18.02(1+s)} + \dfrac{1}{\mathbb{M}_{dg}(1+s)}} \tag{5.3-4}$$

The specific humidity s of moist atmospheric air can be calculated from the wet-bulb t_w and dry-bulb t_d temperature measurements using

$$s = \frac{s_w(h_{fg})_w - c_{pdg}(t_d - t_w)}{(h_g)_d - (h_f)_w} \tag{5.3-5}$$

and

$$s_w = \frac{18 p_e}{\mathbf{M}_{dg}(p_b - p_e)} \qquad (5.3\text{-}6)$$

These equations can also be used to calculate the specific humidity of any other wet gas, provided reliable wet-bulb and dry-bulb temperature measurements can be made. Refer to the ASME Steam Tables for values of h_{fg}, h_g, h_f, and p_e. Refer to Eq. (5.3-12) for the calculation of the specific heat of the dry gases (C_{pdg}).

In the event a condensation/desiccation method is used to measure moisture content, a calculation method appropriate to the measurement method shall be used.

5.3.3 Specific Heat [Ref. (14)]. The specific heat of dry air $c_{p\,\mathrm{air}}$ shall be computed from

$$c_{p\,\mathrm{air}} = C_5\left[0.343 - \frac{1.253}{(C_3T)^{1/2}} - \frac{83.76}{(C_3T)} + \frac{3.087 \times 10^4}{(C_3T)^2}\right] \qquad (5.3\text{-}7)$$

The specific heat of the dry gas c_{pdg} shall be computed from the component specific heats c_{pX} using

$$c_{pCO_2} = C_5 \frac{16.2 - \dfrac{6.53 \times 10^3}{(C_3T)} + \dfrac{1.4 \times 10^6}{(C_3T)^2}}{44.01} \qquad (5.3\text{-}8)$$

$$c_{pO_2} = C_5 \frac{11.515 - \dfrac{172}{(C_3T)^{1/2}} + \dfrac{1530}{(C_3T)}}{32.0} \qquad (5.3\text{-}9)$$

$$c_{pN_2} = C_5 \frac{9.47 - \dfrac{3.47 \times 10^3}{(C_3T)} + \dfrac{1.16 \times 10^6}{(C_3T)^2}}{28.02} \qquad (5.3\text{-}10)$$

$$c_{pCO} = C_5 \frac{9.46 - \dfrac{3.29 \times 10^3}{(C_3T)} + \dfrac{1.07 \times 10^6}{(C_3T)^2}}{28.01} \qquad (5.3\text{-}11)$$

$$c_{pdg} = \frac{44.01(CO_2)c_{pCO_2} + 32.00(O_2)c_{pO_2} + 28.02(N_2)c_{pN_2} + 28.01(CO)c_{pCO} + \cdots}{\mathbf{M}_{dg}} \qquad (5.3\text{-}12)$$

The specific heat of the water vapor c_{pH_2O} shall be calculated from

$$c_{pH_2O} = C_5 \frac{19.86 - \dfrac{597}{(C_3T)^{1/2}} + \dfrac{7500}{(C_3T)}}{18} \qquad (5.3\text{-}13)$$

The specific heat of moist air c_{pma} shall be calculated from

$$c_{pma} = c_{p_{air}} \frac{1}{1+s} + c_{pH_2O} \frac{s}{1+s} \tag{5.3-14}$$

The specific heat of the wet gas c_{pwg} shall be calculated from

$$c_{pwg} = c_{pdg} \frac{1}{1+s} + c_{pH_2O} \frac{s}{1+s} \tag{5.3-15}$$

5.3.4 Specific Gas Constant and Specific Heat Ratios. The specific gas constant R shall be calculated from the molecular weight $\mathbb{M}_x$ and the universal constant R_o using

$$R = \frac{R_o}{\mathbb{M}_x} \tag{5.3-16}$$

The specific heat ratio k is

$$k = \frac{c_j^p}{c_j^p - R} \tag{5.3-17}$$

5.3.5 Viscosity [Ref (15)]. The viscosity of air μ_{air} shall be calculated from

$$\mu_{air} = C_4 \frac{10.874\,(C_3T)^{3/2}}{C_3T + 199} \times 10^{-7} \tag{5.3-18}$$

The viscosities of the gas components μ_X shall be calculated from

$$\mu_{CO_2} = C_4 \frac{12.721\,(C_3T)^{3/2}}{(C_3T + 515.04)} \times 10^{-7} \tag{5.3-19}$$

$$\mu_{CO} = C_4 \frac{10.86\,(C_3T)^{3/2}}{(C_3T + 214.72)} \times 10^{-7} \tag{5.3-20}$$

$$\mu_{N_2} = C_4 \frac{10.75\,(C_3T)^{3/2}}{(C_3T + 204.67)} \times 10^{-7} \tag{5.3-21}$$

$$\mu_{O_2} = C_4 \frac{13.11\,(C_3T)^{3/2}}{(C_3T + 238.54)} \times 10^{-7} \tag{5.3-22}$$

$$\mu_{H_2O} = C_4 \frac{12.03\,(C_3T)^{3/2}}{(C_3T + 987.4)} \times 10^{-7} \tag{5.3-23}$$

The viscosity of moist air μ_{ma} shall be calculated from

$$\mu_{ma} = \left\{ \sqrt{28.965}\,\mu_{air} + \sqrt{18.02}\,\frac{28.965s}{18.02}\,\mu_{H_2O} \right\} \Big/ \left\{ \sqrt{28.965} + \sqrt{18.02}\,\frac{28.965s}{18.02} \right\} \tag{5.3-24}$$

The viscosity of the moist gas μ_{mg} shall be calculated from

$$\begin{aligned}\mu_{mg} = \Big\{ & \sqrt{44.01}\,(\mathrm{CO_2})\,\mu_{\mathrm{CO_2}} + \sqrt{32.00}\,(\mathrm{O_2})\,\mu_{\mathrm{O_2}} + \sqrt{28.01}\,(\mathrm{CO})\,\mu_{\mathrm{CO}} \\ & + \sqrt{28.02}\,(\mathrm{N_2})\,\mu_{\mathrm{N_2}} + \cdots + \sqrt{18.02}\left[\frac{s\,\mathbb{M}_{dg}}{18.02}\right]\mu_{\mathrm{H_2O}}\Big\} \Big/ \\ & \Big\{\sqrt{44.01}\,(\mathrm{CO_2}) + \sqrt{32.00}\,(\mathrm{O_2}) + \sqrt{28.01}\,(\mathrm{CO}) \\ & + \sqrt{28.02}\,(\mathrm{N_2}) + \cdots + \sqrt{18.02}\left[\frac{s\,\mathbb{M}_{dg}}{18.02}\right]\Big\}\end{aligned} \tag{5.3-25}$$

5.4 DENSITY

5.4.1 Atmospheric Air. The density of atmospheric air in the vicinity of the test shall be determined from measurements of dry-bulb temperature t_d, wet-bulb temperature t_w, and barometric pressure p_b using Fig. 5.1 or a curve fit similar to the following. The saturated vapor pressure p_e and the partial pressure p_p of water vapor in air can be determined from

$$p_e = C_6 t_w^2 + C_7 t_w + C_8 \tag{5.4-1}$$

for air between 40°F and 100°F (5°C and 40°C), and

$$p_p = p_e - p_b\left(\frac{t_d - t_w}{C_9}\right) \tag{5.4-2}$$

The density of the atmospheric air-vapor mixture ρ_o shall be calculated using the ideal gas relationship

$$\rho_o = \frac{C_{10}(p_b - 0.378 p_p)}{R(t_d + C_1)} \tag{5.4-3}$$

The point values of density shall then be calculated from

$$\rho_j = \rho_o \frac{(t_d + C_1)\,p_{saj}}{C_{13} T_{sj} p_b} \tag{5.4-4}$$

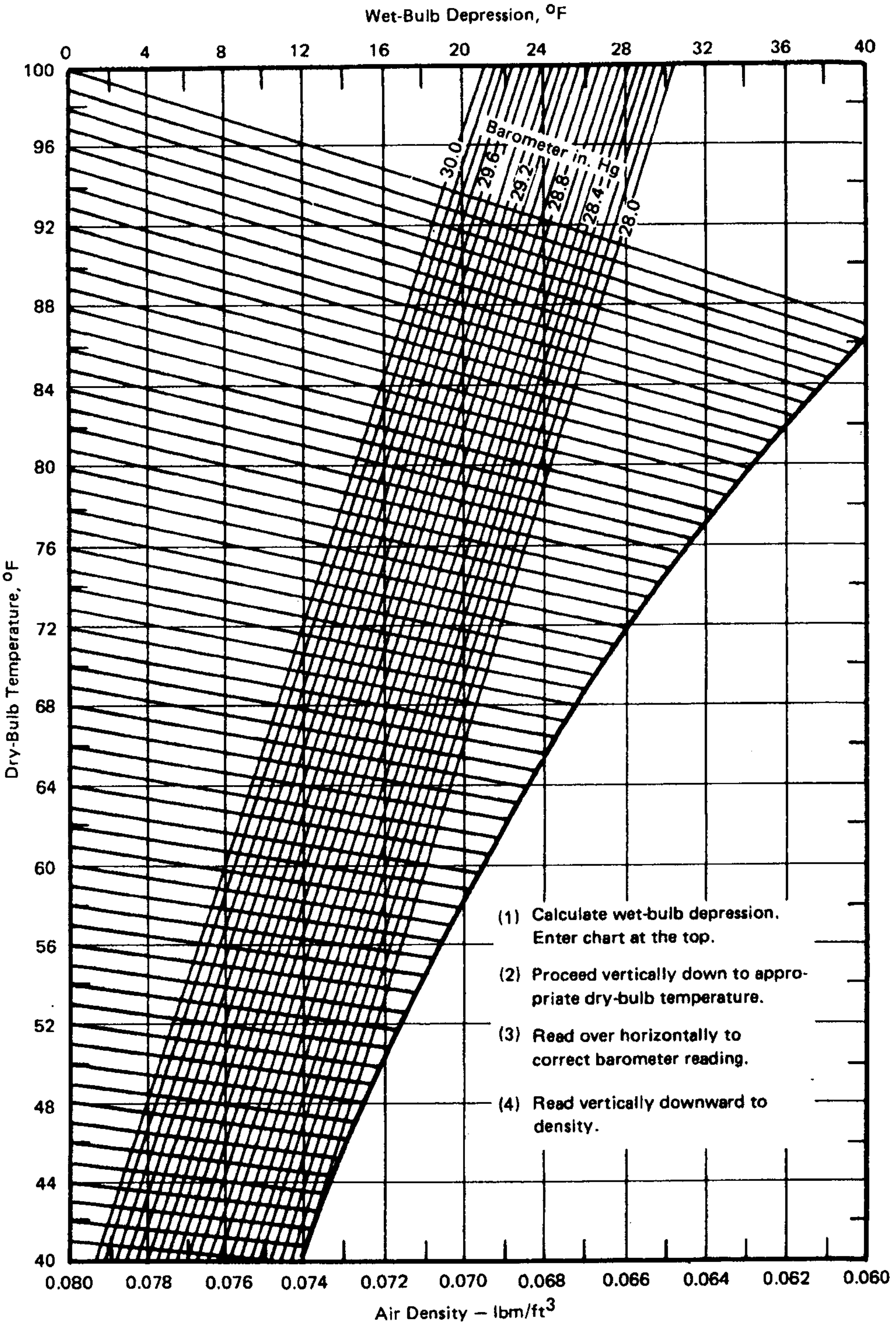
5.4.2 Gas Products of Combustion. The density of products of combustion ρ_j at each point shall be calculated from absolute pressure p_{sa}, absolute temperature T_{sj}, and specific gas constant R using the ideal gas relationship

$$\rho_j = \frac{C_{11} p_{saj}}{R T_{sj}} \tag{5.4-5}$$

5.5 FLUID VELOCITY

5.5.1 Point Velocities. The velocity V_j at each point in a traverse plane shall be calculated from

$$V_j = C_{12}\sqrt{\frac{p_{vj}}{\rho_j}} \tag{5.5-1}$$



(1) Calculate wet-bulb depression. Enter chart at the top.

(2) Proceed vertically down to appropriate dry-bulb temperature.

(3) Read over horizontally to correct barometer reading.

(4) Read vertically downward to density.

FIG. 5.1 PSYCHROMETRIC DENSITY CHART

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5.5.2 Correction for Probe Calibration Coefficient. For each point j, calculate the probe Reynolds Number $\mathbb{R}_{pj}$ using

$$\mathbb{R}_{pj} = \frac{\rho_j V_j d}{\mu_x C_2} \qquad (5.5\text{-}2)$$

Using the probe calibration, obtain new values of K_{tj} and K_{vj} at each point. Recompute p_{tj}, K_{vjc}, p_{sj}, ρ_{sdj}, p_{vj}, and T_{sj} at each point using new K_{tj} and K_{vj} in Eqs. (5.2-1), (5.2-2), (5.2-3), (5.2-4), (5.2-5), and (5.2-6). Recompute velocity at each point V_j using new p_{vj} in Eq. (5.5-1). At any point at which the value of K_{tj} and K_{vj} has been changed by more than 0.1%, it will be necessary to repeat the calculations of Pars. 5.2, 5.3, 5.4, and 5.5 using corrected values of measured pressures and temperatures. If no points have K_{tj} and K_{vj} changed by more than 0.1%, calculations may proceed using the latest values of V_j, p_{tj}, K_{vjc}, ρ_{sj}, p_{vj}, and T_{sj}.

5.6 MASS FLOW RATE

5.6.1 Mass Flow Rate at Plane x. The mass flow rate $\dot{m}_x$ at plane x shall be calculated from

$$\dot{m}_x = \sum_{j=1}^{n} (\dot{m}_j)_x = \frac{A_x}{C_2}\frac{1}{n}\sum_{j=1}^{n} (\rho_j V_j \cos\psi_j \cos\phi_j) \qquad (5.6\text{-}1)$$

5.6.2 Fan Mass Flow Rate. If $\dot{m}_1$ and $\dot{m}_2$ are both acceptable, see Par. 4.2.3.

$$\dot{m}_F = \frac{\dot{m}_1 + \dot{m}_2}{2} \qquad (5.6\text{-}2)$$

If only $\dot{m}_1$ or $\dot{m}_2$ is acceptable, $\dot{m}_F = \dot{m}_1$ or $\dot{m}_2$ as appropriate. (5.6-3)

If neither $\dot{m}_1$ nor $\dot{m}_2$ is acceptable, $\dot{m}_F = \dot{m}_3$. (5.6-4)

5.7 FLOW WEIGHTED AVERAGES

The averages which properly represent the mass and energy flows through the fan and reduce to the customary one-dimensional values in the case of uniform, parallel, constant density gas motion shall be calculated as follows [Ref. (10)].

5.7.1 Average Static Pressure at Plane x

$$p_{sx} \equiv \frac{\sum_{j=1}^{n} (p_{sj} V_j \cos\psi_j \cos\phi_j)}{\sum_{j=1}^{n} (V_j \cos\psi_j \cos\phi_j)} \qquad (5.7\text{-}1)$$

5.7.2 Average Density at Plane x

$$\rho_x \equiv \frac{\sum_{j=1}^{n} (\rho_j V_j \cos\psi_j \cos\phi_j)}{\sum_{j=1}^{n} (V_j \cos\psi_j \cos\phi_j)} = \frac{C_2 n \dot{m}_x}{A_x \sum_{j=1}^{n} (V_j \cos\psi_j \cos\phi_j)} \qquad (5.7\text{-}2)$$

5.7.3 Average Temperature at Plane x

$$T_{sx} \equiv \frac{\sum_{j=1}^{n} (T_{sj}\rho_j V_j \cos\psi_j \cos\phi_j)}{\sum_{j=1}^{n} (\rho_j V_j \cos\psi_j \cos\phi_j)} = \frac{A_x \sum_{j=1}^{n} (T_{sj}\rho_j V_j \cos\psi_j \cos\phi_j)}{C_2 n \dot{m}_x} \tag{5.7-3}$$

5.7.4 Average Specific Kinetic Energy at Plane x

$$e_{Kx} \equiv \frac{\sum_{j=1}^{n} (\rho_j V_j^3 \cos^3\psi_j \cos^3\phi_j)}{2\sum_{j=1}^{n} (\rho_j V_j \cos\psi_j \cos\phi_j) g_c C_2^2} = \frac{A_x \sum_{j=1}^{n} (\rho_j V_j^2 \cos^3\psi_j \cos^3\phi_j)}{2 g_c n \dot{m}_x C_2^3} \tag{5.7-4}$$

5.7.5 Kinetic Energy Correction Factor at Plane x

$$\alpha_x \equiv \frac{2 g_c \rho_x^2 e_{Kx} A_x^2}{m_x^2} \tag{5.7-5}$$

5.7.6 Average Velocity Pressure at Plane x

$$p_{vx} = \frac{\rho_x e_{Kx}}{C_{11}} \tag{5.7-6}$$

5.7.7 Average Total Pressure at Plane x

$$p_{tx} = p_{sx} + p_{vx} \tag{5.7-7}$$

5.7.8 Average Absolute Pressures at Plane x

$$p_{sax} = p_{sx} + C_{13} p_b \tag{5.7-8}$$

$$p_{tax} = p_{tx} + C_{13} p_b \tag{5.7-9}$$

5.8 FAN INPUT POWER

The fan input power P_I shall be calculated from one of the following as appropriate.

5.8.1 AC Motors (Three Phase)

$$P_I = \frac{\sqrt{3} \cdot E \cdot I \cdot \theta \cdot \eta_M}{C_{14}} = \frac{10^3 W \eta_M}{C_{14}} \tag{5.8-1}$$

5.8.2 DC Motors (Calibrated)

$$P_I = \frac{E \cdot I \cdot \eta_M}{C_{14}} \qquad (5.8\text{-}2)$$

5.8.3 Torque Meters

$$P_I = \frac{\tau_N}{C_{15}} \qquad (5.8\text{-}3)$$

5.8.4 Steam Turbines. (Refer to PTC 6 or PTC 6S.)

$$P_I = P_T \qquad (5.8\text{-}4)$$

5.9 FAN SPEED (SLIP METHOD)

When the speed is measured by the slip method, the stroboscope is operated on line frequency and the slip is determined by measuring the period of time a single mark on the shaft passes a fixed reference mark illuminated by the strobe light a set number n of times (e.g., ten times). Fan speed shall be calculated using

$$\text{slip} = \frac{120n}{tn_p} \qquad (5.9\text{-}1)$$

$$\text{synchronous speed} = \frac{120\,f}{n_p} \qquad (5.9\text{-}2)$$

$$N = (\text{synchronous speed}) - (\text{slip}) \qquad (5.9\text{-}3)$$

5.10 MASS FLOW RATE — SPECIFIC ENERGY APPROACH

When the mass flow rate — specific energy approach [Ref. (1)] is selected, the following calculations shall be performed.

5.10.1 Fan Mass Flow Rate. (Refer to Par. 5.6.2.)

5.10.2 Fan Mean Density

$$\rho_m = \frac{\rho_1 + \rho_2}{2} \qquad (5.10\text{-}1)$$

5.10.3 Fan Specific Energy

$$y_F = \frac{C_{11}(p_{s2} - p_{s1})}{\rho_m} + \frac{\dot{m}_F^2}{2g_c}\left[\frac{\alpha_2}{\rho_2^2 A_2^2} - \frac{\alpha_1}{\rho_1^2 A_1^2}\right] \qquad (5.10\text{-}2)$$

5.10.4 Fan Output Power

$$P_O = \frac{\dot{m}_F\, y_F}{C_{16}} \qquad (5.10\text{-}3)$$

5.10.5 Compressibility Coefficient

$$K_\rho \equiv \frac{\rho_1}{\rho_m} = \frac{2\rho_1}{\rho_2 + \rho_1} \qquad (5.10\text{-}4)$$

5.10.6 Fan Efficiency

$$\eta = \frac{\mathrm{P}_O}{\mathrm{P}_I} \qquad (5.10\text{-}5)$$

5.10.7 Conversion Calculations for $\dot{m}_F$ and y_F [Ref. (16)]. When operating conditions differ from specified operating conditions, converted performance shall be calculated using

$$b = \left(\frac{N_c}{N}\right)^2 \left(\frac{T_1}{T_{1c}}\right) \qquad (5.10\text{-}6)$$

$$K_{\rho c} = 1 - b(1 - K_\rho)\,\frac{\eta k_c - (k_c - 1)(1 + b[1 + K_\rho])}{\eta k - (k - 1)(1 + [1 + K_\rho])} \qquad (5.10\text{-}7)$$

$$\rho_{mc} = \frac{\rho_{1c}}{K_{\rho c}} \qquad (5.10\text{-}8)$$

$$\dot{m}_{Fc} = \dot{m}_F \left(\frac{\rho_{1c}}{\rho_1}\right)\left(\frac{N_c}{N}\right)\left(\frac{K_\rho}{K_{\rho c}}\right) \qquad (5.10\text{-}9)$$

$$y_{Fc} = y_F \left(\frac{N_c}{N}\right)^2 \qquad (5.10\text{-}10)$$

$$\mathrm{P}_{Oc} = \frac{M_{Fc} y_{Fc}}{C_{16}} \qquad (5.10\text{-}11)$$

$$\mathrm{P}_{Ic} = \mathrm{P}_I \left(\frac{N_c}{N}\right)^3 \left(\frac{\rho_{1c}}{\rho_1}\right)\left(\frac{K_\rho}{K_{\rho c}}\right) \qquad (5.10\text{-}12)$$

$$\eta_c = \eta \qquad (5.10\text{-}13)$$

5.11 VOLUME FLOW RATE — PRESSURE APPROACH

When the volume flow rate — pressure approach [Ref. (1)] is selected, the following calculations shall be performed.

5.11.1 Fan Gas Density

$$\rho_F = \rho_1 \frac{p_{ia1}}{p_{sa1}\left[1 + \dfrac{e_{K1}}{Jc_{p1}T_{s1}}\right]} \qquad (5.11\text{-}1)$$

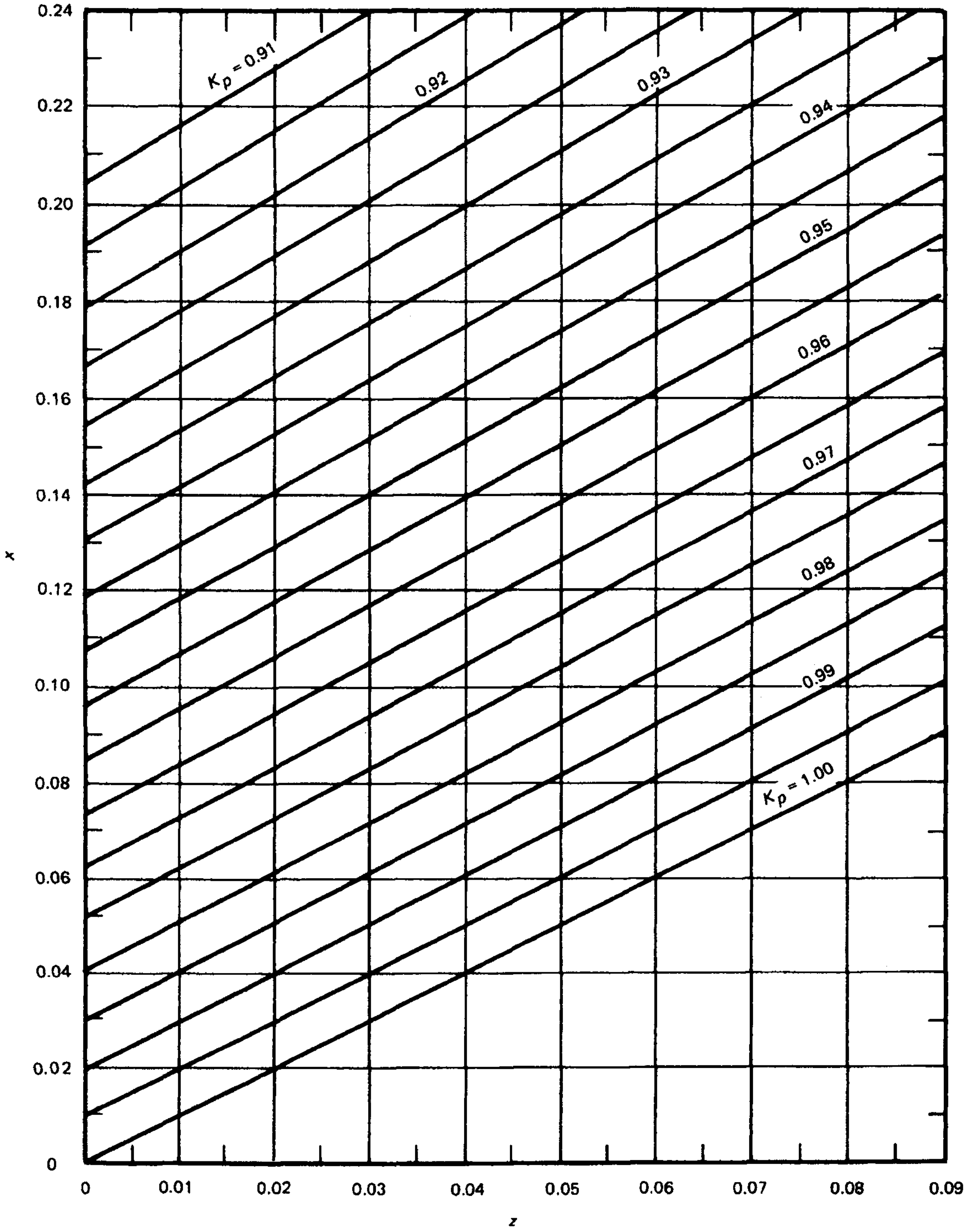

FIG. 5.2 COMPRESSIBILITY COEFFICIENTS (VOLUME FLOW — PRESSURE APPROACH)
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5.11.2 Fan Volume Flow Rate

$$Q_F = \frac{C_2 \dot{m}_F}{\rho_F} \qquad (5.11\text{-}2)$$

5.11.3 Fan Pressures

Fan total pressure $$p_{Ft} = p_{t2} - p_{t1} \qquad (5.11\text{-}3)$$

Fan velocity pressure $$p_{Fv} = \frac{\rho_2 e_{K2}}{C_{11}} \qquad (5.11\text{-}4)$$

Fan static pressure $$p_{Fs} = p_{Ft} - p_{Fv} \qquad (5.11\text{-}5)$$

5.11.4 Compressibility Coefficient

$$z = \left(\frac{k-1}{k}\right) \frac{P_I C_{17}}{Q_F p_{ta1}} \qquad (5.11\text{-}6)$$

$$x = \frac{p_{Ft}}{p_{ta1}} \qquad (5.11\text{-}7)$$

$$K_p = \frac{z \ln(1+x)}{x \ln(1+z)} \quad \text{[or use Fig. 5.2]} \qquad (5.11\text{-}8)$$

5.11.5 Fan Output Power

$$P_O = \frac{Q_F p_{Ft} K_p}{C_{17}} \qquad (5.11\text{-}9)$$

5.11.6 Efficiency

Fan total efficiency $$\eta_t = \frac{P_O}{P_I} \qquad (5.11\text{-}10)$$

Fan static efficiency $$\eta_s = \eta_t \frac{p_{Fs}}{p_{Ft}} \qquad (5.11\text{-}11)$$

5.11.7 Conversion Calculations for Q_F and p_{Ft} [Ref. (4)]. When actual operating conditions differ from the specified operating conditions, converted performance shall be calculated using

$$\frac{z}{z_c} = \left(\frac{k-1}{k}\right)\left(\frac{k_c}{k_c-1}\right)\left(\frac{p_{ta1c}}{p_{ta1}}\right)\left(\frac{N}{N_c}\right)^2\left(\frac{\rho_F}{\rho_{Fc}}\right) \qquad (5.11\text{-}12)$$

$$a = 1n(1 + x_c) = 1n(1 + x)\frac{1n(1 + z_c)}{1n(1 + z)}\left(\frac{k - 1}{k}\right)\left(\frac{k_c}{k_c - 1}\right) \quad (5.11\text{-}13)$$

$$x_c = e^a - 1 \quad (5.11\text{-}14)$$

$$\frac{K_p}{K_{pc}} = \left(\frac{z}{z_c}\right)\left(\frac{x_c}{x}\right)\left(\frac{k}{k - 1}\right)\left(\frac{k_c - 1}{k_c}\right) \quad (5.11\text{-}15)$$

$$K_{pc} = K_p/K_p/K_{pc} \quad (5.11\text{-}16)$$

$$Q_{Fc} = Q_F\left(\frac{N_c}{N}\right)\left(\frac{K_p}{K_{pc}}\right) \quad (5.11\text{-}17)$$

$$p_{Ftc} = p_{Ft}\left(\frac{\rho_{Fc}}{\rho_F}\right)\left(\frac{N_c}{N}\right)^2\left(\frac{K_p}{K_{pc}}\right) \quad (5.11\text{-}18)$$

$$p_{Fvc} = p_{Fv}\left(\frac{N_c}{N}\right)^2\left(\frac{\rho_{Fc}}{\rho_F}\right) \quad (5.11\text{-}19)$$

$$p_{Fsc} = p_{Ftc} - p_{Fvc} \quad (5.11\text{-}20)$$

$$P_{O_c} = \frac{Q_{Fc}p_{Ftc}K_{pc}}{C_{17}} \quad (5.11\text{-}21)$$

$$P_{Ic} = P_I\left(\frac{\rho_{Fc}}{\rho_F}\right)\left(\frac{N_c}{N}\right)^3\left(\frac{K_p}{K_{pc}}\right) \quad (5.11\text{-}22)$$

$$\eta_{tc} = \eta_t,\ \eta_{sc} = \eta_t\frac{p_{Fsc}}{p_{Ftc}} \quad (5.11\text{-}23)$$

5.12 UNCERTAINTIES

Systematic U^S and u^S and random U^R and u^R uncertainties shall be calculated for each of the performance variables according to the approach chosen for calculating the results of the test. The systematic and random uncertainties for any particular variable can be combined using

$$u^2 = (u^R)^2 + (u^S)^2 \quad \text{or} \quad U^2 = (U^R)^2 + (U^S)^2 \quad (5.12\text{-}1,\ 5.12\text{-}2)$$

The equations listed below (some of which are derived in Appendix D) shall be applied to both random and systematic uncertainties by substituting the appropriate individual values. The individual values should reflect the actual circumstances. (Appendix E lists individual values that generally reflect circumstances that meet Code specifications.)

Paragraphs 5.12.1 through 5.12.11 apply to both approaches. Paragraphs 5.12.12 through 5.12.16 apply only to the mass flow rate — specific energy approach. Paragraphs 5.12.17 through 5.12.22 apply only to the volume flow rate — pressure approach.

5.12.1 Mass Flow Rate at Plane *x*

$$u_{\dot m_x}^2 = u_{F_n}^2 + u_{F_{sm}}^2 + u_{A_x}^2 + \sum_{j=1}^{n} \left(\frac{\dot m_j}{\dot m_x}\right)^2 \left[\frac{1}{4}\left(u_R^2 + u_{T_{sj}}^2 + u_{p_{vj}}^2\right) + \left(\frac{U_{p_{sj}}^2 + C_{13}^2 U_{p_b}^2}{p_{saj}^2}\right) + \left(\frac{\tan^2 \psi_j + \tan^2 \phi_j \, U_{\phi_j}^2}{57.30^2}\right)\right] \qquad (5.12\text{-}3)$$

5.12.2 Fan Mass Flow Rate

$$u_{\dot m_F}^2 = \frac{1}{4}\left(u_{\dot m_1}^2 + u_{\dot m_2}^2\right) \quad \text{or} \quad u_{\dot m_F}^2 = u_{\dot m_1}^2 \quad \text{or} \qquad (5.12\text{-}4, 5.12\text{-}5)$$

$$u_{\dot m_F}^2 = u_{\dot m_2}^2 \quad \text{or} \quad u_{\dot m_F}^2 = u_{\dot m_3}^2 \qquad (5.12\text{-}6, 5.12\text{-}7)$$

as appropriate. See Par. 5.6.2.

A general equation will be useful in calculating uncertainties of other results.

$$u_{\dot m_F}^2 = w_1^2 u_{\dot m_1}^2 + w_2^2 u_{\dot m_2}^2 + w_3^2 u_{\dot m_3}^2 \qquad (5.12\text{-}8)$$

where

$\dot m_F$	w_1	w_2	w_3
$(\dot m_1 + \dot m_2)/2$	1/2	1/2	0
$\dot m_1$	1	0	0
$\dot m_2$	0	1	0
$\dot m_3$	0	0	1

5.12.3 Average Static Pressure at Plane *x*

$$u_{p_{sx}}^2 = \frac{1}{n^2} \sum_{j=1}^{n} \left(\frac{p_{sj}}{p_{sx}}\right)^2 u_{p_{sj}}^2 \qquad (5.12\text{-}9)$$

5.12.4 Average Density at Plane *x*

$$u_{\rho_x}^2 = u_{F_{s\rho}}^2 + \frac{1}{n^2} \sum_{j=1}^{n} \left(\frac{\rho_j}{\rho_x}\right)^2 \left[u_R^2 + u_{T_{sj}}^2 + \left(\frac{U_{p_{sj}}^2 + C_{13}^2 U_{p_b}^2}{p_{saj}^2}\right)\right] \qquad (5.12\text{-}10)$$

5.12.5 Average Temperature at Plane *x*

$$u_{T_{sx}}^2 = \frac{1}{n^2} \sum_{j=1}^{n} \left(\frac{T_{sj}}{T_{sx}}\right)^2 u_{T_{sj}}^2 \qquad (5.12\text{-}11)$$

5.12.6 Average Specific Kinetic Energy at Plane *x*

$$u^2_{e_{Kx}} \quad \frac{1}{n^2}\sum_{j=1}^{n}\left(\frac{e_{Kj}}{e_{Kx}}\right)^2\left[u^2_R + u^2_{T_{sj}} + u^2_{\rho_{vj}} + \left(\frac{U^2_{\rho_{sj}} + C^2_{13}U^2_{\rho b}}{\rho^2_{saj}}\right) + 4\left(\frac{\tan^2\psi_j U^2_{\psi j} + \tan^2\phi_j U^2_{\phi j}}{57.30^2}\right)\right] \tag{5.12-12}$$

where

$$e_{K_j} = \frac{1}{2}V_j^2\cos^2\phi_j\cos^2\psi_j$$

5.12.7 Average Velocity Pressure at Plane *x*

$$u^2_{\rho_{vx}} = \frac{1}{n^2}\sum_{j=1}^{n}\left(\frac{\rho_{vj}\cos^2\psi_j\cos^2\phi_j}{\rho_{vx}}\right)^2\left[u^2_{\rho_{vj}} + 4\left(\frac{\tan^2\psi_j U^2_{\psi j} + \tan^2\phi_j U^2_{\phi j}}{57.30^2}\right)\right] \tag{5.12-13}$$

5.12.8 Average Total Pressure at Plane *x*

$$u^2_{p_{tx}} = \frac{1}{n^2}\left\{\sum_{j=1}^{n}\left(\frac{p_{sj}}{p_{tx}}\right)^2 u^2_{p_{sj}} + \sum_{j=1}^{n}\left(\frac{\rho_{vj}\cos^2\psi_j\cos^2\phi_j}{p_{tx}}\right)^2 \left[u^2_{\rho_{vj}} + 4\left(\frac{\tan^2\psi_j U^2_{\psi j} + \tan^2\phi_j U^2_{\phi j}}{57.30^2}\right)\right]\right\} \tag{5.12-14}$$

5.12.9 Average Absolute Pressure at Plane *x*

$$u^2_{\rho_{sax}} = \frac{U^2_{\rho_{sx}} + C^2_{13}U^2_{\rho_b}}{\rho^2_{sax}} \tag{5.12-15}$$

5.12.10 Fan Input Power

$u^2_{P_I} = u^2_{F_{sP}} + u^2_{\eta_M} + u^2_W$ for AC motors (5.12-16)

$u^2_{P_I} = u^2_{F_{sP}} + u^2_{\eta_M} + u^2_E + u^2_I$ for DC motors (5.12-17)

$u^2_{P_I} = u^2_{F_{sP}} + u^2_{\tau} + u^2_N$ for torque meters (5.12-18)

$u^2_{P_I} = u^2_{F_{sP}} + u^2_{P_t}$ for turbines (5.12-19)

5.12.11 Fan Speed

$u^2_N = u^2_N$ for electronic counters (5.12-20)

$u^2_N = u^2_n + u^2_t$ for slip method (5.12-21)

5.12.12 Fan Mean Density

$$u^2_{\rho_m} = \frac{U^2_{\rho_1} + U^2_{\rho_2}}{(\rho_1 + \rho_2)^2} \tag{5.12-22}$$

5.12.13 Fan Specific Energy

$$\begin{aligned}
u^2_{y_F} = {} & u^2_{F_{sy}} + u^2_R + \left(\frac{C_{11}}{y_F}\right)^2 \left[\left(\frac{\rho_1(p_{s2} - p_{s1})}{2\rho_m^2} - \frac{p_{v1}}{\rho_1}\right)^2 u^2_{T_1}\right. \\
& + \left(\frac{\rho_2(p_{s2} - p_{s1})}{2\rho_m^2} + \frac{p_{v2}}{\rho_2}\right)^2 u^2_{T_2} \\
& + \left[\frac{p_{v1}}{\rho_1}\,\frac{p_b}{p_{sa1}} - \frac{(p_{s2} - p_{s1})}{2\rho_m^2}\left(\frac{p_b}{RT_1} + \frac{p_b}{RT_2}\right) - \frac{p_{v2}}{\rho_2}\,\frac{p_b}{p_{sa2}}\right]^2 u^2_{p_b} \\
& + \left(\frac{p_{v1}}{\rho_1}\,\frac{p_{s1}}{p_{sa1}} - \frac{\rho_1(p_{s2} - p_{s1})}{2\rho_m^2}\,\frac{p_{s1}}{p_{sa1}} - \frac{p_{s1}}{\rho_m}\right)^2 u^2_{p_{s1}} \\
& + \left(\frac{p_{s2}}{\rho_m} - \frac{\rho_2(p_{s2} - p_{s1})}{2\rho_m^2}\,\frac{p_{s2}}{p_{sa2}} - \frac{p_{v2}}{\rho_2} - \frac{p_{v2}}{\rho_2}\,\frac{p_{s2}}{p_{sa2}}\right)^2 u^2_{p_{s2}} \\
& \left. + \left(\frac{p_{v1}}{\rho_1}\right)^2 u^2_{p_{v1}} + \left(\frac{p_{v2}}{\rho_2}\right)^2 u^2_{p_{v2}}\right]
\end{aligned} \tag{5.12-23}$$

5.12.14 Fan Output Power

$$\begin{aligned}
u^2_{P_O} = {} & u^2_{F_{sm}} + u^2_{F_{sy}}\,\frac{1}{4}\,u^2_R + \left(\frac{\dot{w}_1\dot{m}_1}{\dot{m}_F}\right)^2 u^2_{A_1} + \left(\frac{w_2\dot{m}_2}{\dot{m}_F}\right)^2 u^2_{A_2} \\
& + \left(\frac{w_3\dot{m}_3}{\dot{m}_F}\right)^2 u^2_{A_3} + \left(\frac{w_1\dot{m}_1}{2\dot{m}_F} - \frac{C_{11}}{y_F}\,\frac{\rho_1(p_{s2} - p_{s1})}{2\rho_m^2} - \frac{e_{K1}}{y_F}\right)^2 u^2_{T_1} \\
& + \left(\frac{w_2\dot{m}_2}{2\dot{m}_F} - \frac{C_{11}}{y_F}\,\frac{\rho_2(p_{s2} - p_{s1})}{2\rho_m^2} + \frac{e_{K2}}{y_F}\right)^2 u^2_{T_2} + \left(\frac{w_3\dot{m}_3}{2\dot{m}_F}\right)^2 u^2_{T_3} \\
& + \left[\frac{w_1\dot{m}_1}{2\dot{m}_F}\,\frac{p_b}{p_{sa1}} + \frac{w_2\dot{m}_2}{2\dot{m}_F}\,\frac{p_b}{p_{sa2}} + \frac{w_3\dot{m}_3}{2\dot{m}_F}\,\frac{p_b}{p_{sa3}}\right. \\
& \left. + \frac{e_{11}}{y_F}\left(\frac{p_{v1}}{\rho_1}\,\frac{p_b}{p_{sa1}} - \frac{(p_{s2} - p_{s1})}{2\rho_m^2}\left(\frac{p_b}{RT_1} + \frac{p_b}{RT_2}\right) - \frac{p_{v2}}{\rho_2}\,\frac{p_b}{p_{sa1}}\right)\right]^2 u^2_{p_b}
\end{aligned}$$

$$+\left[\frac{w_1\dot{m}_1}{2\dot{m}_F}\frac{p_{s1}}{p_{sa1}}+\frac{C_{11}}{y_F}\left(\frac{p_{v1}}{\rho_1}\frac{p_{s1}}{p_{sa1}}-\frac{\rho_1(p_{s2}-p_{s1})}{2\rho_m^2}\frac{p_{s1}}{p_{sa1}}-\frac{p_{s1}}{\rho_m}\right)\right]^2 u_{p_{s1}}^2$$

$$+\left[\frac{w_2\dot{m}_2}{2\dot{m}_F}\frac{p_{s2}}{p_{sa2}}+\frac{C_{11}}{y_F}\left(\frac{p_{s2}}{\rho_m}-\frac{\rho_1(p_{s2}-p_{s1})}{2\rho_m^2}\frac{p_{s2}}{p_{sa2}}-\frac{p_{v2}}{\rho_2}\frac{p_{s2}}{p_{sa2}}\right)\right]^2 u_{p_{s2}}^2$$

$$+\left(\frac{w_1\dot{m}_1}{2\dot{m}_F}-\frac{e_{k1}}{y_F}\right)^2 u_{p_{v1}}^2+\left(\frac{w_2\dot{m}_2}{2\dot{m}_F}+\frac{e_{k2}}{y_F}\right)^2 u_{p_{v2}}^2+\left(\frac{w_3\dot{m}_3}{2\dot{m}_F}\right)^2 u_{p_{v3}}^2 \tag{5.12-24}$$

5.12.15 Fan Efficiency

$$u_\eta^2 = u_{\mathrm{P}_O}^2 + u_{\mathrm{P}_I}^2 \tag{5.12-25}$$

5.12.16 Conversions

$$u_{\dot{m}_{Fc}}^2 = u_{\dot{m}_F}^2 + u_N^2 + u_{\rho_1}^2 \tag{5.12-26}$$

$$u_{y_{Fc}}^2 = u_{y_F}^2 + 4u_N^2 \tag{5.12-27}$$

$$u_{\mathrm{P}_{oc}}^2 = u_{\mathrm{P}_o}^2 + 9u_N^2 + u_\rho^2 \tag{5.12-28}$$

$$u_{\mathrm{P}_{Ic}}^2 = u_{\mathrm{P}_I}^2 + 9u_N^2 + u_{\rho_1}^2 \tag{5.12-29}$$

$$u_{\eta_c}^2 = u_\eta^2 \tag{5.12-30}$$

5.12.17 Fan Gas Density

$$u_{\rho_F}^2 = u_{\rho_1}^2 \tag{5.12-31}$$

5.12.18 Fan Volume Flow Rate

$$u_{Q_F}^2 = u_{f_n}^2 = u_{F_{sQ}}^2 + \frac{1}{4}u_R^2 + \left(\frac{w_1\dot{m}_1}{\dot{m}_F}\right)^2 u_{A_1}^2 + \left(\frac{w_2\dot{m}_2}{\dot{m}_F}\right)^2 u_{A_2}^2 + \left(\frac{w_3\dot{m}_3}{\dot{m}_F}\right)^2 u_{A_3}^2$$

$$+\left(\frac{w_1\dot{m}_1}{2\dot{m}_F}-1\right)^2 u_{T_1}^2+\left(\frac{w_2\dot{m}_2}{2\dot{m}_F}\right)^2 u_{T_2}^2+\left(\frac{w_3\dot{m}_3}{2\dot{m}_F}\right)^2 u_{T_3}^2$$

$$+\left(\frac{w_1\dot{m}_1}{2\dot{m}_F}\frac{p_b}{p_{sa1}}+\frac{w_2\dot{m}_2}{2\dot{m}_F}\frac{p_b}{p_{sa2}}+\frac{w_3\dot{m}_3}{2\dot{m}_F}\frac{p_b}{p_{sa3}}-\frac{p_b}{p_{sa1}}\right)^2 u_{p_b}^2$$

$$+\left(\frac{w_1\dot{m}_1}{2\dot{m}_F}\frac{p_{s1}}{p_{sa1}}-\frac{p_{s1}}{p_{sa1}}\right)^2 u_{p_{s1}}^2+\left(\frac{w_2\dot{m}_2}{2\dot{m}_F}\frac{p_{s2}}{p_{sa2}}\right)^2 u_{p_{s2}}^2$$

$$+\left(\frac{w_3\dot{m}_3}{2\dot{m}_F}\frac{p_{s3}}{p_{sa3}}\right)^2 u_{p_{s3}}^2+\left(\frac{w_1\dot{m}_1}{2\dot{m}_F}\right)^2 u_{p_{v1}}^2+\left(\frac{w_2\dot{m}_2}{2\dot{m}_F}\right)^2 u_{p_{v2}}^2$$

$$+\left(\frac{w_3\dot{m}_3}{2\dot{m}_F}\right)^2 u_{p_{v3}}^2 \tag{5.12-32}$$

5.12.19 Fan Pressure

$$u^2_{p_{Ft}} = u^2_{F_{spt}} + \frac{U^2_{p_{t2}} + U^2_{p_{t1}}}{p^2_{Ft}} \tag{5.12-33}$$

$$u^2_{p_{Fv}} = u^2_{p_{v2}} \tag{5.12-34}$$

$$u^2_{p_{Fs}} = \frac{U^2_{p_{Ft}} + U^2_{p_{Fv}}}{p^2_{Fs}} \tag{5.12-35}$$

5.12.20 Fan Output Power

$$\begin{aligned}
u^2_{\mathrm{P}_O} = {} & u^2_{f_{sQ}} + u^2_{f_{spt}} + \frac{1}{4} u^2_R + \left(\frac{w_1 \dot{m}_1}{\dot{m}_F}\right)^2 u^2_{A_1} + \left(\frac{w_2 \dot{m}_2}{\dot{m}_F}\right)^2 u^2_{A_2} \\
& + \left(\frac{w_3 \dot{m}_3}{\dot{m}_F}\right)^2 u^2_{A_3} + \left(\frac{w_1 \dot{m}_1}{2\dot{m}_F} - 1\right)^2 u^2_{T_1} + \left(\frac{w_2 \dot{m}_2}{2\dot{m}_F}\right)^2 u^2_{T_2} \\
& + \left(\frac{w_3 \dot{m}_3}{2\dot{m}_F}\right)^2 u^2_{T_3} + \left(\frac{w_1 \dot{m}_1}{2\dot{m}_F} \frac{p_b}{p_{sa1}} + \frac{w_2 \dot{m}_2}{2\dot{m}_F} \frac{p_b}{p_{sa2}} + \frac{w_3 \dot{m}_3}{2\dot{m}_F} \frac{p_b}{p_{sa3}} \right. \\
& \left. - \frac{p_b}{p_{sa1}}\right)^2 u^2_{p_b} + \left(\frac{w_1 \dot{m}_1}{2\dot{m}_F} \frac{p_{s1}}{p_{sa1}} - \frac{p_{s1}}{p_{sa1}} - \frac{p_{s1}}{p_{Ft}}\right)^2 u^2_{p_{s1}} \\
& + \left(\frac{w_2 \dot{m}_2}{2\dot{m}_F} \frac{p_{s2}}{p_{sa2}} + \frac{p_{s2}}{p_{Ft}}\right)^2 u^2_{p_{s2}} + \left(\frac{w_3 \dot{m}_3}{2\dot{m}_F} \frac{p_{s3}}{p_{sa3}}\right)^2 u^2_{p_{s3}} \\
& + \left(\frac{w_1 \dot{m}_1}{2\dot{m}_F} - \frac{p_{v1}}{p_{Ft}}\right)^2 u^2_{p_{v1}} + \left(\frac{w_2 \dot{m}_2}{2\dot{m}_F} + \frac{p_{v2}}{p_{Ft}}\right)^2 u^2_{p_{v2}} + \left(\frac{w_3 \dot{m}_3}{2\dot{m}_F}\right)^2 u^2_{p_{v3}}
\end{aligned} \tag{5-12-36}$$

5.12.21 Efficiency

$$u^2_{\eta_t} = u^2_{\mathrm{P}_O} + u^2_{\mathrm{P}_I} \tag{5.12-37}$$

$$u^2_{\eta_s} = u^2_{\eta_t} \tag{5.12-38}$$

5.12.22 Conversions

$$u^2_{Q_{Fc}} = u^2_{Q_F} + u^2_N \tag{5.12-39}$$

$$u^2_{p_{Ftc}} = u^2_{p_{Ft}} + 4u^2_N + u^2_{\rho_1} \tag{5.12-40}$$

$$u^2_{p_{Fvc}} = u^2_{p_{Fv}} + 4u^2_N + u^2_{\rho_1} \tag{5.12-41}$$

$$u^2_{p_{Fsc}} = u^2_{p_{Fs}} + 4u^2_N + u^2_{\rho_1} \tag{5.12-42}$$

$$u^2_{p_{oc}} = u^2_{p_o} + 9u^2_N + u^2_{\rho_1} \tag{5.12-43}$$

$$u^2_{P_{Ic}} = u^2_{P_I} + 9u^2_N + u^2_{\rho_1} \tag{5.12-44}$$

$$u^2_{\eta_{tc}} = u^2_{\eta_t} \tag{5.12-45}$$

SECTION 6 — REPORT OF RESULTS

6.1 GENERAL REQUIREMENTS

The results of the test shall be presented in a written report.

The preparation of the report shall be the responsibility of the person in charge of the test who shall certify its correctness.

Prior to writing the report, the parties shall decide whether to use SI units, U.S. customary units, or both. This selection will generally depend upon the units in which the fan performance is specified.

6.2 TEST REPORT

The following subsections shall be included in the test report. The descriptions of each of the subsections that follow include the information that shall be contained in the test report.

(*a*) Abstract
(*b*) Introduction
(*c*) Test Procedure
(*d*) Instruments and Methods of Measurement
(*e*) Methods of Calculation
(*f*) Results
(*g*) Discussion
(*h*) Conclusions
(*i*) Appendices

6.2.1 Abstract. The abstract is intended to provide a brief introduction to and summary of the test. It shall state the location and type of fan, the reason for testing, the specified fan performance, the measured fan performance converted to specified operating conditions, and the conclusions drawn from the test results.

6.2.2 Introduction. The introduction shall identify the fan being tested, and list the authorization for the test, the test objective, contractual obligations and guarantees, stipulated agreements, the person in charge of the test, and the representatives of the various parties to the test. It should clearly identify:

(*a*) manufacturer
(*b*) type of fan(s)
(*c*) serial number(s)
(*d*) owner and location
(*e*) specified fan boundaries
(*f*) specified fan performance
(*g*) specified operating conditions

A description of the system of which the fan is a part and any other auxiliary apparatus, the operation of which may influence the test result, shall be included. If any modifications have been made to the fan or to those parts of the system that would affect fan performance which are deviations from the original design, they shall be described in detail.

6.2.3 Test Procedure. The test procedure shall deal with the sequence of events followed during the test program. Items such as equipment operating conditions for the various tests shall be described. For instance, in a system with multiple fans, the test procedure may include tests of each fan's performance as well as of all fans operating in unison. The test procedure must indicate which fan was operating during each test. Any preliminary exploration required to locate traverse planes shall be described here.

6.2.4 Instruments and Methods of Measurement. This portion of the report shall describe what instrumentation was used for the test, where it was located, and how it was calibrated. Details concerning the instrumentation used, including the instrument's manufacturer, model number, serial number, and date of calibration, shall be located in either this section or, if preferred, in an appendix depending upon the quantity of information to be included. The location of each instrument is usually best identified on a sketch of the fan and duct system. If instruments or measurement methods other than those specified in this Code are adopted, reasons for such decisions shall be explained in detail.

6.2.5 Methods of Calculation. The techniques used to reduce the raw data to fan performance parameters shall be documented. A sample calculation which may be a computer output or a calculation sheet shall be presented. This section shall explain any conversion factors applied to the test measurements to compensate for deviations in the test conditions from those specified.

6.2.6 Results. The test results shall be presented in a clear format such as the Results Summary Sheet from Appendix A of this Code. This presentation shall include both the measured fan performance, fan performance converted to specified operating conditions, and uncertainties in the performance variables. Sufficient information about uncertainties shall be presented so that both systematic and random components can be identified. General observations concerning the test environment, fluctuations of test conditions, or other things relevant to the test shall be recorded in this section. Graphical presentations such as plotting the test point(s) on the specified fan curves may be helpful in presenting and interpreting the results.

6.2.7 Discussion. The results and observations obtained from the test shall be discussed. Possible sources of errors in the test and the uncertainties of the results shall also be discussed. Actions taken by the person in charge of the test to remedy inconsistencies in accordance with Par. 3.10 shall be documented here.

6.2.8 Conclusions. Any conclusions drawn from the test results shall be simply stated or itemized.

6.2.9 Appendices. This portion of the report should include any information that will clarify any portion of the test report or make it a complete, self-contained document. This can include, without being limited to, tabulated data, equipment or instrumentation illustrations, calibration apparatus details, results of preliminary inspections and trials, computer codes, computer output, and any special calculations such as those to determine the uncertainties of the measurements or results.

APPENDIX A

TYPICAL RESULTS SUMMARY AND DATA SHEETS

RESULTS SUMMARY

Date ____________ Test No. ____________ Time: From ________ to ________

User ____________ Plant Name/Unit No. ____________

Fan: Function ____________ Mfg. ____________ Model No. ________

Contract Curve No. ____________ Serial No. ____________

---

* SPECIFIED OPERATING CONDITIONS:

Fan Speed N ____________ Specific Heat Ratio k ____________
Inlet Gas Temperature t_1 ____________ Gas Being Moved ____________
Inlet Static Pressure p_{s1} ____________ Inlet Density total ☐ or static ☐ ________

* DESIGN FAN PERFORMANCE PARAMETERS:

Flow Rate $\dot{m}_f$ ☐ or Q_f ☐ ____________ Fan Input Power P_f ____________
Fan Pressure p_{fs} ☐ or p_{ft} ☐ ____________
Fan Specific Energy y_f ____________

* INLET CHARACTERISTICS:

Duct Area A_1 ____________ No. Ports ____________ No. Points/Port ____________
Probe Type ____________

* OUTLET CHARACTERISTICS:

Duct Area A_2 ____________ No. Ports ____________ No. Points/Port ____________
Probe Type ____________

* FLOW TRAVERSES AT OTHER THAN FAN BOUNDARIES:

Identify Location ____________
Duct Area A_x ____________ No. Ports ____________ No. Points/Port ____________
Probe Type ____________

* RESULTS:

OPERATING CONDITIONS:

Fan Speed N ____________ Inlet Gas Temperature t_1 ____________
Inlet Static Pressure p_{s1} ____________ Outlet Static Pressure p_{s2} ____________
Barometric Pressure p_b ____________ Line Frequency f ____________
Dry Gas Composition by % CO_2 ________ %O_2 ________ % CO ________
Volume measured at %N_2 ________ % ________ % ________
Inlet ☐ or Discharge ☐ % ________ % ________ % ________
Inlet density total ☐ or static ☐ ____________ Specific Humidity s ____________
Specific Heat Ratio k ____________

* FAN PERFORMANCE PARAMETERS:

	As Measured	Converted to Specified Operating Conditions
Flow Rate $\dot{m}_f$ ☐ or Q_f ☐	____________	____________
Fan Pressure p_{fs} ☐ or p_{ft} ☐	____________	____________
Fan Specific Energy y_f	____________	____________
Fan Input Power P_f	____________	____________
Fan Efficiency η ☐ η_t ☐ or η_s ☐		____________

NAMES OF TEST PERSONNEL:

____________ ____________
____________ ____________
____________ Approved ____________
Test Supervisor: ____________ Date ____________

---

* Identify measurement units

FAN TEST DATA SHEET

TEST ________ DATE ________ TIME ________ to ________ PAGE ________ of ________

User ______________________ Plant Name/Unit No. ______________________

Fan: Function ________________ Identification No. ________ Barometric Press. ________

Recorded by ____________ Checked by ____________ Ambient Temp. ____________

Probe No. ________________

DATA LOCATION	VELOCITY PRESSURE	STATIC PRESSURE	TEMP.	YAW ANGLE	PITCH PRESSURE (ΔP)	TIME
	MAN. IDENT. ____ MAN. UNITS____	MAN. IDENT. ____ MAN. UNITS____	T.C. IDENT. ____ T.C. UNITS____	DEGREES	MAN. IDENT. ____ MAN. UNITS____	

DATA LOCATION	VELOCITY PRESSURE	STATIC PRESSURE	TEMP.	YAW ANGLE	PITCH PRESSURE (ΔP)	TIME

Additional sheets should be prepared for data on speed, input power, ambient conditions, and gas properties. Sample data sheets appear on the following two pages.

SAMPLE DATA SHEET
GAS ANALYSIS AND AMBIENT CONDITIONS

AMBIENT TEMPERATURE

INBOARD				OUTBOARD			Dry Bulb	Wet Bulb	Barometric Pressure
Time	CO_2	O_2	CO	CO_2	O_2	CO			
Average									

Note: Inboard and outboard gas analyses are averaged together for data processing. Separate analyses for each inlet are recommended for informational purposes in order to explain temperature differences for fans handling products of combustion where infiltration may occur.

Date ________________ Time: From __________ to ____________ Recorded by ____________________

Test No. ______________ Fan Identification No. ________________

User ______________________________ Plant Name/Unit No. ______________________________

SAMPLE DATA SHEET
POWER

					SPEED		
					Slip Method		
Time	Volts	Amps	Phase Angle	Torque	Counts	Seconds	Pulse Frequency
Average							

$$\text{Speed} = \text{Synchronous} - \text{slip} = \left(\frac{120 \times \text{line freq. (cps)}}{\text{no. of motor poles}}\right) - \left(\frac{120 \times \text{no. counts}^*}{\text{seconds}^* \times \text{no. of poles}}\right) = \qquad \text{rpm}$$

$$\text{Speed} = \frac{\text{Pulse freq.}^* \text{ (cps)}}{60 \times \text{no. pulses/rev.}} = \qquad \text{rpm}$$

$$\text{Power} = \frac{\text{Torque}^* \text{ (ft lb)} \times \text{rpm}}{33{,}000} = \qquad \text{hp}$$

$$\text{Power} = \frac{\sqrt{3} \times \text{volts}^* \times \text{amps}^* \times \text{power factor}^{**} \times \text{motor eff.} \times \text{meter calib. coeff.}}{745.7}$$

$$= \qquad \text{hp}$$

*Average quantities **Power factor = cos (average phase angle)

Date ________________ Time: From __________ to ______________ Recorded by ________________________

Test No. ______________ Fan Identification No. ________________

User __________________________________ Plant Name/Unit No. ______________________________

APPENDIX B

COMPUTER CODE AND INPUT FORMS

The following computer code was originally developed under a grant from the Electrical Power Research Institute and modified by the PTC 11 Committee. This computer code is available in the tape form from:

Electric Power Software Center
University Computing Company
1930 Hiline Drive
Dallas, Texas 75207
(214) 655-8883

PROGRAM INPUT FORM FOR DETERMINATION OF FAN PERFORMANCE

CARD NO 1

FILL IN BLANKS AS REQUIRED (FREE FORMAT) TO IDENTIFY CUSTOMER/CLIENT, CONT NO., TEST IDENTIFICATION, DATE, ETC

☐☐
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

CARD NO 2

IU —
MEASUREMENT UNITS
ENTER 1 — U S CUSTOMARY
2 — S.I

IPR —
TYPE OF MEASUREMENT
ENTER 1 — TOTAL & STATIC PRESSURE
2 — STATIC & VELOCITY PRESSURE
3 — TOTAL & VELOCITY PRESSURE

IMASS —
LOCATION OF MASS FLOW MEASUREMENT
ENTER. 1 — INLET
2 — OUTLET
3 — INLET & OUTLET AVERAGED
4 — REMOTE FROM FAN BOUNDARY

ICALC —
PERFORMANCE CALCULATION
ENTER 1 — MASS FLOW / SPECIFIC ENERGY
2 — VOLUME FLOW / PRESSURE
3 — BOTH OF THE ABOVE

IAIR —
GAS COMPOSITION
ENTER: 1 — AIR
2 — OTHER GASES

IPOW —
INPUT POWER SOURCE
ENTER 1 — AC MOTOR (CAL)
2 — DC MOTOR (CAL)
3 — TORQUE METER
4 — STEAM TURBINE

CARD COLUMN —	☐	☐	☐	☐	☐	☐
	5	10	15	20	25	30

CARD NO 3

TD — DRY BULB TEMP	TW — WET BULB TEMP.	S — SPECIFIC HUMIDITY	— AIR WHEN IAIR = 1
CO₂ — % CO₂ by dry volume	O₂ — % O₂ by dry volume	CO — % CO by dry volume	S — Specific humidity
☐☐☐☐●☐☐☐☐☐	☐☐☐☐●☐☐☐☐☐	☐☐☐☐●☐☐☐☐☐	☐☐☐☐●☐☐☐☐☐
1 2 3 4 5 6 7 8 9 10	11 12 13 14 15 16 17 18 19 20	21 22 23 24 25 26 27 28 29 30	31 32 33 34 35 36 37 38 39 40

OTHER GASES
WHEN IAIR = 2

NOTE. WHEN:	DRY BULB TEMP.	WET BULB TEMP	SPECIFIC HUMIDITY
IU = 1	°F	°F	lbm H_2O / lbm DRY GAS — U.S CUSTOMARY
IU = 2	°C	°C	kg H_2O / kg DRY GAS — S I

CARD NO. 4 — FAN DESIGN CONDITIONS — GAS PROPERTIES AT INLET

RPMC — SHAFT SPEED	PTA1C — ABSOLUTE PRESS.	T1C — TEMPERATURE	RHO1C — INLET DENSITY	KC — SPECIFIC HEAT RATIO	
rpm	in. wa.	°F	lbm / ft.³	dimensionless	— U S CUSTOMARY WHEN. IU = 1
rev / s	kPa	°C	kg / m³	dimensionless	— S.I IU = 2
☐☐☐☐●☐☐☐☐☐	☐☐☐☐●☐☐☐☐☐	☐☐☐☐●☐☐☐☐☐	☐☐☐☐●☐☐☐☐☐	☐☐☐☐●☐☐☐☐☐	
1 2 3 4 5 6 7 8 9 10	11 12 13 14 15 16 17 18 19 20	21 22 23 24 25 26 27 28 29 30	31 32 33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48 49 50	

CARD NO 5 — TEST MEASUREMENTS

RPMI — SHAFT SPEED	POWI — INPUT POWER	
rpm	hp	— U.S CUSTOMARY WHEN. IU = 1
rev/s	kW	— S.I. IU = 2
☐☐☐☐●☐☐☐☐☐	☐☐☐☐☐☐☐☐☐●	
1 2 3 4 5 6 7 8 9 10	11 12 13 14 15 16 17 18 19 20	

CARD NO 7

RP	
no. of ports	(RIGHT JUSTIFIED)
☐☐☐☐☐	
1 2 3 4 5	

CARD NO 6

PB — BAROMETRIC PRESS.	
in. Hg	— U.S CUSTOMARY WHEN IU = 1
kPa	— S.I IU = 2
☐☐☐☐●☐☐☐☐☐	
1 2 3 4 5 6 7 8 9 10	

CARD NO. 8

	*TRAVERSE PLANE DIMENSIONS (SEE NOTE)	
DS — PROBE DIAMETER	*DIM. 1	*DIM. 2
in.	in.	in
mm	m	m
☐☐☐☐●☐☐☐☐☐	☐☐☐☐●☐☐☐☐☐	☐☐☐☐●☐☐☐☐☐
1 2 3 4 5 6 7 8 9 10	11 12 13 14 15 16 17 18 19 20	21 22 23 24 25 26 27 28 29 30

CARD NO. 9
BLOCK — CALCULATE PROBE BLOCKAGE. YES OR NO
(LEFT JUSTIFIED)

1	2	3

CARD NO 11

NT OR NT 1					NT 2				
1	2	3	4	5	6	7	8	9	10

NT — NUMBER OF TRAVERSE POSITIONS PER PORT IF PROBE INSERTION FROM ONE SIDE
OR
NT 1 — NUMBER OF TRAVERSE POSITIONS FROM ONE SIDE
NT 2 — NUMBER OF TRAVERSE POSITIONS FROM OTHER SIDE
(RIGHT JUSTIFIED)

CARD NO 10
INSERT

1	2	3	4	5

— 1 IF PROBE INSERTED FROM ONE SIDE
2 IF PROBE INSERTED FROM BOTH SIDES
(RIGHT JUSTIFIED)
} ASSUMES ONE PROBE TEAM AND SINGLE INLET FAN

NOTES:

IF IU = 1, THEN ALL PRESSURES ARE TO BE EXPRESSED IN in wg AND TEMPERATURE IN °F.

IF IU = 2, THEN ALL PRESSURES ARE TO BE EXPRESSED IN kPa AND TEMPERATURE IN °C

ALL ANGLES ARE TO BE EXPRESSED IN DEGREES.

ALL PROBES USED MUST BE IDENTIFIED WITH AN INTEGER VALUE AND APPROPRIATE CHANGES MUST BE MADE IN SUBROUTINE PRBCL TO MATCH PROBE IDENTIFICATION NUMBER WITH THE PROPER POLYNOMICAL EQUATION. THE EQUATION MUST REPRESENT THE CALIBRATION CURVE FIT FOR THE PROBE USED

IF TRAVERSE SECTION IS ROUND, DIM. 1 = DIAMETER
DIM. 2 = 0.0

CARD NOS. 12 through N. See NOTES above

Traverse point ident.				PTIS — Total pressure										PSIS — Static pressure										TIS — Temperature										YAWS — Yaw angle										PITCHS — Pitch pressure										IDPBS — Probe ident.									
				PSIS — Static pressure										PVIS — Velocity pressure										TIS — Temperature										YAWS — Yaw angle										PITCHS — Pitch pressure										Enter w/o decimal point									
				PTIS — Total pressure										PVIS — Velocity pressure										TIS — Temperature										YAWS — Yaw angle										PITCHS — Pitch pressure										or trailing blanks									
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64
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IF IPR = 1
IF IPR = 2
IF IPR = 3

NOTE: Card numbers 7 through N must be entered for each test plane in the following order:

Inlet plane
Outlet plane
Auxiliary plane (IMASS = 4)

```
LAB*LABSRC(1).PTC11-MAIN(6)
C*******************************************************************C
C*******************************************************************C
C                                                                   C
C          THIS PROGRAM WILL CALCULATE THE PERFORMANCE              C
C           OF A FAN USING THE METHOD PRESCRIBED IN:                C
C                                                                   C
C         A.S.M.E.  P.T.C. 11 DRAFT CODE SEPTEMBER 1982             C
C                                                                   C
C                                                                   C
C     THIS COMPUTER CODE IS PROVIDED TO SERVE AS A GUIDE ONLY.      C
C                                                                   C
C     NO CLAIMS ARE MADE OR IMPLIED AS TO ITS CORRECTNESS.          C
C                                                                   C
C*******************************************************************C
C*******************************************************************C
C                                                                   C
C           PROGRAMMED BY:   M.J. DORSEY , U. OF AKRON              C
C                                                                   C
C           DATE:            SEPTEMBER 1980                         C
C                                                                   C
C           UPDATED BY:      S.P. NUSPL  , BABCOCK & WILCOX         C
C                                                                   C
C           DATE:            MAY 1981                               C
C                                                                   C
C           UPDATED BY:      R.W. LIPKE  , BUFFALO FORGE            C
C                                                                   C
C           DATE:            OCTOBER 1983                           C
C                                                                   C
C*******************************************************************C
C*******************************************************************C
C
      REAL    JC     ,KVJC  ,KTJ   ,MU     ,MDOT  ,MDOT1 ,MDOT2 ,MDOT3
     1       ,KC    ,N2    ,KRHO  ,N      ,MDOTC
C
      INTEGER Z
C
      CHARACTER *3 ,ANS ,TERM ,TAG*17
C
C
      COMMON / AVRGS  / MDOT  ,PTX   ,PSX   ,PVX   ,PSAX  ,PTAX   ,
     1                  TSX   ,RHOX  ,EKX   ,ALPHAX
      COMMON / CONST  / RO    ,JC    ,GC
      COMMON / CONST1 / C     ,CC
      COMMON / CNTRL  / NP    ,NT    ,PB    ,IAIR  ,IMASS ,IPOW
      COMMON / CONTRL / IU    ,IPR
      COMMON / DATAI  / PTI   ,PSI   ,PVI   ,TI    ,YAW   ,
     1                  IDPRB ,D     ,PITCH
      COMMON / DATAJ  / PTJ   ,PSJ   ,PVJ   ,TSJ   ,PSAJ  ,
     1                  AREA  ,RHOJ  ,PITCHJ
      COMMON /  GAS   / CO2   ,O2    ,CO    ,N2    ,S
      COMMON / PRFRM  / RHO1  ,RHO2  ,EK1   ,EK2   ,POWI  ,POWO   ,
     1                  POWOC ,RPM1  ,RPMC  ,KC    ,RHO1C ,T1C    ,
     2                  PTA1C
      COMMON / PRFRM1 / ALPHA1,ALPHA2
      COMMON / OUTME  / MDOTC ,YFC   ,POWIC ,KRHOC ,ETAC  ,RHOMC
      COMMON / UMASS  / UMDTFR,UYFR  ,UPIR  ,UETAR ,URHOMR,UPOR   ,
     1                  UMDTFS,UYFS  ,UPIS  ,UETAS ,URHOMS,UPOS
      COMMON / UMASSC / UMDTCR,UYFCR ,URHOCR,UMDTCS,UYFCS ,URHOCS
      COMMON / OUTVP  / QFC   ,PFTC  ,PFVC  ,PFSC  ,KPC   ,ETASC  ,
     1                  ETAT  ,ETATC ,ETAS
      COMMON / PROP   / K     ,R     ,MU
C
      COMMON / UPAN   / UAR   ,URR   ,UTSJR ,UPVJR ,UPSJR ,UPBR   ,
     1                  UYAWR ,UPCHR ,UETAMR,UWR   ,UER   ,UIR    ,
     2                  UTAUR ,UNR   ,UPTR  ,UFNR
      COMMON / USYS   / UAS   ,URS   ,UTSJS ,UPVJS ,UPSJS ,UPBS   ,
     1                  UYAWS ,UPCHS ,UETAMS,UWS   ,UES   ,UIS    ,
     2                  UTAUS ,UNS   ,UPTS  ,UFNS
      COMMON / UNCT1R / UMDT1R,UPS1R ,URHO1R,UTS1R ,UEK1R ,UPV1R  ,
     1                  UPT1R ,UPSA1R
      COMMON / UNCT2R / UMDT2R,UPS2R ,URHO2R,UTS2R ,UEK2R ,UPV2R  ,
     1                  UPT2R ,UPSA2R
      COMMON / UNCT1S / UMDT1S,UPS1S ,URHO1S,UTS1S ,UEK1S ,UPV1S  ,
     1                  UPT1S ,UPSA1S
      COMMON / UNCT2S / UMDT2S,UPS2S ,URHO2S,UTS2S ,UEK2S ,UPV2S  ,
```

```
     1                  UPT2S ,UPSA2S
      COMMON / UNCT3R / UMDT3R,UPS3R ,URHO3R,UTS3R ,UEK3R ,UPV3R ,
     1                  UPT3R ,UPSA3R
      COMMON / UNCT3S / UMDT3S,UPS3S ,URHO3S,UTS3S ,UEK3S ,UPV3S ,
     1                  UPT3S ,UPSA3S
      COMMON / UNCRT  / UMDOT ,UPX   ,URHOX ,UTSX  ,UEKX  ,UPVX  ,
     1                  UPTX  ,UPSX  ,UPSAX
      COMMON /  STDY  / UFSMR ,UFSQR ,UFSYR ,UFSPTR,UFSROR,UFSNR ,
     1                  UFSPR
      COMMON / PLNAVG / MDOT1 ,MDOT2 ,MCOT3 ,YF    ,PS1   ,PS2   ,
     1                  PS3   ,PV1   ,PV2   ,PT1   ,PT2   ,PSA1  ,
     2                  PSA2  ,PSA3  ,TS1   ,TS2   ,PFT   ,PFS   ,
     3                  PFV   ,KP
      COMMON / UVOPRP / UQFR  ,UPFTR ,UPFVR ,UPFSR ,UETATR,UETASR,
     1                  URHOFR
      COMMON / UVOPRS / UQFS  ,UPFTS ,UPFVS ,UPFSS ,UETATS,UETASS,
     1                  URHOFS
      COMMON / UVPCR  / UQFCR ,UPFTCR,UPFSCR,UPFVCR,UPICR ,UPOCR ,
     1                  UETACR
      COMMON / UVPCS  / UQFCS ,UPFTCS,UPFSCS,UPFVCS,UPICS ,UPOCS ,
     1                  UETACS
C
      DIMENSION    C(18)       ,PTJ(25,10)  ,PSJ(25,10)  ,PVJ(25,10)   ,
     1             PSAJ(25,10) ,TSJ(25,10)  ,TI(25,10)   ,RHOJ(25,10)  ,
     2             VJ(25,10)   ,YAW(25,10)  ,PTI(25,10)  ,PSI(25,10)   ,
     3             PVI(25,10)  ,IDPRB(25,10),KVJC(25,10) ,EP(25,10)    ,
     4             ET(25,10)   ,RPJ(25,10)  ,PITCH(25,10),PITCHJ(25,10),
     5             IM(25,10)   ,ITER(25,10) ,KTJ(25,10)  ,AREA(3)
C
      DATA Z/20/
C
C**********************************************************************C
C                                                                      C
C                      OPEN TEMPORARY PRINT FILE                       C
C                                                                      C
C**********************************************************************C
C
      CALL FTAG(TAG)
      CALL FACSF('@ASG,CP '//TAG)
      CALL FACSF('@USE ALT-PR.,'//TAG)
      OPEN(20,FILE='ALT-PR.',TYPE='APRNTA',MRECL=132)
C
C**********************************************************************C
C                                                                      C
C       OPEN TEMPORARY DATA FILE & READ STEADINESS UNCERTAINTIES       C
C                              CLOSE FILE                              C
C                                                                      C
C**********************************************************************C
C
      OPEN(15,FILE='LAB*UNCERT',ACCESS='DIR',FORM='UNFORMATTED',RECL=80
     1   ,RCDS=1,ASSOC=IREC,STATUS='OLD')
      READ(15'1)UFSMR,UFSQR,UFSYR,UFSPTR,UFSROR,UFSNR,UFSPR
      CLOSE(15)
C
      UMDT3R  = 0.0
      UPV3P   = 0.0
      UPSA3R  = 0.0
      UPS3R   = 0.0
      URHO3R  = 0.0
      UTS3R   = 0.0
      UEK3R   = 0.0
      UNDT3S  = 0.0
      UPU3S   = 0.0
      UPT3S   = 0.0
      UPSA3S  = 0.0
      UPS3S   = 0.0
      URHO3S  = 0.0
      UTS3S   = 0.0
      UEK3S   = 0.0
      MDOT    = 0.0
C
      L       = 0
      NOTE    = 0
C
C**********************************************************************C
C                                                                      C
```

```
C                   INDICATE WHETHER PORTABLE TERMINAL IS TO BE USED         C
C                                    READ INPUT DATA                         C
C                                   SUBROUTINE INPUT                         C
C                                                                            C
C****************************************************************************C
C
   10 WRITE(6,1000)
      READ (5,5140) TERM
   20 PRINT *,' CALL INPUT'
C
      IF ( TERM .EQ. 'YES' ) CALL INPUT1 ( L,ICALC,TD,TW,IM )
      IF ( TERM .EQ. 'NO'  ) CALL INPUT  ( L,ICALC,TD,TW,IM )
C
      IF (( TERM .NE. 'YES' ) .AND. ( TERM .NE. 'NO' )) GO TO 10
C
C****************************************************************************C
C                                                                            C
C                 INITIALIZE VARIABLES FOR TEST PLANE CALCULATIONS           C
C                                                                            C
C****************************************************************************C
C
      ISTOP = NT * NP
      N     = NT * NP
C
      DO 30 I = 1,NP
      DO 30 J = 1,NT
C
      VJ(I,J)    = 0.0
      ITER(I,J)  = 0.0
C
   30 CONTINUE
C
      TX = 0.0
C
      DO 50 I = 1,NP
      DO 50 J = 1,NT
C
      TX = TX + TI(I,J)
C
   50 CONTINUE
C
      TX = TX / N
C
C****************************************************************************C
C                                                                            C
C               CALCULATE AVERAGE GAS PROPERTIES AT THE TEST PLANE           C
C                               SUBROUTINE GASPRP                            C
C                                                                            C
C****************************************************************************C
C
      CALL GASPRP ( TX,CP,TD,TW,RHO0 )
C
C****************************************************************************C
C                                                                            C
C               CORRECT THE PRESSURE AND TEMPERATURE READINGS BEFORE         C
C                  CALCULATING AVERAGE VALUES IN THE TEST PLANE              C
C                               SUBROUTINE CORECT                            C
C                                                                            C
C****************************************************************************C
C
      CALL CORECT ( ITER,VJ,KVJC,KTJ,EP,ET,RPJ,RHO0,TD,L )
C
C****************************************************************************C
C                                                                            C
C                          OUTPUT OF TEST PLANE RESULTS                      C
C                                                                            C
C****************************************************************************C
C
      IF ( TERM .EQ. 'NO' ) THEN
      IF (( NP .EQ .1 ) .AND. ( NT .EQ. 1 )) GO TO 60
C
      WRITE(Z,5070)
      WRITE(Z,5080)
      WRITE(Z,5080)
      WRITE(Z,5020)
C
```

```
      IF ( L .EQ. 1) WRITE(Z,5040)
      IF ( L .EQ. 2) WRITE(Z,5050)
      IF ( L .EQ. 3) WRITE(Z,5060)
C
      WRITE(Z,5020)
      WRITE(Z,5080)
      WRITE(Z,5080)
      WRITE(Z,5020)
   56 WRITE(Z,5010)
C
      IF ( IU .EQ. 1 ) WRITE(Z,5011)
      IF ( IU .EQ. 2 ) WRITE(Z,6011)
C
      DO 60 I = 1,NP
C
      WRITE(Z,5020)
C
      DO 60 J = 1,NT
C
      IF ( ITER(I,J) .GT. 100 ) THEN
         WRITE(Z,5031) IM(I,J)      ,PTJ(I,J)     ,PSJ(I,J)     ,PVJ(I,J)     ,
     1                 TSJ(I,J)     ,RHOJ(I,J)    , EP(I,J)     ,ET(I,J)      ,
     2                 RPJ(I,J)     ,KVJC(I,J)    ,KTJ(I,J)     ,VJ(I,J)      ,
     3                 YAW(I,J)     ,PITCHJ(I,J),ITER(I,J)
         NOTE = 1
      ELSE
         WRITE(Z,5030) IM(I,J)      ,PTJ(I,J)     ,PSJ(I,J)     ,PVJ(I,J)     ,
     1                 TSJ(I,J)     ,RHOJ(I,J)    , EP(I,J)     ,ET(I,J)      ,
     2                 RPJ(I,J)     ,KVJC(I,J)    ,KTJ(I,J)     ,VJ(I,J)      ,
     3                 YAW(I,J)     ,PITCHJ(I,J),ITER(I,J)
      END IF
C
   60 CONTINUE
C
      IF ( NOTE .EQ. 1 ) THEN
         WRITE(Z,5150)
      END IF
      END IF
C
C*********************************************************************C
C                                                                     C
C           CALCULATE AVERAGE PROPERTY VALUES IN TEST PLANE           C
C                         SUBROUTINE AVRGES                           C
C                                                                     C
C*********************************************************************C
C
      CALL AVRGES ( YAW,VJ,C(2),C(11),C(13),GC,L,TERM )
C
      GO TO ( 70 ,80 ,90 ),L
C
C*********************************************************************C
C                                                                     C
C           SAVE VALUES OF PERTINENT VARIABLES AT FAN INLET           C
C                   AND CALCULATE UNCERTAINTIES                       C
C                         SUBROUTINE UNCERT                           C
C                                                                     C
C*********************************************************************C
C
   70 MDOT1   = MDOT
      PS1     = PSX
      PSA1    = PSAX
      PTA1    = PTAX
      RHO1    = RHOX
      EK1     = EKX
      CP1     = CP
      TS1     = TSX
      PV1     = PVX
      PT1     = PTX
      ALPHA1  = ALPHAX
C
      CALL UNCERT ( 1,VJ,C(2),C(11),C(13),N,RHOM,L,R )
C
      UMDT1R  = SQRT(UMDOT)
      UPS1R   = SQRT(UPSX)
      URHO1R  = SQRT(URHOX)
      UTS1R   = SQRT(UTSX)
```

```
      UEK1R   = SQRT(UEKX)
      UPV1R   = SQRT(UPVX)
      UPT1R   = SQRT(UPTX)
      UPSA1R  = SQRT(UPSAX)
C
      CALL UNCERT ( 2,VJ,C(2),C(11),C(13),N,RHOM,L,R )
C
      UMDT1S  = SQRT(UMDOT)
      UPS1S   = SQRT(UPSX)
      URHO1S  = SQRT(URHOX)
      UTS1S   = SQRT(UTSX)
      UEK1S   = SQRT(UEKX)
      UPV1S   = SQRT(UPVX)
      UPT1S   = SQRT(UPTX)
      UPSA1S  = SQRT(UPSAX)
C
      GO TO 20
C
C**********************************************************************C
C                                                                      C
C           SAVE VALUES OF PERTINENT VARIABLES AT FAN OUTLET          C
C                       AND CALCULATE UNCERTAINTIES                    C
C                            SUBROUTINE UNCERT                         C
C                                                                      C
C**********************************************************************C
C
   80 MDOT2   = MDOT
      PS2     = PSX
      PTA2    = PTAX
      RHO2    = RHOX
      EK2     = EKX
      TS2     = TSX
      PV2     = PVX
      PT2     = PTX
      PSA2    = PSAX
      ALPHA2  = ALPHAX
C
      CALL UNCERT ( 1,VJ,C(2),C(11),C(13),N,RHOM,L,R )
C
      UMDT2R  = SQRT(UMDOT)
      UPS2R   = SQRT(UPSX)
      URHO2R  = SQRT(URHOX)
      UTS2R   = SQRT(UTSX)
      UEK2R   = SQRT(UEKX)
      UPV2R   = SQRT(UPVX)
      UPT2R   = SQRT(UPTX)
      UPSA2R  = SQRT(UPSAX)
C
      CALL UNCERT ( 2,VJ,C(2),C(11),C(13),N,RHOM,L,R )
C
      UMDT2S  = SQRT(UMDOT)
      UPS2S   = SQRT(UPSX)
      URHO2S  = SQRT(URHOX)
      UTS2S   = SQRT(UTSX)
      UEK2S   = SQRT(UEKX)
      UPV2S   = SQRT(UPVX)
      UPT2S   = SQRT(UPTX)
      UPSA2S  = SQRT(UPSAX)
C
C**********************************************************************C
C                                                                      C
C           MASS FLOW RATE DETERMINED AT THIRD TEST PLANE             C
C                          SUBROUTINE UNCERT                           C
C                                                                      C
C**********************************************************************C
C
      IF ( IMASS .EQ. 4 ) GO TO 20
90    IF ( IMASS .LT. 4 ) GO TO 95
C
      MDOT3  = MDOT
      PSA3   = PSAX
C
      CALL UNCERT ( 1,VJ,C(2),C(11),C(13),N,RHOM,L,R )
C
      UMDT3R = SQRT(UMDOT)
      UPS3R  = SQRT(UPSX)
```

```
      URHO3R = SQRT(URHOX)
      UTS3R  = SQRT(UTSX)
      UEK3R  = SQRT(UEKX)
      UPV3R  = SQRT(UPVX)
      UPT3R  = SQRT(UPTX)
      UPSA3R = SQRT(UPSAX)
C
      CALL UNCERT ( 2,VJ,C(2),C(11),C(13),N,RHOM,L,R )
C
      UMDT3S = SQRT(UMDOT)
      UPS3S  = SQRT(UPSX)
      URHO3S = SQRT(URHOX)
      UTS3S  = SQRT(UTSX)
      UEK3S  = SQRT(UEKX)
      UPV3S  = SQRT(UPVX)
      UPT3S  = SQRT(UPTX)
      UPSA3S = SQRT(UPSAX)
C
  95  IF ( IMASS .EQ. 1 ) MDOT = MDOT1
      IF ( IMASS .EQ. 2 ) MDOT = MDOT2
      IF ( IMASS .EQ. 3 ) MDOT = ( MDOT1 + MDOT2 ) / 2.
      IF ( IMASS .EQ. 4 ) MDOT = MDOT3
      IF ( ICALC .EQ. 2 ) GO TO 100
C
      IF ( TERM .EQ. 'NO' ) WRITE(Z,5100)
C
C**********************************************************************C
C                                                                      C
C                CALCULATE FAN PERFORMANCE USING THE                   C
C              MASS FLOW RATE/SPECIFIC ENERGY APPROACH                 C
C                    AND CALCULATE UNCERTAINTIES                       C
C                          SUBROUTINE MASNRG                           C
C                          SUBROUTINE UNCERT                           C
C                                                                      C
C**********************************************************************C
C
      CALL MASNRG ( MDOT,C(11),C(16),RHOM,KRHO,ETA,GC,AREA )
C
      CALL UNCERT ( 3,VJ,C(2),C(11),C(13),N,RHOM,L,R )
C
C**********************************************************************C
C                                                                      C
C       OUTPUT RESULTS FROM MASS FLOW RATE/SPEC ENERGY APPROACH        C
C                             SUBROUTINE OUTM                          C
C                                                                      C
C**********************************************************************C
C
      IF ( TERM .EQ. 'NO'  ) CALL OUTM  ( MDOT,RHOM,KRHO,ETA,IU )
      IF ( TERM .EQ. 'YES' ) CALL OUTM1 ( IU , KRHO )
C
C
  100 IF ( ICALC .EQ. 1 ) GO TO 110
C
      IF ( TERM .EQ. 'NO' ) WRITE(Z,5100)
C
C**********************************************************************C
C                                                                      C
C                 CALCULATE FAN PERFORMANCE USING THE                  C
C                 VOLUME FLOW RATE/PRESSURE APPROACH                   C
C                     AND CALCULATE UNCERTAINTIES                      C
C                            SUBROUTINE VOLPRS                         C
C                            SUBROUTINE UNCERT                         C
C                                                                      C
C**********************************************************************C
C
      CALL VOLPRS ( PTA1,CP1,MDOT,C(2),C(11),C(17),JC,OF,RHOF )
C
      CALL UNCERT ( 4,VJ,C(2),C(11),C(13),N,RHOM,L,R )
C
C**********************************************************************C
C                                                                      C
C       OUTPUT RESULTS FROM VOLUME FLOW RATE/PRESSURE APPROACH         C
C                            SUBROUTINE OUTV                           C
C                                                                      C
C**********************************************************************C
C
```

```
      IF ( TERM .EQ. 'NO'  ) CALL OUTV  ( QF,RHOF,IU )
      IF ( TERM .EQ. 'YES' ) CALL OUTV1 ( IU )
C
C****************************************************************C
C                                                                C
C                      CLOSE TEMPORARY PRINT FILE                C
C                                                                C
C****************************************************************C
C
      PRINT *,'DESIRE PRINTOUT : Y-YES OR N-NO'
      READ(5,5140)ANS
      IF ( ANS .EQ. 'N' ) GO TO 120
C
      CALL FACSF('@FREE,R ALT-PR.')
      CALL FACSF('@ASG,A ALT-PR.')
      CALL FACSF('@SYM ALT-PR.,,PR1')
C
      GO TO 110
C
  120 CLOSE(25,STATUS='DELETE')
C
  110 PRINT *,'                         END OF PTC-11'
C
      CALL EXIT
C
C****************************************************************C
C****************************************************************C
C
 1000 FORMAT(' PORTABLE TERMINAL USED - "YES" OR "NO"')
 5010 FORMAT(1X,'POINT',3X,'PT(J)',4X,'PS(J)',3X,'PV(J)',3X,
     1   'TS(J)',3X,'RHO(J)',3X,'1 - EP',3X,'1 + ET',3X,'PROBE RE',
     2   5X,'KVJC',5X,'KTJ',5X,'VELOCITY',4X,'YAW',4X,'PITCH',5X,'ITER')
 5011 FORMAT(16X,'(IN. WG)',11X,'(R)',2X,
     1          '(LBM/CU FT)',49X,'(FPM)',5X,'(DEG)',3X,'(DEG)',/)
 6011 FORMAT(18X,'(KPA)',12X,'(K)',3X,
     1          '(KG/CU M)',50X,'(M/S)',5X,'(DEG)',3X,'(DEG)',/)
 5020 FORMAT(/)
 5030 FORMAT(1X,A4,F9.3,F9.3,F8.3,F9.2,F8.5,2F9.5,F12.3,2F9.5,
     1   F10.2,F9.2,F9.3,I7)
 5031 FORMAT(1X,A4,F9.3,F9.3,F8.3,F9.2,F8.5,2F9.5,F12.3,2F9.5,
     1   F10.2,F9.2,F9.3,I7,'*')
 5040 FORMAT(56X,22HRESULTS AT INLET PLANE)
 5050 FORMAT(56X,23HRESULTS AT OUTLET PLANE)
 5060 FORMAT(56X,47HRESULTS AT AUXILLIARY PLANE (FINDING FLOW RATE))
 5070 FORMAT(1H1)
 5080 FORMAT(1X,132(1H*))
 5100 FORMAT(1H1,2(132(1H*)/1X)/60X,
     1 19HPERFORMANCE PESULTS//2(1X,132(1H*)/))
 5110 FORMAT(1H1,2(30(1H*)/1X)/6X,25HMACH NO. GREATER THAN 0.4,
     1 /2(1X,30(1H*)/)/6X,5HPOINT,5X,8HK*PV/PSA//)
 5120 FORMAT(1H0,6X,A4,6X,F6.4)
 5130 FOPMAT(1H0,///10X,
     1 49HPERCENTAGE OF TOTAL POINTS WITH MACH NO. OVER 0.4,1X,F6.2)
 5140 FORMAT(A3)
 5150 FORMAT(6(/),20X,'* W A R N I N G - MAY NOT HAVE CONVERGED')
C
      END

@PRT,L LABSRC.INPUT
```

```
LAB*LABSRC(1).INPUT(43)
C*********************************************************C
C*********************************************************C
C                                                         C
C     SUBROUTINE INPUT READS THE INPUT DATA AND ECHOS THE INPUT   C
C     DATA TO THE MAINFRAME PRINTER FOR VERIFICATION BY THE USER  C
C                                                         C
C*********************************************************C
C*********************************************************C
C
      SUBROUTINE INPUT ( L ,ICALC ,TD ,TW ,IPNT )
C
      REAL     JC     ,KC     ,N2
      INTEGER Z
      CHARACTER BLOCK *3
C
      COMMON / CONST  / RO     ,JC     ,GC
      COMMON / CONST1 / C      ,CC
      COMMON / CNTRL  / NP     ,NT     ,PB     ,IAIR   ,IMASS ,IPOW
      COMMON / CONTRL / IU     ,IPR
      COMMON / BLKAGE / SPJ
      COMMON / DATAI  / PTI    ,PSI    ,PVI    ,TI     ,YAW    ,
     1                  IDPRB  ,D      ,PITCH
      COMMON / DATAJ  / PTJ    ,PSJ    ,PVJ    ,TSJ    ,PSAJ   ,
     1                  AREA   ,RHOJ   ,PITCHJ
      COMMON /  GAS   / CO2    ,O2     ,CO     ,N2     ,S
      COMMON / PRFRM  / RHO1   ,RHO2   ,EK1    ,EK2    ,POWI   ,POWO   ,
     1                  POWOC  ,RPM1   ,RPMC   ,KC     ,RHO1C  ,T1C    ,
     2                  PTA1C
      COMMON /  URAN  / UAR    ,UPR    ,UTSJR  ,UPVJR  ,UPSJR  ,UPBR   ,
     1                  UYAWR  ,UPCHR  ,UETAPR ,UWR    ,UER    ,UIR    ,
     2                  UTAUR  ,UNR    ,UPTR   ,UFNR
      COMMON /  USYS  / UAS    ,URS    ,UTSJS  ,UPVJS  ,UPSJS  ,UPBS   ,
     1                  UYAWS  ,UPCHS  ,UETAPS ,UWS    ,UES    ,UIS    ,
     2                  UTAUS  ,UNS    ,UPTS   ,UFNS
      COMMON /  STDY  / UFSMR  ,UFSQR  ,UFSYR  ,UFSPTR,UFSRCR,UFSNR  ,
     1                  UFSPR
C
      DIMENSION     C(18)        ,PTJ(25,10)   ,PSJ(25,10)   ,PVJ(25,10)   ,
     1              PTI(25,10)   ,PSI(25,10)   ,PVI(25,10)   ,YAW(25,10)   ,
     2              TI(25,10)    ,TSJ(25,10)   ,PSAJ(25,10)  ,IDPRB(25,10),
     3              RHOJ(25,10)  ,SPJ(3,25)    ,C1(20)       ,C2(20)       ,
     4              AREA(3)
C
      DIMENSION     TITLE(25)     ,PITCH(25,10) ,PITCHJ(25,10)   ,
     1              IPNT(25,10)
C
      DATA Z  / 20 /
      DATA C1 /  459.7    ,60.     ,1.0     ,0.672   ,1.0     ,2.96E-4
     1          ,-1.59E-2,0.41    ,2700.   ,70.77   ,5.193   ,1097.
     2          ,13.62    ,745.7   ,5252.1  ,550.    ,6354.   ,32.17
     3          ,778.2    ,1545.   /
C
      DATA C2 /  273.2    ,1.0     ,1.8     ,1.0     ,4166.   ,.00325
     1          ,.0186    ,.692    ,1500.   ,1000.   ,1000.   ,44.72
     2          ,1.0      ,1000.   ,159.15  ,1000.   ,1.0     ,1.0
     3          ,1.0      ,8314.   /
C
      L = L + 1
C
C*********************************************************C
C                                                         C
C             READ JOB TITLE AND CONTROL DATA             C
C                                                         C
C*********************************************************C
C
      IF ( L .GT. 1 ) GO TO 75
C
      READ(5, 1030) (TITLE(I), I= 1, 20)
      READ(5,1000) IU   ,IPR ,IMASS,ICALC,IAIR,IPOW
C
C*********************************************************C
C                                                         C
C             SET UNITS TO U.S. CUSTOMARY OR S.I.         C
C                                                         C
C*********************************************************C
```

```
C
      IF( IU .EQ. 2 ) GO TO 6
C
      DO 4 I = 1,17
C
      C(I) = C1(I)
C
    4 CONTINUE
C
      RO = C1(20)
      JC = C1(19)
      GC = C1(18)
C
      GO TO 18
C
    6 DO 7 I = 1,17
C
      C(I) = C2(I)
C
    7 CONTINUE
C
      RO = C2(20)
      JC = C2(19)
      GC = C2(18)
C
C*********************************************************************C
C                                                                     C
C                  OUTPUT TITLE AND CONTROL PARAMETERS                C
C                                                                     C
C*********************************************************************C
C
   18 WRITE(Z,1060)
      WRITE(Z,1100)
      WRITE(Z,1190)
      WRITE(Z,1070)
      WRITE(Z,1050)(TITLE(I),I = 1,20)
      WRITE(Z,1070)
      WRITE(Z,1190)
      WRITE(Z,1100)
      WRITE(Z,1080)
      WRITE(Z,5000)
C
      IF ( IU     .EQ. 1 ) WRITE(Z,5010)
      IF ( IU     .EQ. 2 ) WRITE(Z,6010)
      IF ( IPR    .EQ. 1 ) WRITE(Z,5020)
      IF ( IPR    .EQ. 2 ) WRITE(Z,5030)
      IF ( IPR    .EQ. 3 ) WRITE(Z,5040)
      IF ( IMASS  .EQ. 1 ) WRITE(Z,5050)
      IF ( IMASS  .EQ. 2 ) WRITE(Z,5060)
      IF ( IMASS  .EQ. 3 ) WRITE(Z,5070)
      IF ( IMASS  .EQ. 4 ) WRITE(Z,5080)
      IF ( ICALC  .EQ. 1 ) WRITE(Z,5090)
      IF ( ICALC  .EQ. 2 ) WRITE(Z,5100)
      IF ( ICALC  .EQ. 3 ) WRITE(Z,5110)
      IF ( IAIR   .EQ. 1 ) WRITE(Z,5120)
      IF ( IAIR   .EQ. 2 ) WRITE(Z,5130)
      IF ( IPOW   .EQ. 1 ) WRITE(Z,5140)
      IF ( IPOW   .EQ. 2 ) WRITE(Z,5150)
      IF ( IPOW   .EQ. 3 ) WRITE(Z,5160)
      IF ( IPOW   .EQ. 4 ) WRITE(Z,5170)
C
C*********************************************************************C
C                                                                     C
C                      READ AND WRITE GAS ANALYSIS                    C
C                                                                     C
C*********************************************************************C
C
      WRITE(Z,1080)
      WRITE(Z,1090)
      WRITE(Z,1080)
C
      IF ( IAIR .EQ. 1 ) GO TO 20
C
      READ(5,1010) CO2 ,O2  ,CO  ,S
C
      CO2 = CO2 / 100.
```

```
      O2   = O2   / 100.
      CO   = CO   / 100.
      N2   = 1.0 - CO2 - CO - O2
C
      WRITE(Z,5205) CO2 ,O2 ,CO ,N2
C
      GO TO 25
C
   20 READ(5,1010) TD ,TW ,S
      WRITE(Z,5180)
C
      IF ( IU .EQ. 1 ) WRITE(Z,5190) TD ,TW
      IF ( IU .EQ. 2 ) WRITE(Z,6190) TD ,TW
   25 IF ( IU .EQ. 1 ) WRITE(Z,5200) S
      IF ( IU .EQ. 2 ) WRITE(Z,6200) S
C
      WRITE(Z,1080)
      WRITE(Z,1090)
      WRITE(Z,1090)
      WRITE(Z,1060)
C
C**********************************************************************C
C                                                                      C
C           READ AND WRITE SPECIFIED OPERATING CONDITIONS              C
C                                                                      C
C**********************************************************************C
C
      WRITE(Z,1090)
      WRITE(Z,1090)
      READ(5,1010) RPMC ,PTA1C ,T1C ,RHO1C ,KC
      WRITE(Z,1080)
      WRITE(Z,5210)
C
      IF ( IU .EQ. 1 ) WRITE(Z,5220) RPMC ,PTA1C ,T1C ,RHO1C ,KC
      IF ( IU .EQ. 2 ) WRITE(Z,6220) RPMC ,PTA1C ,T1C ,RHO1C ,KC
C
      T1C = T1C + C(1)
C
      WRITE(Z,1080)
      WRITE(Z,1090)
      WRITE(Z,1080)
C
C**********************************************************************C
C                                                                      C
C    READ AND WRITE FAN SPEED, INPUT POWER, AND BAROMETRIC PRESSURE    C
C                                                                      C
C**********************************************************************C
C
      READ(5,1010) RPM1 ,POWI
      WRITE(Z,5230)
C
      IF ( IU .EQ. 1 ) WRITE(Z,5240) RPM1 ,POWI
      IF ( IU .EQ. 2 ) WRITE(Z,6240) RPM1 ,POWI
C
      READ(5,1010) PB
C
      IF ( IU .EQ. 1 ) WRITE(Z,5250) PB
      IF ( IU .EQ. 2 ) WRITE(Z,6250) PB
C
      WRITE(Z,1080)
      WRITE(Z,1090)
      WRITE(Z,1090)
      WRITE(Z,1060)
      WRITE(Z,1090)
      WRITE(Z,1090)
      WRITE(Z,5260)
      WRITE(Z,1090)
      WRITE(Z,1090)
      WRITE(Z,1080)
      WRITE(Z,5270)
      WRITE(Z,5280)
C
      IF ( IU .EQ. 1 ) THEN
       WRITE(Z,5290) UAR    , UAS
        WRITE(Z,5300) URR    , URS
        WRITE(Z,5310) UTSUR  , UTSUS
```

```
           WRITE(Z,5320) UPVJR , UPVJS
           WRITE(Z,5330) UPSJR , UPSJS
           WRITE(Z,5340) UPBR  , UPBS
           WRITE(Z,5350) UYAWR , UYAWS
           WRITE(Z,5360) UPCHR , UPCHS
           WRITE(Z,5370) UETAMR, UETAMS
           WRITE(Z,5360) UWR   , UWS
           WRITE(Z,5390) UER   , UES
           WRITE(Z,5400) UIR   , UIS
           WRITE(Z,5410) UTAUR , UTAUS
           WRITE(Z,5420) UNR   , UNS
           WRITE(Z,5430) UPTR  , UPTS
           WRITE(Z,5440) UFNR  , UFNS
         ELSE
           WRITE(Z,6290) UAR   , UAS
           WRITE(Z,6300) URR   , URS
           WRITE(Z,6310) UTSJR , UTSJS
           WRITE(Z,6320) UPVJR , UPVJS
           WRITE(Z,6330) UPSJR , UPSJS
           WRITE(Z,6340) UPBR  , UPBS
           WRITE(Z,5350) UYAWR , UYAWS
           WRITE(Z,5360) UPCHR , UPCHS
           WRITE(Z,5370) UETAMR, UETAMS
           WRITE(Z,5380) UWR   , UWS
           WRITE(Z,5390) UER   , UES
           WRITE(Z,5400) UIR   , UIS
           WRITE(Z,6410) UTAUR , UTAUS
           WRITE(Z,6420) UNR   , UNS
           WRITE(Z,6430) UPTR  , UPTS
           WRITE(Z,5440) UFNR  , UFNS
         END IF
C
         WRITE(Z,1080)
         WRITE(Z,1090)
         WRITE(Z,1090)
         WRITE(Z,1060)
         WRITE(Z,1090)
         WRITE(Z,1090)
         WRITE(Z,5450)
         WRITE(Z,1090)
         WRITE(Z,1090)
         WRITE(Z,1080)
         WRITE(Z,5460)
         WRITE(Z,5470) UFSMR
         WRITE(Z,5480) UFSQR
         WRITE(Z,5490) UFSYR
         WRITE(Z,5500) UFSPTR
         WRITE(Z,5510) UFSROR
         WRITE(Z,5520) UFSNR
         WRITE(Z,5530) UFSPR
         WRITE(Z,1080)
         WRITE(Z,1090)
         WRITE(Z,1090)
C
         CD = 1.2
C
C**********************************************************************C
C                                                                      C
C                    READ AND WRITE TEST PLANE DATA                    C
C                                                                      C
C**********************************************************************C
C
      75 WRITE(Z,1060)
C
         IF ( L .EQ. 1 ) WRITE(Z,5540)
         IF ( L .EQ. 2 ) WRITE(Z,5640)
         IF ( L .EQ. 3 ) WRITE(Z,5650)
C
         READ(5,1000) NP
C
C**********************************************************************C
C                                                                      C
C   READ : PROBE DIAMETER                                              C
C                                                                      C
C          TRAVERSE PLANE DIMENSIONS                                   C
C                                                                      C
```

```
C        ( DIM1 = DIMENSION PARALLEL TO PROBE INSERTION )              C
C                                                                      C
C**********************************************************************C
C
      READ(5,1010)  D ,DIM1 ,DIM2
C
      READ(5,1040) BLOCK
C
      IPRT = 0
      II   = 0
C
C**********************************************************************C
C                                                                      C
C     INSERT - 1 IF PROBE INSERTED FROM ONE SIDE                       C
C              2 IF INSERTED FROM BOTH SIDES                           C
C                                                                      C
C**********************************************************************C
C
      READ(5,1000) INSERT
C
C**********************************************************************C
C                                                                      C
C     NT1 = NUMBER OF TRAVERSE POSITIONS FROM FIRST SIDE               C
C                                                                      C
C     NT2 = NUMBER OF TRAVERSE POSITIONS FROM SECOND SIDE              C
C                                                                      C
C**********************************************************************C
C
      IF (INSERT.EQ.2) THEN
        READ(5,1000) NT1 ,NT2
        NT = NT1 + NT2
      ELSE
        READ(5,1000) NT
      END IF
C
      WRITE(Z,5550) NP
      WRITE(Z,5560) NT
C
      IF (INSERT.EQ.1) THEN
        WRITE(Z,5570)
      ELSE
        WRITE(Z,5580) NT1 ,NT2
      END IF
C
      IF ( IU .EQ. 1 ) THEN
        WRITE(Z,5590) DIM1 ,DIM2
        DIM1 = DIM1 / 12.
        DIM2 = DIM2 / 12.
      END IF
C
      IF ( IU .EQ. 2 ) WRITE(Z,6590) DIM1 ,DIM2
C
      IF ( DIM2 .EQ. 0. ) THEN
        AREA(L) = 3.14159265359 * DIM1**2. / 4.
      ELSE
        AREA(L) = DIM1 * DIM2
      END IF
C
      IF ( IU .EQ. 1 ) THEN
        WRITE(Z,5600) D
        D = D / 12.
      END IF
C
      IF ( IU .EQ. 2 ) THEN
        WRITE(Z,6600) D
        D = D / 1000.
      END IF
C
      WRITE(Z,5620) BLOCK
C
      X1 = DIM1 / NT
      X2 = X1   / 2.
C
C**********************************************************************C
C                                                                      C
C             CALCULATE PROBE BLOCKAGE IF CORRECTION DESIRED           C
```

```
C                                                                      C
C**********************************************************************C
C
      DO 50 I = 1,NP
      DO 50 J = 1,NT
C
      IF ( BLOCK .EQ. 'YES' ) THEN
      IF (   INSERT .EQ. 2    ) THEN
      IF (      J .LE. NT1    ) THEN
        SPJ(L,J) = ( J * X1 -X2 ) * D
      ELSE
        SPJ(L,J) = (( J - NT1 ) * X1 - X2 ) * D
      END IF
      ELSE
        SPJ(L,J) = ( J * X1 - X2 ) * D
      END IF
      ELSE
        SPJ(L,J) = 0.0
      END IF
C
      GO TO (40,60,80),IPR
C
   40 READ(5,1020) IPNT(I,J)    ,PTI(I,J)     ,PSI(I,J)     ,TI(I,J)      ,
     1             YAW(I,J)     ,PITCH(I,J)   ,IDPRB(I,J)
C
      PVI(I,J) = PTI(I,J) - PSI(I,J)
C
      GO TO 90
C
   60 READ(5,1020) IPNT(I,J)    ,PSI(I,J)     ,PVI(I,J)     ,TI(I,J)      ,
     1             YAW(I,J)     ,PITCH(I,J)   ,IDPRB(I,J)
C
      PTI(I,J) = PSI(I,J) + PVI(I,J)
C
      GO TO 90
C
   80 READ(5,1020) IPNT(I,J)    ,PTI(I,J)     ,PVI(I,J)     ,TI(I,J)      ,
     1             YAW(I,J)     ,PITCH(I,J)   ,IDPRB(I,J)
C
      PSI(I,J) = PTI(I,J) - PVI(I,J)
C
   90 IF ( IPRT .EQ. 0 .AND. IU .EQ. 1 ) WRITE(Z,5630)
      IF ( IPRT .EQ. 0 .AND. IU .EQ. 2 ) WRITE(Z,6630)
      IF ( II   .EQ. 0 ) WRITE(Z,1070)
C
      IPRT = IPRT + 1
      II   = II   + 1
C
      IF ( II .EQ. NT ) II   = 0
      IF ( II .EQ. 0  ) IPRT = IPRT + 2
C
      IP = IPRT + NT
C
      IF ( II .EQ. 0 .AND. IP .GE. 55 ) IPRT = 0
C
      WRITE(Z,5631) IPNT(I,J)    ,PTI(I,J)     ,PSI(I,J)     ,PVI(I,J)
     1             ,TI(I,J)      ,YAW(I,J)     ,PITCH(I,J)   ,SPJ(L,J)
     2             ,IDPRB(I,J)
C
   50 CONTINUE
C
      DO 120 I = 1,NP
      DO 120 J = 1,NT
C
      TI(I,J)    = TI(I,J)  + C(1)
      PSAJ(I,J)  = PSI(I,J) + PB * C(13)
C
  120 CONTINUE
C
      RETURN
C
C**********************************************************************C
C**********************************************************************C
C
 1000 FORMAT(16I5)
 1010 FORMAT(8F10.5)
```

```
 1020 FORMAT(A4,5F10.5,I10)
 1030 FORMAT(20A4)
 1040 FORMAT(A3)
 1050 FORMAT(26X,20A4)
 1060 FORMAT(1H1)
 1070 FORMAT(1H0)
 1080 FORMAT(1X,3(/))
 1090 FORMAT(30X,77(1H*))
 1100 FORMAT(1X,132(1H*))
C
 5000 FORMAT(57X,18HCONTROL PARAMETERS/45X,40(1H-)/)
 5010 FORMAT(41X,34HALL INPUT IN U.S. CUSTOMARY UNITS ,
     1               17H.......... IU = 1//)
 6010 FORMAT(41X,34HALL INPUT IN S.I. UNITS ..........,
     1               17H.......... IU = 2//)
 5020 FORMAT(41X,33HINPUT TOTAL AND STATIC PRESSURES ,
     1               18H.......... IPR = 1//)
 5030 FORMAT(41X,35HINPUT STATIC AND DYNAMIC PRESSURES ,
     1               16H........ IPR = 2//)
 5040 FORMAT(41X,34HINPUT TOTAL AND DYNAMIC PRESSURES ,
     1               17H......... IPR = 3//)
 5050 FORMAT(41X,26HINLET MASS FLOW RATE USED ,
     1 15(1H.),10H IMASS = 1//)
 5060 FORMAT(41X,27HOUTLET MASS FLOW RATE USED ,
     1 14(1H.),10H IMASS = 2//)
 5070 FORMAT(41X,37HINLET AND OUTLET FLOW RATES AVERAGED ,
     1 4(1H.),10H IMASS = 3//)
 5080 FORMAT(41X,36HFLOW RATE FOUND AT THIRD TEST PLANE ,
     1 4(1H.),10H IMASS = 4//)
 5090 FORMAT(41X,31HMASS FLOW RATE/SPECIFIC ENERGY ,
     1 20HUSED ..... ICALC = 1//)
 5100 FORMAT(41X,26HVOLUME FLOW RATE/PRESSURE ,
     1 25HUSED .......... ICALC = 2//)
 5110 FORMAT(41X,41HMASS FLOW/SPEC. ENG. AND VOL. FLOW/PRES..,
     1 10H ICALC = 3//)
 5120 FORMAT(41X,20HAIR IS THE TEST GAS ,22(1H.),9H IAIR = 1//)
 5130 FORMAT(41X,36HCOMBUSTION PRODUCTS IS THE TEST GAS ,
     1 6(1H.),9H IAIR = 2//)
 5140 FORMAT(41X,11HA.C. MOTOR ,31(1H.),9H IPOW = 1)
 5150 FORMAT(41X,11HD.C. MOTOR ,31(1H.),9H IPOW = 2)
 5160 FORMAT(41X,13HTORQUE METER ,29(1H.),9H IPOW = 3)
 5170 FORMAT(41X,8HTURBINE ,31(1H.),9H IPOW = 4)
 5180 FORMAT(57X,17HAIR MOISTURE DATA/52X,27(1H-))
 5190 FORMAT(1H0,/51X,20HDRY BULB TEMPERATURE,5X,F7.2,2X,1HF///
     1 51X,20HWET BULB TEMPERATURE,5X,F7.2,2X,1HF,4(/))
 6190 FORMAT(1H0,/51X,20HDRY BULB TEMPERATURE,5X,F7.2,2X,1HC///
     1 51X,20HWET BULB TEMPERATURE,5X,F7.2,2X,1HC,4(/))
 5200 FORMAT(1H0,40X,18HSPECIFIC HUMIDITY ,10(1H.),2X,F7.5,
     1 2X,21HLBM VAPOR/LBM DRY GAS)
 6200 FORMAT(41X,18HSPECIFIC HUMIDITY ,10(1H.),2X,F7.5,
     1 2X,19HKG VAPOR/KG DRY GAS)
 5205 FORMAT(51X,30HPER CENT BY VOLUME OF EACH GAS,/45X,
     1 40(1H-)//51X,17HCARBON DIOXIDE   ,F10.3//51X,
     2 17HOXYGEN           ,F10.3//51X,
     3 17HCARBON MONOXIDE  ,F10.3//51X,
     4 17HNITROGEN         ,F10.3///)
 5210 FORMAT(51X,30HSPECIFIED OPERATING CONDITIONS/46X,40(1H-)/)
 5220 FORMAT(1H0,45X,18HSPEED OF ROTATION ,14(1H.),1X,F5.0,6X,3HRPM//
     1 46X,24HABSOLUTE TOTAL PRESSURE ,8(1H.),2X,F7.3,3X,6HIN. WA//
     2 46X,18HINLET TEMPERATURE ,14(1H.),1X,F5.0,6X,1HF//
     3 46X,'INLET DENSITY',18('.'),4X,F7.5,1X,'LPM/CU FT',//
     4 46X,20HSPECIFIC HEAT RATIO ,12(1H.),4X,F4.2)
 6220 FORMAT(1H0,45X,'SPEED OF ROTATION',14('.'),1X,F5.0,6X,'REV/S',//
     1 46X,24HABSOLUTE TOTAL PRESSURE ,8(1H.),2X,F7.3,3X,3HKPA//
     2 46X,18HINLET TEMPERATURE ,14(1H.),1X,F5.0,6X,1HC//
     3 46X,'INLET DENSITY',18('.'),4X,F7.5,1X,'KG/CU M',//
     4 46X,20HSPECIFIC HEAT RATIO ,12(1H.),4X,F4.2)
 5230 FORMAT(57X,19HMEASURED CONDITIONS/46X,40(1H-)/)
 5240 FORMAT(1H0,40X,27HMEASURED SPEED OF ROTATION ,10(1H.),1X,
     1 F7.0,3X,3HRPM////41X,16HFAN INPUT POWER ,21(1H.),1X,F7.2,
     2 3X,2HHP//)
 6240 FORMAT(1H0,40X,27HMEASURED SPEED OF ROTATION ,10(1H.),1X,
     1 F7.2,2X,'REV/S'////41X,'FAN INPUT POWER',21('.'),1X,F7.2,
     2 2X,2HKW//)
 5250 FORMAT(1H0,40X,21HATMOSPHERIC PRESSURE ,16(1H.),1X,
     1 F8.3,2X,6HIN. HG)
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```
6250 FORMAT(/,41X,21HATMOSPHERIC PRESSURE ,15(1H.),1X,F8.3,2X,3HKPA)
5260 FORMAT(/,57X,'MEASUREMENT UNCERTAINTIES',/)
5270 FORMAT(59X,'A B S O L U T E',25X,'R E L A T I V E',/)
5280 FORMAT(17X,'PARAMETER',12X,'UNITS',12X,'RANDOM',7X,'SYSTEMATIC',
           17X,'RANDOM',7X,'SYSTEMATIC',/,17X,101('-'),//)
5290 FORMAT(13X,'AREA                   SQ FT',F59.3,F15.3,/)
6290 FORMAT(13X,'AREA                   SQ M',F60.3,F15.3,/)
5300 FORMAT(13X,'GAS CONSTANT           FT*LB/LBM.R',F53.3,F15.3,/)
6300 FORMAT(13X,'GAS CONSTANT           J/KG.K',F58.3,F15.3,/)
5310 FORMAT(13X,'TEMPERATURE            F',F23.3,F15.3,/)
6310 FORMAT(13X,'TEMPERATURE            C',F23.3,F15.3,/)
5320 FORMAT(13X,'VELOCITY PRESSURE      IN. WG',F58.3,F15.3,/)
6320 FORMAT(13X,'VELOCITY PRESSURE      KPA',F61.3,F15.3,/)
5330 FORMAT(13X,'STATIC PRESSURE        IN. WG',F58.3,F15.3,/)
6330 FORMAT(13X,'STATIC PRESSURE        KPA',F61.3,F15.3,/)
5340 FORMAT(13X,'BAROMETRIC PRESSURE    IN. HG',F18.3,F15.3,/)
6340 FORMAT(13X,'BAROMETRIC PRESSURE    KPA',F21.3,F15.3,/)
5350 FORMAT(13X,'YAW ANGLE              DEG',F21.3,F15.3,/)
5360 FORMAT(13X,'PITCH ANGLE            DEG',F21.3,F15.3,/)
5370 FORMAT(13X,'MOTOR EFFICIENCY       DECIMAL',F57.3,F15.3,/)
5380 FORMAT(13X,'WATTS',F82.3,F15.3,/)
5390 FORMAT(13X,'VOLTS',F82.3,F15.3,/)
5400 FORMAT(13X,'AMPERES',F80.3,F15.3,/)
5410 FORMAT(13X,'TORQUE                 LB*FT',F59.3,F15.3,/)
6410 FORMAT(13X,'TORQUE                 N*M',F61.3,F15.3,/)
5420 FORMAT(13X,'FAN SPEED              RPM',F21.3,F15.3,/)
6420 FORMAT(13X,'FAN SPEED              REV/S',F19.3,F15.3,/)
5430 FORMAT(13X,'TURBINE POWER          HP',F62.3,F15.3,/)
6430 FORMAT(13X,'TURBINE POWER          KW',F62.3,F15.3,/)
5440 FORMAT(13X,'NO. OF PTS. FACTOR',F69.3,F15.3,/)
5450 FORMAT(/,38X,'RANDOM RELATIVE UNCERTAINTIES IN THE STEADY OPERATIO
   1N FACTORS',/)
5460 FORMAT(53X,'QUANTITY',16X,'UNCERTAINTY',//)
5470 FORMAT(49X,'MASS FLOW RATE',13X,'UFSMR  =',F5.3,/)
5480 FORMAT(49X,'VOLUME FLOW RATE',11X,'UFSQR  =',F5.3,/)
5490 FORMAT(49X,'SPECIFIC ENERGY',12X,'UFSYR  =',F5.3,/)
5500 FORMAT(49X,'TOTAL PRESSURE',13X,'UFSPTR =',F5.3,/)
5510 FORMAT(49X,'DENSITY',20X,'UFSROR =',F5.3,/)
5520 FORMAT(49X,'SPEED',22X,'UFSNR  =',F5.3,/)
5530 FORMAT(49X,'POWER',22X,'UFSPR  =',F5.3)
5540 FORMAT(1H0,2(130(1H*)/1X)//50X,23HINPUT DATA AT FAN INLET///1X,
   1 2(130(1H*)/1X))
5550 FORMAT(////40X,'THE NUMBER OF PORTS',1X,25('.'),1X,'NP =',I3)
5560 FORMAT(////40X,'NUMBER OF TRAVERSE POINTS PER PORT',1X,10('.')
   1,1X,'NT =',I3)
5570 FORMAT(////40X,'TRAVERSE FROM ONE SIDE')
5580 FORMAT(////40X,'TRAVERSE FROM BOTH SIDES   NT1 =',I3,'   NT2 ='
   1,I3)
5590 FORMAT(////40X,'TRAVERSE PLANE DIMENSIONS ....',F8.3,' X',F8.3,
   1' IN.')
6590 FORMAT(////40X,'TRAVERSE PLANE DIMENSIONS ....',F8.3,' X',F8.3,
   1' M')
5600 FORMAT(////40X,'PROBE DIAMETER',31('.'),F7.3,' IN.')
6600 FORMAT(////40X,'PROBE DIAMETER',32('.'),F6.2,' MM')
5610 FORMAT(////40X,'CROSS SECTIONAL AREA OF CALIBRATION JET ...',
   1F8.3,' SQ FT')
6610 FORMAT(////40X,'CROSS SECTIONAL AREA OF CALIBRATION JET ...',
   1F8.3,' SQ M')
5620 FORMAT(////40X,'EFFECTS OF PROBE BLOCKAGE CALCULATED ... ',
   1             A3)
5630 FORMAT('1',16X,'TOTAL',10X,'STATIC',9X,'VELOCITY',37X,'PITCH',
    1       12X,'PROBE',10X,'PROBE',/3X,'POINT',7X,'PRESSURE',8X,
    2       'PRESSURE',8X,'PRESSURE',8X,'TEMPERATURE',8X,'YAW',6X,
    3       'PRESSURE',9X,'BLOCKAGE',9X,'ID',/15X,'(IN. WG)',8X,
    4       '(IN. WG)',8X,'(IN. WG)',12X,'(F)',11X,'(DEG)',5X,
    5       '(IN. WG)',9X,'(SQ FT)',/3X,126('-'))
6630 FORMAT('1',16X,'TOTAL',10X,'STATIC',9X,'VELOCITY',37X,'PITCH',
    1       12X,'PROBE',10X,'PROBE',/3X,'POINT',7X,'PRESSURE',8X,
    2       'PRESSURE',8X,'PRESSURE',8X,'TEMPERATURE',8X,'YAW',6X,
    3       'PRESSURE',9X,'BLOCKAGE',9X,'ID',/16X,'(KPA)',11X,
    4       '(KPA)',11X,'(KPA)',14X,'(F)',11X,'(DEG)',6X,
    5       '(KPA)',12X,'(SQ M)',/3X,125('-'))
5631 FORMAT(4X,A4,F14.3,2F16.3,F17.2,F14.1,F13.3,F15.4,I13)
5640 FORMAT(1H0,2(130(1H*)/1X)//50X,24HINPUT DATA AT FAN OUTLET///1X,
   1 2(130(1H*)/1X))
5650 FORMAT(1H0,2(130(1H*)/1X)//50X,
```

```
                1 60HINPUT DATA AT AUXILLIARY TEST PLANE (FINDING MASS FLOW RATE),
                2 ///1X,2(130('*')/1X))
           5660 FORMAT(13X,'NO. OF PTS. FACTOR',F68.3,F15.2,/)
         C
                  END

@PRT,L LABSRC.UNCERT
```

```
LAB*LABSRC(1).UNCERT(25)
      SUBROUTINE UNCERT( L1,VJ,C2,C11,C13,N,RHOM,L,R )
C
      REAL  MDOT, MDOT1, MDOT2, MDOT3, N, KP
C
      COMMON / AVRGS  / MDOT  ,PTX   ,PSX   ,PVX   ,PSAX  ,PTAX  ,
     1                  TSX   ,RHOX  ,EKX   ,ALPHAX
      COMMON / CONST  / RO    ,JC    ,GC
      COMMON / CONST1 / C     ,CC
      COMMON / CNTRL  / NP    ,NT    ,PB    ,IAIR  ,IMASS ,IPOW
      COMMON / DATAI  / PTI   ,PSI   ,PVI   ,TI    ,YAW   ,
     1                  IDPRB ,D     ,PITCH
      COMMON / DATAJ  / PTJ   ,PSJ   ,PVJ   ,TSJ   ,PSAJ  ,
     1                  AREA  ,RHOJ  ,PITCHJ
      COMMON / PRFRM  / RHO1  ,RHO2  ,EK1   ,EK2   ,POWI  ,POWO  ,
     1                  POWOC ,RPM1  ,RPMC  ,KC    ,RHO1C ,T1C   ,
     2                  PTA1C
      COMMON / UMASS  / UMDTFR,UYFR  ,UPIR  ,UETAR ,URHOMR,UPOR  ,
     1                  UMDTFS,UYFS  ,UPIS  ,UETAS ,URHOMS,UPOS
      COMMON / UMASSC / UMDTCR,UYFCR ,URHOCR,UMDTCS,UYFCS ,URHOCS
      COMMON / URAN   / UAR   ,URR   ,UTSJR ,UPVJR ,UPSJR ,UPBR  ,
     1                  UYAWR ,UPCHR ,UETAMR,UWR   ,UER   ,UIR   ,
     2                  UTAUR ,UNR   ,UPTR  ,UFNR
      COMMON / USYS   / UAS   ,URS   ,UTSJS ,UPVJS ,UPSJS ,UPBS  ,
     1                  UYAWS ,UPCHS ,UETAMS,UWS   ,UES   ,UIS   ,
     2                  UTAUS ,UNS   ,UPTS  ,UFNS
      COMMON / UNCT1R / UMDT1R,UPS1R ,URHO1R,UTS1R ,UEK1R ,UPV1R ,
     1                  UPT1R ,UPSA1R
      COMMON / UNCT2R / UMDT2R,UPS2R ,URHO2R,UTS2R ,UEK2R ,UPV2R ,
     1                  UPT2R ,UPSA2R
      COMMON / UNCT1S / UMDT1S,UPS1S ,URHO1S,UTS1S ,UEK1S ,UPV1S ,
     1                  UPT1S ,UPSA1S
      COMMON / UNCT2S / UMDT2S,UPS2S ,URHO2S,UTS2S ,UEK2S ,UPV2S ,
     1                  UPT2S ,UPSA2S
      COMMON / UNCT3R / UMDT3R,UPS3R ,URHO3R,UTS3R ,UEK3R ,UPV3R ,
     1                  UPT3R ,UPSA3R
      COMMON / UNCT3S / UMDT3S,UPS3S ,URHO3S,UTS3S ,UEK3S ,UPV3S ,
     1                  UPT3S ,UPSA3S
      COMMON / UNCRT  / UMDOT ,UPX   ,URHOX ,UTSX  ,UEKX  ,UPVX  ,
     1                  UPTX  ,UPSX  ,UPSAX
      COMMON /  STDY  / UFSMR ,UFSQR ,UFSYR ,UFSPTR,UFSROR,UFSNR ,
     1                  UFSPR
      COMMON / PLNAVG / MDOT1 ,MDOT2 ,MDOT3 ,YF    ,PS1   ,PS2   ,
     1                  PS3   ,PV1   ,PV2   ,PT1   ,PT2   ,PSA1  ,
     2                  PSA2  ,PSA3  ,TS1   ,TS2   ,PFT   ,PFS   ,
     3                  PFV   ,KP
      COMMON / UVOPRR / UQFR  ,UPFTR ,UPFVR ,UPFSR ,UETATR,UETASR,
     1                  URHOFR
      COMMON / UVOPRS / UQFS  ,UPFTS ,UPFVS ,UPFSS ,UETATS,UETASS,
     1                  URHOFS
      COMMON / UVPCR  / UQFCR ,UPFTCR,UPFSCR,UPFVCR,UPICR ,UPOCR ,
     1                  UETACR
      COMMON / UVPCS  / UQFCS ,UPFTCS,UPFSCS,UPFVCS,UPICS ,UPOCS ,
     1                  UETACS
C
      DIMENSION   YAW(25,10)  ,PITCHJ(25,10) ,RHOJ(25,10) ,VJ(25,10)
     1           ,PSAJ(25,10) ,PSJ(25,10)    ,PVJ(25,10)  ,TSJ(25,10)
     2           ,PTJ(25,10)  ,PTI(25,10)    ,PSI(25,10)  ,PVI(25,10)
     3           ,TI(25,10)   ,IDPRB(25,10)  ,PITCH(25,10),AREA(3)
C
C*****************************************************************C
C                                                                 C
C            MASS FLOW RATE / SPECIFIC ENERGY APPROACH            C
C                                                                 C
C*****************************************************************C
C
      DATA RAD/.0174533/
C
      UMDOT  = 0.
      UPSX   = 0.
      URHOX  = 0.
      UTSX   = 0.
      UEKX   = 0.
      UPVX   = 0.
      UPTX   = 0.
C
```

```
      RUNR   = UNR   / RPM1
      RUNS   = UNS   / RPM1
      RUPBR  = UPBR  / PB
      RUPBS  = UPBS  / PB
C
      GO TO (10,20,30,30),L1
C
   10 RUTSJR = UTSJR / TSX
C
      DO 15 I=1,NP
      DO 15 J=1,NT
C
      COSYAW = COS ( YAW(I,J)      * RAD )
      COSPIT = COS ( PITCHJ(I,J) * RAD )
      TANYAW = TAN ( YAW(I,J)      * RAD )
      TANPIT = TAN ( PITCHJ(I,J) * RAD )
C
      AUPSJR = UPSJR * PSX
      MDOTJ  = AREA(L) / C2 / N * RHOJ(I,J) * VJ(I,J) * COSYAW * COSPIT
      UMDOT  = UMDOT +
     .         ( MDOTJ / MDOT )**2. * (((( ( URR**2. + RUTSJR**2.
     .         + UPVJR**2. ) / 4. + ( AUPSJR**2. + C13**2. * UPBR**2. )
     .         / PSAJ(I,J)**2. + ( TANYAW**2. * UYAWR**2. + TANPIT**2.
     .         * UPCHR**2. ) / 57.30**2. ))))
      UPSX   = UPSX +
     .         ( PSJ(I,J) / PSX )**2. * UPSJR**2.
      URHOX  = URHOX +
     .         ( RHOJ(I,J) / RHOX )**2. * (((( URR**2. + RUTSJR**2. +
     .         ( AUPSJR**2. + C13**2. * UPBR**2. ) / PSAJ(I,J)**2. ))))
      UTSX   = UTSX +
     .         ( TSJ(I,J) / TSX )**2. * RUTSJR**2.
      EKJ    = VJ(I,J)**2. / 2. * COSPIT**2. * COSYAW**2.
      UEKX   = UEKX +
     .         ( EKJ / EKX )**2. * (((( URR**2. + RUTSJR**2. +
     .         UPVJR**2. + ( AUPSJR**2. + C13**2. * UPBR**2. ) /
     .         PSAJ(I,J)**2. + 4. * ( TANYAW**2. * UYAWR**2. +
     .         TANPIT**2. * UPCHR**2. ) / 57.30**2. ))))
      UPVX   = UPVX +
     .         ( PVJ(I,J) * COSYAW**2. * COSPIT**2. / PVX )**2. *
     .         (((( UPVJR**2. + 4. * ( TANYAW**2. * UYAWR**2. +
     .         TANPIT**2. * UPCHR**2. ) / 57.30**2. ))))
      UPTX   = UPTX +
     .         ( PSJ(I,J) / PTX )**2. * UPSJR**2. +
     .         ( PVJ(I,J) * COSYAW**2. * COSPIT**2. / PTX )**2. *
     .         (((( UPVJR**2. + 4. * ( TANYAW**2. * UYAWR**2. +
     .         TANPIT**2. * UPCHR**2. ) / 57.30**2. ))))
C
   15 CONTINUE
C
      UMDOT = UMDOT + UFSMR**2. + UAR**2.
      UPSX  = UPSX  / N**2.
      URHOX = UFSROR**2. + URHOX / N**2.
      UTSX  = UTSX / N**2.
      UEKX  = UEKX / N**2.
      UPVX  = UPVX / N**2.
      UPTX  = UPTX / N**2.
      AUPSX = SQRT(UPSX) * PSX
      UPSAX = ( AUPSX**2. + C13**2. * UPBR**2. ) / PSAX**2.
C
      GO TO 99
C
   20 RUTSJS = UTSJS / TSX
C
      DO 25 I=1,NP
      DO 25 J=1,NT
C
      COSYAW = COS( YAW(I,J)      * RAD )
      COSPIT = COS( PITCHJ(I,J) * RAD )
      TANYAW = TAN( YAW(I,J)      * RAD )
      TANPIT = TAN( PITCHJ(I,J) * RAD )
C
      AUPSJS = UPSJS * PSX
      MDOTJ = AREA(L)/C2/N*RHOJ(I,J)*VJ(I,J)*COSYAW*COSPIT
      UMDOT  = UMDOT +
     .         ( MDOTJ / MDOT )**2. * (((( ( URS**2. + RUTSJS**2.
     .         + UPVJS**2. ) / 4. + ( AUPSJS**2. + C13**2. * UPBS**2. )
```

```
     .              / PSAJ(I,J)**2. + ( TANYAW**2. * UYAWS**2. + TANPIT**2.
     .              * UPCHS**2. ) / 57.30**2. )))))
      UPSX    = UPSX +
     .              ( PSJ(I,J) / PSX )**2. * UPSJS**2.
      URHOX   = URHOX +
     .              ( RHOJ(I,J) / RHOX )**2. * (((( URS**2. + RUTSJS**2. +
     .              ( AUPSJS**2. + C13**2. * UPBS**2. ) / PSAJ(I,J)**2. ))))
      UTSX    = UTSX +
     .              ( TSJ(I,J) / TSX )**2. * RUTSJS**2.
      EKJ     = VJ(I,J)**2. / 2. * COSPIT**2. * COSYAW**2.
      UEKX    = UEKX +
     .              ( EKJ / EKX )**2. * (((( URS**2. + RUTSJS**2. +
     .              UPVJS**2. + ( AUPSJS**2. + C13**2. * UPBS**2. ) /
     .              PSAJ(I,J)**2. + 4. * ( TANYAW**2. * UYAWS**2. +
     .              TANPIT**2. * UPCHS**2. ) / 57.30**2. ))))
      UPVX    = UPVX +
     .              ( PVJ(I,J) * COSYAW**2. * COSPIT**2. / PVX )**2. *
     .              (((( UPVJS**2. + 4. * ( TANYAW**2. * UYAWS**2. +
     .              TANPIT**2. * UPCHS**2. ) / 57.30**2. ))))
      UPTX    = UPTX +
     .              ( PSJ(I,J) / PTX )**2. * UPSJS**2. +
     .              ( PVJ(I,J) * COSYAW**2. * COSPIT**2. / PTX )**2. *
     .              (((( UPVJS**2. + 4. * ( TANYAW**2. * UYAWS**2. +
     .              TANPIT**2. * UPCHS**2. ) / 57.30**2. ))))
C
   25 CONTINUE
C
      UMDOT = UMDOT + UFNS + UAS**2.
      UPSX  = UPSX  / N**2.
      URHOX = URHOX / N**2.
      UTSX  = UTSX  / N**2.
      UEKX  = UEKX  / N**2.
      UPVX  = UPVX  / N**2.
      UPTX  = UPTX  / N**2.
C
      AUPSX = SQRT(UPSX) * PSX
      UPSAX = ( AUPSX**2. + C13**2. * UPBS**2. ) / PSAX**2.
C
      GO TO 99
C
   30 W1 = 0.
      W2 = 0.
      W3 = 0.
C
      GO TO (40,50,60,70),IMASS
C
   40 W1 = 1.
      GO TO 80
   50 W2 = 1.
C
      GO TO 80
C
   60 W1 = 0.5
      W2 = 0.5
C
C
      GO TO 80
C
   70 W3 = 1.
C
   80 IF ( IPOW .EQ. 1 ) THEN
        UPIR = UFSPR**2. + UETAMR**2. + UWR**2.
        UPIS =             UETAMS**2. + UWS**2.
      END IF
C
      IF ( IPOW .EQ. 2 ) THEN
        UPIR = UFSPR**2. + UETAMR**2. + UER**2. + UIR**2.
        UPIS =             UETAMS**2. + UES**2. + UIS**2.
      END IF
C
      IF ( IPOW .EQ. 3 ) THEN
        UPIR = UFSPR**2. + UTAUR**2. + RUNR**2.
        UPIS =             UTAUS**2. + RUNS**2.
      END IF
C
      IF ( IPOW .EQ. 4 ) THEN
```

```
          UPIR = UFSPR**2. + UPTR**2.
          UPIS =             UPTS**2.
        END IF
C
        IF ( L1 .EQ. 4 ) GO TO 90
C
        IF ( IMASS .EQ. 1 ) THEN
          UMDTFR = UMDT1R**2.
          UMDTFS = UMDT1S**2.
        END IF
C
        IF ( IMASS .EQ. 2 ) THEN
          UMDTFR = UMDT2R**2.
          UMDTFS = UMDT2S**2.
        END IF
C
        IF ( IMASS .EQ. 3 ) THEN
          UMDTFR = ( UMDT1R**2. + UMDT2R**2. ) / 4.
          UMDTFS = ( UMDT1S**2. + UMDT2S**2. ) / 4.
        END IF
C
        IF ( IMASS .EQ. 4 ) THEN
          UMDTFR = UMDT3R**2.
          UMDTFS = UMDT3S**2.
        END IF
C
C                 ********** R A N D O M **********
C
        AURO1R = URHO1R * RHO1
        AURO2R = URHO2R * RHO2
        URHOMR = ( AURO1R**2. + AURO2R**2. ) / ( RHO1 + RHO2 )**2
C
        UYFR   = UFSYR**2. + URR**2. + ( C11 / YF )**2. * (((( (( RHO1 *
     .           ( PS2 - PS1 ) / ( 2. * RHOM**2. ) - PV1 / RHO1 ))**2. *
     .           UTS1R**2. + (( RHO2 * ( PS2 - PS1 ) / ( 2. * RHOM**2. )
     .           + PV2 / RHO2 ))**2. * UTS2R**2. + ((( PV1 / RHO1 *
     .           PB / PSA1 - ( PS2 - PS1 ) / ( 2. * RHOM**2. ) * (( PB /
     .           ( R * TS1 ) + PB / ( R * TS2 ) )) - PV2 / RHO2 * PB /
     .           PSA2 )))**2. * RUPBR**2. + (( PV1 / RHO1 * PS1 / PSA1 -
     .           RHO1 * ( PS2 - PS1 ) / ( 2. * RHOM**2. ) * PS1 / PSA1
     .           - PS1 / RHOM ))**2. * UPS1R**2. + (( PS2 / RHOM - RHO2
     .           * ( PS2 - PS1 ) / ( 2. * RHOM**2. ) * PS2 / PSA2 -
     .           PV2 / RHO2 * PS2 / PSA2 ))**2. * UPS2R**2. + ( PV1 /
     .           RHO1 )**2. * UPV1R**2. + ( PV2 / RHO2 )**2. *
     .           UPV2R**2. ))))
C
        UPOR   = UFSMR**2. + UFSYR**2. + URR**2. / 4. + ( W1 * MDOT1 /
     .           MDOT )**2. * UAR**2. + ( W2 * MDOT2 / MDOT )**2. *
     .           UAR**2. + ( W3 * MDOT3 / MDOT )**2. * UAR**2. + (( W1 *
     .           MDOT1 / ( 2. * MDOT ) - C11 / YF * RHO1 * ( PS2 -PS1 ) /
     .           ( 2. * RHOM**2. ) - EK1 / YF ))**2. * UTS1R**2. + (( W2
     .           * MDOT2 / ( 2. * MDOT ) - C11 / YF * RHO2 * ( PS2 - PS1
     .           ) / ( 2. * RHOM**2. ) + EK2 / YF ))**2. * UTS2R**2. + (
     .           W3 * MDOT3 / ( 2. * MDOT ))**2. * UTS3R**2. + (((( W1 *
     .           MDOT1 / ( 2. * MDOT ) * PB / PSA1 + W2 * MDOT2 / ( 2. *
     .           MDOT ) * PB / PSA2 + W3 * MDOT3 / ( 2. * MDOT ) * PB /
     .           PSA3 + C11 / YF * ((( PV1 / RHO1 * PB / PSA1 - ( PS2 -
     .           PS1 ) / ( 2. * RHOM**2. ) * (( PB / ( R * TS1 ) + PB /
     .           ( R * TS2 ) )) - PV2 / RHO2 * PB / PSA2 ))) ))))**2. *
     .           RUPBR**2. + ((( W1 * MDOT1 / ( 2. * MDOT ) * PS1 / PSA1
     .           + C11 / YF * (( PV1 / RHO1 * PS1 / PSA1 - RHO1 * ( PS2 -
     .           PS1 ) / ( 2. * RHOM**2. ) * PS1 / PSA1 - PS1 / RHOM ))
     .           )))**2. * UPS1R**2. + ((( W2 * MDOT2 / ( 2. * MDOT ) *
     .           PS2 / PSA2 + C11 / YF * (( PS2 / RHOM - RHO1 * ( PS2 -
     .           PS1 ) / ( 2. * RHOM**2. ) * PS2 / PSA2 - PV2 / RHO2 *
     .           PS2 / PSA2 )) )))**2. * UPS2R**2. + ( W1 * MDOT1 /
     .           ( 2. * MDOT ) - EK1 / YF )**2. * UPV1R**2. + ( W2 *
     .           MDOT2 / ( 2. * MDOT ) + EK2 / YF )**2. * UPV2R**2. + (
     .           W3 * MDOT3 / ( 2. * MDOT ))**2. * UPV3R**2.
C
C             ********** S Y S T E M A T I C **********
C
        AURO1S = URHO1S*RHO1
        AURO2S = URHO2S*RHO2
        URHOMS = (AURO1S**2.+AURO2S**2.)/(RHO1+RHO2)**2
C
```

```
     UYFS   =           URS**2. + ( C11 / YF )**2. * (((( (( RHO1 *
    .       ( PS2 - PS1 ) / ( 2. * RHOM**2. ) - PV1 / RHO1 ))**2. *
    .       UTS1S**2. + (( RHO2 * ( PS2 - PS1 ) / ( 2. * RHOM**2. )
    .       + PV2 / RHO2 ))**2. * UTS2S**2. + ((( PV1 / RHO1 *
    .       PB / PSA1 - ( PS2 - PS1 ) / ( 2. * RHOM**2. ) * (( PB /
    .       ( R * TS1 ) + PB / ( R * TS2 ) )) - PV2 / RHO2 * PB /
    .       PSA2 )))**2. * RUPBS**2. + (( PV1 / RHO1 * PS1 / PSA1 -
    .       RHO1 * ( PS2 - PS1 ) / ( 2. * RHOM**2. ) * PS1 / PSA1
    .       - PS1 / RHOM ))**2. * UPS1S**2. + (( PS2 / RHOM - RHO2
    .       * ( PS2 - PS1 ) / ( 2. * RHOM**2. ) * PS2 / PSA2 -
    .       PV2 / RHO2 * PS2 / PSA2 ))**2. * UPS2S**2. + ( PV1 /
    .       RHO1 )**2. * UPV1S**2. + ( PV2 / RHO2 )**2. *
    .       UPV2S**2. ))))
C
     UPOS   =           URS**2. / 4. + ( W1 * MDOT1 /
    .       MDOT )**2. * UAS**2. + ( W2 * MDOT2 / MDOT )**2. *
    .       UAS**2. + ( W3 * MDOT3 / MDOT )**2. * UAS**2. + (( W1 *
    .       MDOT1 / ( 2. * MDOT ) - C11 / YF * RHO1 * ( PS2 -PS1 ) /
    .       ( 2. * RHOM**2. ) - EK1 / YF ))**2. * UTS1S**2. + (( W2
    .       * MDOT2 / ( 2. * MDOT ) - C11 / YF * RHO2 * ( PS2 - PS1
    .       ) / ( 2. * RHOM**2. ) + EK2 / YF ))**2. * UTS2S**2. + (
    .       W3 * MDOT3 / ( 2. * MDOT ))**2. * UTS3S**2. + (((( W1 *
    .       MDOT1 / ( 2. * MDOT ) * PB / PSA1 + W2 * MDOT2 / ( 2. *
    .       MDOT ) * PB / PSA2 + W3 * MDOT3 / ( 2. * MDOT ) * PB /
    .       PSA3 + C11 / YF * ((( PV1 / RHO1 * PB / PSA1 - ( PS2 -
    .       PS1 ) / ( 2. * RHOM**2. ) * (( PB / ( R * TS1 ) + PB /
    .       ( R * TS2 ) )) - PV2 / RHO2 * PB / PSA2 ))) ))))**2. *
    .       RUPBS**2. + ((( W1 * MDOT1 / ( 2. * MDOT ) * PS1 / PSA1
    .       + C11 / YF * (( PV1 / RHO1 * PS1 / PSA1 - RHO1 * ( PS2 -
    .       PS1 ) / ( 2. * RHOM**2. ) * PS1 / PSA1 - PS1 / RHOM ))
    .       )))**2. * UPS1S**2. + ((( W2 * MDOT2 / ( 2. * MDOT ) *
    .       PS2 / PSA2 + C11 / YF * (( PS2 / RHOM - RHO1 * ( PS2 -
    .       PS1 ) / ( 2. * RHOM**2. ) * PS2 / PSA2 - PV2 / RHO2 *
    .       PS2 / PSA2 )) )))**2. * UPS2S**2. + ( W1 * MDOT1 /
    .       ( 2. * MDOT ) - EK1 / YF )**2. * UPV1S**2. + ( W2 *
    .       MDOT2 / ( 2. * MDOT ) + EK2 / YF )**2. * UPV2S**2. + (
    .       W3 * MDOT3 / ( 2. * MDOT ))**2. * UPV3S**2.
C
C             ********** R A N D O M **********
C
     UETAR  = UPOR   + UPIR
     UMDTCR = UMDTFR + RUNR**2. + URHO1R**2.
     UYFCR  = UYFR   + 4.       * RUNR**2.
C
     UPOCR  = UPOR + 9. * RUNR**2. + URHO1R**2.
C
     UPICR  = UPIR   + 9.       * RUNR**2. + URHO1R**2.
     UETACR = UETAR
C
C         ********** S Y S T E M A T I C **********
C
     UETAS  = UPOS   + UPIS
     UMDTCS = UMDTFS + RUNS**2. + URHO1S**2.
     UYFCS  = UYFS   + 4.       * RUNS**2.
C
     UPOCS  = UPOS + 9. * RUNS**2. + URHO1S**2.
C
     UPICS  = UPIS   + 9.       * RUNS**2. + URHO1S**2.
     UETACS = UETAS
C
     GO TO 99
C
C
C*****************************************************C
C                                                     C
C           VOLUME FLOW RATE / PRESSURE APPROACH      C
C                                                     C
C*****************************************************C
C
  90 URHOFR = URHO1R**2.
C
     UQFR   = UFNR**2. + UFSQR**2. + URR**2. / 4. + ( W1 * MDOT1 /
    .       MDOT )**2. * UAR**2. + ( W2 * MDOT2 / MDOT )**2. *
    .       UAR**2. + ( W3 * MDOT3 / MDOT )**2. * UAR**2. + (( W1 *
    .       MDOT1 / ( 2. * MDOT ) - 1. ))**2. * UTS1R**2. + (( W2 *
    .       MDOT2 / ( 2. * MDOT ) ))**2. * UTS2R**2. + (( W3 *
```

```
     .         MDOT3 / ( 2. * MDOT ) ))**2. * UTS3R**2. + (( W1 *
     .         MDOT1 / ( 2. * MDOT ) * PB / PSA1 + W2 * MDOT2 / (
     .         2. * MDOT ) * PB / PSA2 + W3 * MDOT3 / ( 2. * MDOT ) *
     .         PB / PSA3 - PB / PSA1 ))**2. * RUPBR**2. + (( W1 *
     .         MDOT1 / ( 2. * MDOT ) * PS1 / PSA1 - PS1 / PSA1 ))**2. *
     .         UPS1R**2. + (( W2 * MDOT2 / ( 2. * MDOT ) * PS2 / PSA2
     .         ))**2. * UPS2R**2. + (( W3 * MDOT3 / ( 2. * MDOT ) *
     .         PS3 / PSA3 ))**2. * UPS3R**2. + (( W1 * MDOT1 / ( 2. *
     .         MDOT ) ))**2. * UPV1R**2. + (( W2 * MDOT2 / ( 2. *
     .         MDOT ) ))**2. * UPV2R**2. + (( W3 * MDOT3 / ( 2. *
     .         MDOT ) ))**2. * UPV3R**2.
C
      AUPT1R = UPT1R * PT1
      AUPT2R = UPT2R * PT2
      UPFTR  = UFSPTR**2. + ( AUPT2R**2. + AUPT1R**2. ) / PFT**2.
      UPFVR  = UPV2R**2.
      AUPFTR = SQRT( UPFTR ) * PFT
      AUPFVR = SQRT( UPFVR ) * PFV
      UPFSR  = ( AUPFTR**2. + AUPFVR**2. ) / PFS**2.
C
C
      UPOR   = UFSQR**2. + UFSPTR**2. + URR**2. / 4. + ( W1 * MDOT1 /
     .         MDOT )**2. * UAR**2. + ( W2 * MDOT2 / MDOT )**2. *
     .         UAR**2. + ( W3 * MDOT3 / MDOT )**2. * UAR**2. + (( W1 *
     .         MDOT1 / ( 2. * MDOT ) - 1. ))**2. * UTS1R**2. + (( W2 *
     .         MDOT2 / ( 2. * MDOT ) ))**2. * UTS2R**2. + (( W3 *
     .         MDOT3 / ( 2. * MDOT ) ))**2. * UTS3R**2. + (( W1 *
     .         MDOT1 / ( 2. * MDOT ) * PB / PSA1 + W2 * MDOT2 / ( 2. *
     .         MDOT ) * PB / PSA2 + W3 * MDOT3 / ( 2. * MDOT ) * PB /
     .         PSA3 - PB / PSA1 ))**2. * RUPBR**2. + (( W1 * MDOT1 /
     .         ( 2. * MDOT ) * PS1 / PSA1 - PS1 / PSA1 - PS1 / PFT ))
     .         **2. * UPS1R**2. + (( W2 * MDOT2 / ( 2. * MDOT ) * PS2 /
     .         PSA2 + PS2 / PFT ))**2. * UPS2R**2. + (( W3 * MDOT3 /
     .         ( 2. * MDOT ) * PS3 / PSA3 ))**2. * UPS3R**2. + (( W1 *
     .         MDOT1 / ( 2. * MDOT ) - PV1 / PFT ))**2. * UPV1R**2. +
     .         (( W2 * MDOT2 / ( 2. * MDOT ) + PV2 / PFT ))**2. *
     .         UPV2R**2. + (( W3 * MDOT3 / ( 2. * MDOT ) ))**2. *
     .         UPV3R**2.
C
      UETATR = UPOR  + UPIR
      UETASR = UETATR
      UQFCR  = UQFR  +         RUNR**2.
      UPFTCR = UPFTR + 4. * RUNR**2. + URHC1R**2.
      UPFVCR = UPFVR + 4. * RUNR**2. + URHC1R**2.
      UPFSCR = UPFSR + 4. * RUNR**2. + URHC1R**2.
      UPOCR  = UPOR + 9. * RUNR**2. + URHO1R**2.
      UPICR  = UPIR  + 9. * RUNR**2. + URHO1R**2.
      UETACR = UETATR
C
C               ********** S Y S T E M A T I C **********
C
      URHOFS = URHO1S**2.
C
      UQFS   =                         URS**2. / 4. + ( W1 * MDOT1 /
     .         MDOT )**2. * UAS**2. + ( W2 * MDOT2 / MDOT )**2. *
     .         UAS**2. + ( W3 * MDOT3 / MDOT )**2. * UAS**2. + (( W1 *
     .         MDOT1 / ( 2. * MDOT ) - 1. ))**2. * UTS1S**2. + (( W2 *
     .         MDOT2 / ( 2. * MDOT ) ))**2. * UTS2S**2. + (( W3 *
     .         MDOT3 / ( 2. * MDOT ) ))**2. * UTS3S**2. + (( W1 *
     .         MDOT1 / ( 2. * MDOT ) * PB / PSA1 + W2 * MDOT2 / (
     .         2. * MDOT ) * PB / PSA2 + W3 * MDOT3 / ( 2. * MDOT ) *
     .         PB / PSA3 - PB / PSA1 ))**2. * RUPBS**2. + (( W1 *
     .         MDOT1 / ( 2. * MDOT ) * PS1 / PSA1 - PS1 / PSA1 ))**2. *
     .         UPS1S**2. + (( W2 * MDOT2 / ( 2. * MDOT ) * PS2 / PSA2
     .         ))**2. * UPS2S**2. + (( W3 * MDOT3 / ( 2. * MDOT ) *
     .         PS3 / PSA3 ))**2. * UPS3S**2. + (( W1 * MDOT1 / ( 2. *
     .         MDOT ) ))**2. * UPV1S**2. + (( W2 * MDOT2 / ( 2. *
     .         MDOT ) ))**2. * UPV2S**2. + (( W3 * MDOT3 / ( 2. *
     .         MDOT ) ))**2. * UPV3S**2.
C
      AUPT1S = UPT1S * PT1
      AUPT2S = UPT2S * PT2
      UPFTS  = ( AUPT2S**2. + AUPT1S**2. ) / PFT**2.
      UPFVS  = UPV2S**2.
      AUPFTS = SQRT( UPFTS ) * PFT
      AUPFVS = SQRT( UPFVS ) * PFV
```

```
      UPFSS   = ( AUPFTS**2. + AUPFVS**2. ) / PFS**2.
C
      UPOS    =                           URS**2. / 4. + ( W1 * MDOT1 /
     .         MDOT )**2. * UAS**2. + ( W2 * MDOT2 / MDOT )**2. *
     .         UAS**2. + ( W3 * MDOT3 / MDOT )**2. * UAS**2. + (( W1 *
     .         MDOT1 / ( 2. * MDOT ) - 1. ))**2. * UTS1S**2. + (( W2 *
     .         MDOT2 / ( 2. * MDOT ) ))**2. * UTS2S**2. + (( W3 *
     .         MDOT3 / ( 2. * MDOT ) ))**2. * UTS3S**2. + (( W1 *
     .         MDOT1 / ( 2. * MDOT ) * PB / PSA1 + W2 * MDOT2 / ( 2. *
     .         MDOT ) * PB / PSA2 + W3 * MDOT3 / ( 2. * MDOT ) * PB /
     .         PSA3 - PB / PSA1 ))**2. * RUPBS**2. + (( W1 * MDOT1 /
     .         ( 2. * MDOT ) * PS1 / PSA1 - PS1 / PSA1 - PS1 / PFT ))
     .         **2. * UPS1S**2. + (( W2 * MDOT2 / ( 2. * MDOT ) * PS2 /
     .         PSA2 + PS2 / PFT ))**2. * UPS2S**2. + (( W3 * MDOT3 /
     .         ( 2. * MDOT ) * PS3 / PSA3 ))**2. * UPS3S**2. + (( W1 *
     .         MDOT1 / ( 2. * MDOT ) - PV1 / PFT ))**2. * UPV1S**2. +
     .         (( W2 * MDOT2 / ( 2. * MDOT ) + PV2 / PFT ))**2. *
     .         UPV2S**2. + (( W3 * MDOT3 / ( 2. * MDOT ) ))**2. *
     .         UPV3S**2.
C
      UETATS = UPOS   + UPIS
      UETASS = UETATS
      UCFCS  = UCFS   +         RUNS**2.
      UPFTCS = UPFTS  + 4. * RUNS**2. + URHO1S**2.
      UPFVCS = UPFVS  + 4. * RUNS**2. + URHO1S**2.
      UPFSCS = UPFSS  + 4. * RUNS**2. + URHO1S*2.
      UPOCS  = UPOS + 9. * RUNS**2. + URHO1S**2.
      UPICS  = UPIS   + 9. * RUNS**2. + URHO1S**2.
      UETACS = UETATS
C
   99 RETURN
      END
```

```
LAB*LABSRC(1).GASPRP(33)
C*****************************************************************C
C*****************************************************************C
C                                                                 C
C     SUBROUTINE GASPRP DETERMINES THE AVERAGE PROPERTIES OF      C
C     THE FLUID IF THE FLUID CONSISTS OF OXYGEN, NITROGEN,        C
C     CARBON MONOXIDE, CARBON DIOXIDE, AND WATER VAPOR            C
C                                                                 C
C*****************************************************************C
C*****************************************************************C
C
      SUBROUTINE GASPRP ( TX,CP,TD,TW,RHOG )
C
      REAL      JC     ,N2     ,MCO2   ,MO2    ,MCO    ,MN2    ,MDG   ,
     1          MX     ,MUCO2  ,MUO2   ,MUCO   ,MUN2   ,MUH2O  ,MU    ,K
C
      COMMON /  GAS  / CO2    ,O2     ,CO     ,N2     ,S
      COMMON / CONST / RO     ,JC     ,GC
      COMMON / CONST1/ C      ,CC
      COMMON / PROP  / K      ,R      ,MU
      COMMON / CNTRL / NP     ,NT     ,PB     ,IAIR   ,IMASS ,IPOW
C
      DIMENSION C(18)
C
      IF ( IAIR .EQ. 1 ) GO TO 10
C
C*****************************************************************C
C                                                                 C
C          CALCULATE MOLECULAR WEIGHT OF DRY GAS                  C
C                                                                 C
C*****************************************************************C
C
      MCO2 = 44.01 * CO2
      MO2  = 32.   * O2
      MCO  = 28.01 * CO
      MN2  = 28.02 * N2
C
      MDG  = ( MCO2 + MO2 + MCO + MN2 )
C
C*****************************************************************C
C                                                                 C
C          CALCULATE VISCOSITY                                    C
C                                                                 C
C*****************************************************************C
C
      MUCO2 = C(4)*12.721*(C(3)*TX)**1.5/(C(3)*TX+515.04)*1.E-7
      MUCO  = C(4)*10.86 *(C(3)*TX)**1.5/(C(3)*TX+214.72)*1.E-7
      MUN2  = C(4)*10.75 *(C(3)*TX)**1.5/(C(3)*TX+204.67)*1.E-7
      MUO2  = C(4)*13.11 *(C(3)*TX)**1.5/(C(3)*TX+238.54)*1.E-7
      MUH2O = C(4)*12.03 *(C(3)*TX)**1.5/(C(3)*TX+987.4 )*1.E-7
      MU = (SQRT(44.01) * CO2 * MUCO2 + SQRT(32.) * O2 * MUO2 +
     1SQRT(28.01) * CO * MUCO + SQRT(28.02) * N2 * MUN2 + SQRT(18.02) *
     3  (S* MDG / 18.02) * MUH2O) /(SQRT(44.01) * CO2 + SQRT(32.)
     4* O2 + SQRT(28.01) * CO + SQRT(28.02) * N2 + SQRT(18.02)
     5* (S * MDG) / 18.02)

      GO TO 20
C
   10 MDG = 28.965
C
C     MOLECULAR WEIGHT AT PLANE X : EQN 5.3-6
C
      MX = 1./(S/(18.02*(1.+S))+1./(MDG*(1.+S)))
      R = RO/MX
      MU = C(4)*10.874*(C(3)*TX)**1.5/(C(3)*TX+199.)*1.E-7
      MUH2O = C(4)*12.03 *(C(3)*TX)**1.5/(C(3)*TX+987.4 )*1.E-7
      MU=(SQRT(28.965)*MU+SQRT(18.02)*28.965*S/18.02*MUH2O)/
     1 (SQRT(28.965)+SQRT(18.02)*(28.965*S/18.02))
C
C     SATURATED VAPOR PRESSURE : EQN 5.4-1
C
      PE = C(6) * TW**2. + C(7) * TW + C(8)
C
C     PARTIAL PRESSURE OF WATER VAPOR IN AIR : EQN 5.4-2
C
      PP = PE - PB * ( TD - TW ) / C(9)
```

```
C
C     DENSITY OF ATMOSPHERIC AIR-VAPOR MIXTURE : EQN 5.4-3
C
      RHOG = C(10) * ( PB - .378 * PP ) / (( R * ( TD + C(1) ) ))
C
      GO TO 25
C
   20 MX = 1. / (((  S / (( 18.02 * ( 1. + S ) )) +
     .       1. / (( MDG * ( 1. + S ) ))  )))
      R = RO / MX
C
C*********************************************************************C
C                                                                     C
C            CALCULATE SPECIFIC HEAT                                  C
C                                                                     C
C*********************************************************************C
C
   25 CPH2O = C(5)*(19.86-597./(C(3)*TX)**.5+7500./(C(3)*TX))/18.
C
      IF (IAIR .EQ. 2) GO TO 26
C
C     SPECIFIC HEAT OF DRY AIR :  EQN 5.3-7
C
      CPDG = C(5)*(.343-1.253/(C(3)*TX)**.5-83.76/(C(3)*TX)+3.087E4/
     1       (C(3)*TX)**2.)
      CP = CPDG * 1. / (1.+S) + CPH2O * S / (1.+S)
C
      GO TO 30
C
   26 CPCO2 = C(5)*(16.2-6.53E3/(C(3)*TX)+1.4E6/(C(3)*TX)**2.)/44.01
      CPO2  = C(5)*(11.515-172./(C(3)*TX)**.5+1530./(C(3)*TX))/32.0
      CPN2  = C(5)*(9.47-3.47E3/(C(3)*TX)+1.16E6/(C(3)*TX)**2.)/28.02
      CPCO  = C(5)*(9.46-3.29E3/(C(3)*TX)+1.07E6/(C(3)*TX)**2.)/28.01
      CPDG =(44.01*CO2*CPCO2+32.00*O2*CPO2+28.02*N2*CPN2+28.01*CO*CPCO)
     1      / MDG
      CP = CPDG * 1. / (1.+S) + CPH2O * S / (1.+S)
      R = RO/MX
   30 K = CP*JC/(CP*JC - R)
C
      RETURN
C
      END

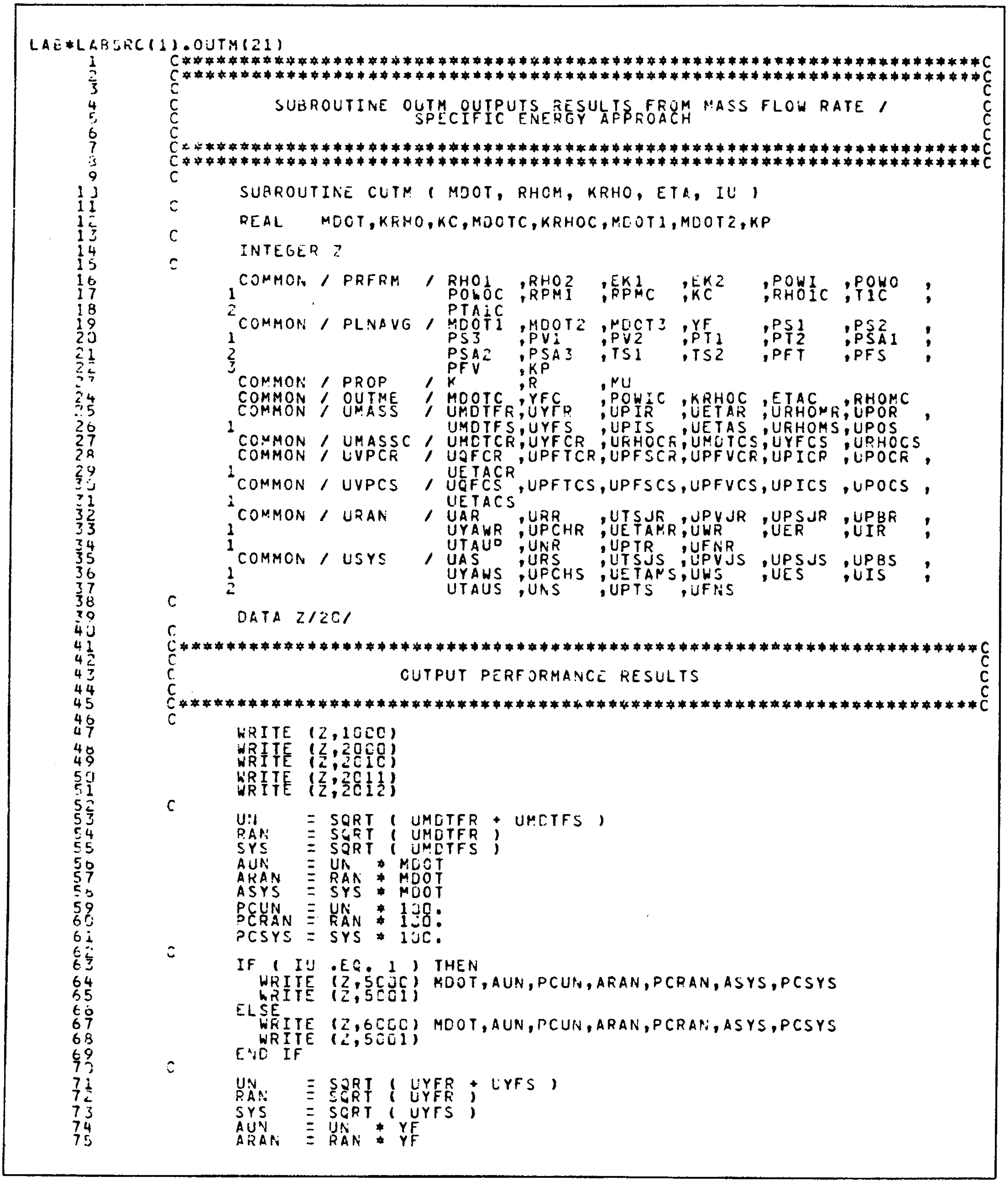
@PRT,L LABSRC.AVPGES
```

```
LAB*LABSRC(1).AVRGES(31)
C********************************************************************C
C********************************************************************C
C                                                                    C
C         SUBROUTINE AVRGES CALCULATES THE AVERAGE                   C
C         VALUES OF FLOW PARAMETERS IN A TEST PLANE                  C
C                                                                    C
C********************************************************************C
C********************************************************************C
C
      SUBROUTINE AVRGES ( YAW,VJ,C2,C11,C13,GC,L,TERM )
C
      REAL       MDOT   ,MU     ,N
C
      INTEGER Z
C
      CHARACTER TERM *3
C
      COMMON / CONTRL/ IU     ,IPR
      COMMON / AVRGS / MDOT   ,PTX    ,PSX    ,PVX   ,PSAX   ,PTAX . ,
     1                 TSX    ,RHOX   ,EKX    ,ALPHAX
      COMMON / CNTRL / NP     ,NT     ,PB     ,IAIR
      COMMON / DATAJ / PTJ    ,PSJ    ,PVJ    ,TSJ   ,PSAJ   ,
     1                 AREA   ,RHOJ   ,PITCHJ
      COMMON / PROP  / K      ,R      ,MU
C
      DIMENSION     YAW(25,10)  ,PTJ(25,10)  ,PSJ(25,10)  ,PVJ(25,10)   ,
     1              PSAJ(25,10) ,TSJ(25,10)  ,RHOJ(25,10) ,AREA(3)      ,
     2              VJ(25,10)   ,PITCHJ(25,10)
C
      DATA  Z / 20 /
      DATA  RAD / .0174533 /
C
C********************************************************************C
C                                                                    C
C                CALCULATE NEEDED SUMS FOR AVERAGING                 C
C                                                                    C
C********************************************************************C
C
      RV     = 0.
      PSV    = 0.
      V      = 0.
      TRV    = 0.
      RV3    = 0.
      N      = FLOAT(NT) * FLOAT(NP)
C
      DO 10 I = 1,NP
      DO 10 J = 1,NT
C
      VJ(I,J) = VJ(I,J) * COS ( YAW(I,J)    * RAD )
      VJ(I,J) = VJ(I,J) * COS ( PITCHJ(I,J) * RAD )
      V      = V     + VJ(I,J)
      RV     = RV    + RHOJ(I,J) * VJ(I,J)
      RV3    = RV3   + RHOJ(I,J) * VJ(I,J)**3
      PSV    = PSV   + PSJ(I,J) * VJ(I,J)
      TRV    = TRV   + TSJ(I,J) * RHOJ(I,J) * VJ(I,J)
      X = (( COS ( YAW(I,J) * RAD ) * COS ( PITCHJ(I,J) * RAD ) ))**2.
C
   10 CONTINUE
C
C********************************************************************C
C                                                                    C
C                    CALCULATE AVERAGE VALUES                        C
C                                                                    C
C********************************************************************C
C
      I = NP
      J = NT
      MDOT = AREA(L) / C2 / N * RV
C
      IF ( V .NE. 0.0 ) PSX  = PSV / V
      IF ( V .EQ. 0.0 ) PSX  = PSJ(I,J)
      IF ( V .NE. 0.0 ) RHOX = N * MDOT / AREA(L) / V * C2
      IF ( V .EQ. 0.0 ) RHOX = RHOJ(1,1)
      IF ( MDOT .NE. 0.0 ) TSX = TRV / MDOT / N * AREA(L) / C2
      IF ( MDOT .EQ. 0.0 ) TSX = TSJ(1,1)
```

```
      IF ( MDOT .NE. 0.0 ) EKX = AREA(L) * RV3 / 2. / GC / MDOT / N /
     .                            C2**3.
      IF ( MDOT .EQ. 0.0 ) EKX = 0.0
      IF ( MDOT .NE. 0.0 ) ALPHAX = 2.* GC * EKX * (( AREA(L) * RHOX /
     .                                 MDOT ))**2.
      IF ( MDOT .EQ. 0.0 ) ALPHAX = 0.0
C
      PVX  = RHOX * EKX / C11
      PTX  = PSX  + PVX
      PSAX = PSX  + PB * C13
      PTAX = PTX  + PB * C13
C
      IF ( TERM .EQ. 'NO' ) THEN
      WRITE(Z,5230)
C
      IF ( L .EQ. 1 ) WRITE(Z,5000)
      IF ( L .EQ. 2 ) WRITE(Z,5001)
      IF ( L .EQ. 3 ) WRITE(Z,5002)
C
      IF ( IU .EQ. 1 ) THEN
         WRITE(Z,5010) MDOT
         WRITE(Z,5020) PSX
         WRITE(Z,5030) PVX
         WRITE(Z,5040) PTX
         WRITE(Z,5050) TSX
         WRITE(Z,5060) RHOX
         WRITE(Z,5070) EKX
         WRITE(Z,5080) ALPHAX
         WRITE(Z,5090) PSAX
         WRITE(Z,5100) PTAX
      ELSE
         WRITE(Z,6020) PSX
         WRITE(Z,6030) PVX
         WRITE(Z,6040) PTX
         WRITE(Z,6050) TSX
         WRITE(Z,6060) RHOX
         WRITE(Z,6070) EKX
         WRITE(Z,5080) ALPHAX
         WRITE(Z,6090) PSAX
         WRITE(Z,6100) PTAX
      END IF
      END IF
C
      IF ( L .EQ. 3 ) WRITE(Z,5220)
C
      WRITE(Z,5210)
C
      IF ( L .EQ. 1 .AND. MDOT .EQ. 0.0 ) WRITE(Z, 5200)
C
      RETURN
C
C*****************************************************************C
C*****************************************************************C
C
 5000 FORMAT(2(40X,50(1H*)/)/50X,
     1 29HAVERAGE VALUES AT INLET PLANE/46X,38(1H-))
 5001 FORMAT(2(40X,50(1H*)/)/50X,
     1 30HAVERAGE VALUES AT OUTLET PLANE/46X,38(1H-))
 5002 FORMAT(2(40X,50(1H*)/)/50X,
     1 34HAVERAGE VALUES AT AUXILLIARY PLANE/46X,38(1H-))
 5010 FORMAT(/43X,'MASS FLOW RATE',15X,F7.2,' LBM/S',//)
 6010 FORMAT(/43X,'MASS FLOW RATE',15X,F7.2,' KG/S',//)
 5020 FORMAT(43X,'STATIC PRESSURE',14X,F7.3,' IN. WG',//)
 6020 FORMAT(43X,'STATIC PRESSURE',14X,F7.3,' KPA',//)
 5030 FORMAT(43X,'VELOCITY PRESSURE',13X,F6.3,' IN. WG',//)
 6030 FORMAT(43X,'VELOCITY PRESSURE',13X,F6.3,' KPA',//)
 5040 FORMAT(43X,'TOTAL PRESSURE',15X,F7.3,' IN. WG',//)
 6040 FORMAT(43X,'TOTAL PRESSURE',15X,F7.3,' KPA',//)
 5050 FORMAT(43X,'TEMPERATURE',18X,F7.2,' R',//)
 6050 FORMAT(43X,'TEMPERATURE',18X,F7.2,' K',//)
 5060 FORMAT(43X,'DENSITY',22X,F7.5,' LBM/CU FT',//)
 6060 FORMAT(43X,'DENSITY',22X,F7.4,' KG/CU M',//)
 5070 FORMAT(43X,'SPECIFIC KINETIC ENERGY',7X,F6.2,' FT*LB/LBM',//)
 6070 FORMAT(43X,'SPECIFIC KINETIC ENERGY',7X,F6.2,' J/KG',//)
 5080 FORMAT(43X,'KINETIC ENERGY CORR FACTOR',3X,F7.5,//)
 5090 FORMAT(43X,'ABSOLUTE STATIC PRESSURE',5X,F7.3,' IN. WA',//)
```

```
       6090 FORMAT(43X,'ABSOLUTE STATIC PRESSURE',5X,F7.3,' KPA',//)
       5100 FORMAT(43X,'ABSOLUTE TOTAL PRESSURE',6X,F7.3,' IN. WA',//)
       6100 FORMAT(43X,'ABSOLUTE TOTAL PRESSURE',6X,F7.3,' KPA',//)
       5200 FORMAT(5(/),10X,'OPEN INLET FAN --- NO TRAVERSE MADE AT INLET')
       5210 FORMAT(1H0,39X,50(1H*)/40X,50(1H*))
       5220 FORMAT(4(/),28X,32HONLY MASS FLOW RATE WILL BE USED,4(/))
       5230 FORMAT(1H1,12(/))
      C
            END

@PRT,L LABSRC.OUTM
```



```
LAB*LABSRC(1).OUTM(21)
      C**********************************************************************C
      C**********************************************************************C
      C                                                                      C
      C        SUBROUTINE OUTM OUTPUTS RESULTS FROM MASS FLOW RATE /         C
      C                      SPECIFIC ENERGY APPROACH                        C
      C                                                                      C
      C**********************************************************************C
      C**********************************************************************C
      C
            SUBROUTINE OUTM ( MDOT, RHOM, KRHO, ETA, IU )
      C
            REAL    MDOT,KRHO,KC,MDOTC,KRHOC,MDOT1,MDOT2,KP
      C
            INTEGER Z
      C
            COMMON / PRFRM    / RHO1   ,RHO2   ,EK1    ,EK2    ,POWI   ,POWO   ,
           1                    POWOC  ,RPMI   ,RPMC   ,KC     ,RHO1C  ,T1C    ,
           2                    PTA1C
            COMMON / PLNAVG / MDOT1  ,MDOT2  ,MDOT3  ,YF     ,PS1    ,PS2    ,
           1                    PS3    ,PV1    ,PV2    ,PT1    ,PT2    ,PSA1   ,
           2                    PSA2   ,PSA3   ,TS1    ,TS2    ,PFT    ,PFS    ,
           3                    PFV    ,KP
            COMMON / PROP     / K      ,R      ,MU
            COMMON / OUTME    / MDOTC  ,YFC    ,POWIC  ,KRHOC  ,ETAC   ,RHOMC
            COMMON / UMASS    / UMDTFR,UYFR    ,UPIR   ,UETAR  ,URHOMR,UPOR    ,
           1                    UMDTFS,UYFS    ,UPIS   ,UETAS  ,URHOMS,UPOS
            COMMON / UMASSC / UMDTCR,UYFCR  ,URHOCR,UMDTCS,UYFCS  ,URHOCS
            COMMON / UVPCR    / UQFCR  ,UPFTCR,UPFSCR,UPFVCR,UPICR  ,UPOCR  ,
           1                    UETACR
            COMMON / UVPCS    / UQFCS  ,UPFTCS,UPFSCS,UPFVCS,UPICS  ,UPOCS  ,
           1                    UETACS
            COMMON / URAN     / UAR    ,URR    ,UTSJR  ,UPVJR  ,UPSJR  ,UPBR   ,
           1                    UYAWR  ,UPCHR  ,UETAMR,UWR     ,UER    ,UIR    ,
           1                    UTAUR  ,UNR    ,UPTR   ,UFNR
            COMMON / USYS     / UAS    ,URS    ,UTSJS  ,UPVJS  ,UPSJS  ,UPBS   ,
           1                    UYAWS  ,UPCHS  ,UETAMS,UWS     ,UES    ,UIS    ,
           2                    UTAUS  ,UNS    ,UPTS   ,UFNS
      C
            DATA Z/20/
      C
      C**********************************************************************C
      C                                                                      C
      C                     OUTPUT PERFORMANCE RESULTS                       C
      C                                                                      C
      C**********************************************************************C
      C
            WRITE (Z,1000)
            WRITE (Z,2000)
            WRITE (Z,2010)
            WRITE (Z,2011)
            WRITE (Z,2012)
      C
            UN     = SQRT ( UMDTFR + UMDTFS )
            RAN    = SQRT ( UMDTFR )
            SYS    = SQRT ( UMDTFS )
            AUN    = UN   * MDOT
            ARAN   = RAN  * MDOT
            ASYS   = SYS  * MDOT
            PCUN   = UN   * 100.
            PCRAN  = RAN  * 100.
            PCSYS  = SYS  * 100.
      C
            IF ( IU .EQ. 1 ) THEN
               WRITE (Z,5000) MDOT,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
               WRITE (Z,5001)
            ELSE
               WRITE (Z,6000) MDOT,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
               WRITE (Z,5001)
            END IF
      C
            UN     = SQRT ( UYFR  + UYFS )
            RAN    = SQRT ( UYFR )
            SYS    = SQRT ( UYFS )
            AUN    = UN   * YF
            ARAN   = RAN  * YF
```

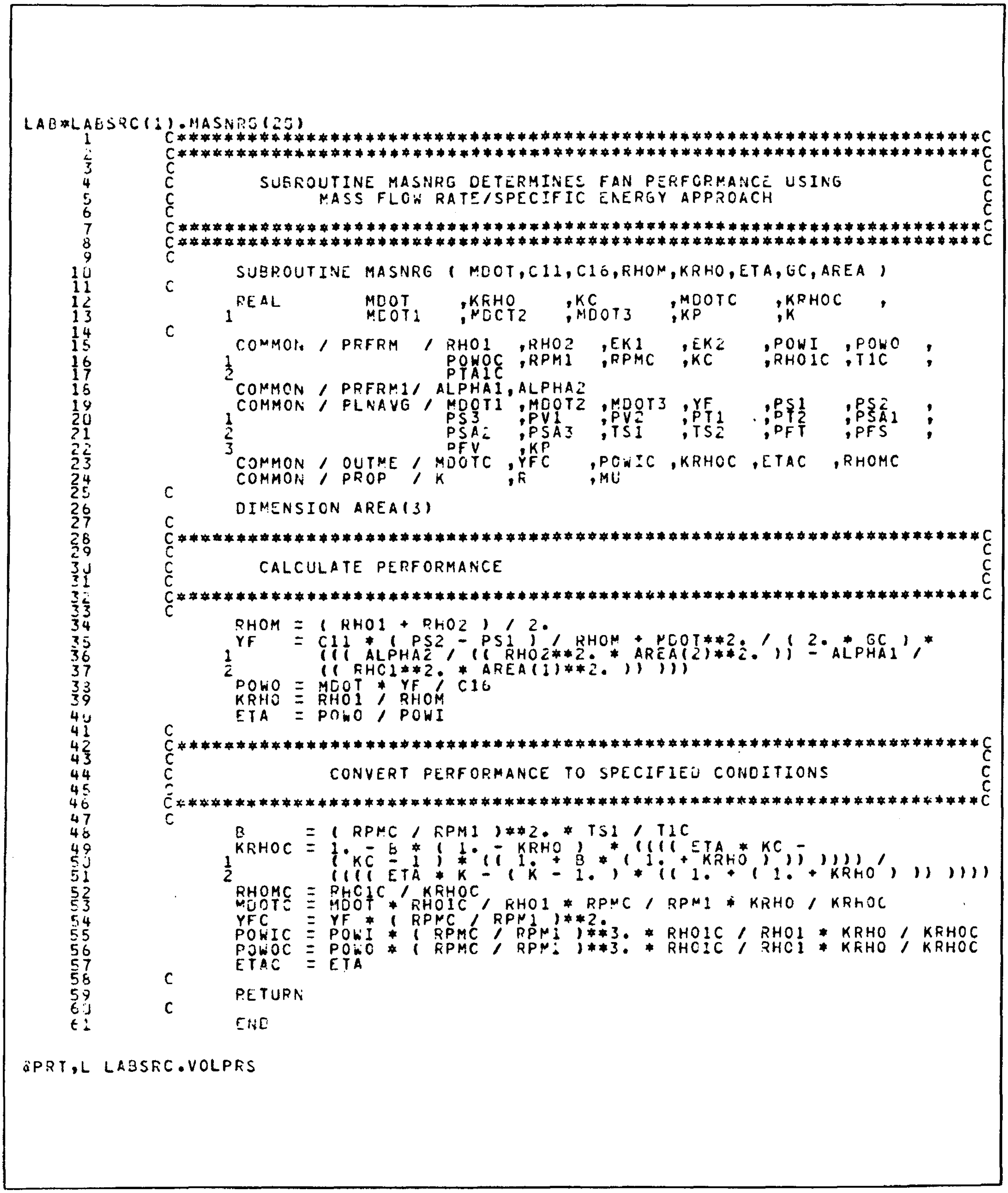
```
      ASYS  = SYS  * YF
      PCUN  = UN   * 100.
      PCRAN = RAN  * 100.
      PCSYS = SYS  * 100.
C
      IF ( IU .EQ. 1 ) THEN
        WRITE (Z,5010) YF,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
        WRITE (Z,5011)
      ELSE
        WRITE (Z,6010) YF,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
        WRITE (Z,5011)
      END IF
C
      UN    = SQRT ( UPIR + UPIS )
      RAN   = SQRT ( UPIR )
      SYS   = SQRT ( UPIS )
      AUN   = UN   * POWI
      ARAN  = RAN  * POWI
      ASYS  = SYS  * POWI
      PCUN  = UN   * 100.
      PCRAN = RAN  * 100.
      PCSYS = SYS  * 100.
C
      IF ( IU .EQ. 1 ) THEN
        WRITE (Z,5030) POWI,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
        WRITE (Z,5021)
      ELSE
        WRITE (Z,6030) POWI,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
        WRITE (Z,5021)
      END IF
C
      UN    = SQRT ( UPOR + UPOS )
      RAN   = SQRT ( UPOR )
      SYS   = SQRT ( UPOS )
      AUN   = UN   * POWO
      ARAN  = RAN  * POWO
      ASYS  = SYS  * POWO
      PCUN  = UN   * 100.
      PCRAN = RAN  * 100.
      PCSYS = SYS  * 100.
C
      IF ( IU .EQ. 1 ) THEN
        WRITE (Z,5020) POWO,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
        WRITE (Z,5021)
      ELSE
        WRITE (Z,6020) POWO,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
        WRITE (Z,5021)
      END IF
C
      UN    = SQRT ( UETAR + UETAS )
      RAN   = SQRT ( UETAR )
      SYS   = SQRT ( UETAS )
      AUN   = UN   * ETA
      ARAN  = RAN  * ETA
      ASYS  = SYS  * ETA
      PCUN  = UN   * 100.
      PCRAN = RAN  * 100.
      PCSYS = SYS  * 100.
C
      WRITE (Z,5040) ETA,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
      WRITE (Z,5041)
C
      UN    = SQRT ( URHOMR + URHOMS )
      RAN   = SQRT ( URHOMR )
      SYS   = SQRT ( URHOMS )
      AUN   = UN   * RHOM
      ARAN  = RAN  * RHOM
      ASYS  = SYS  * RHOM
      PCUN  = UN   * 100.
      PCRAN = RAN  * 100.
      PCSYS = SYS  * 100.
C
      IF ( IU .EQ. 1 ) THEN
        WRITE (Z,5060) RHOM,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
        WRITE (Z,5061)
      ELSE
```

```
        WRITE (Z,6060) RHOM,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
        WRITE (Z,5061)
      END IF
C
      WRITE (Z,5050) KRHO
      WRITE (Z,5051)
C
      WRITE (Z,2020)
C
C*********************************************************************C
C                                                                     C
C                OUTPUT CONVERSION RESULTS                            C
C                                                                     C
C*********************************************************************C
C
      IF ( IU .EQ. 1 ) WRITE(Z,5080) RPMC , RHO1C
      IF ( IU .EQ. 2 ) WRITE(Z,6080) RPMC , RHO1C
C
      WRITE (Z,1000)
      WRITE (Z,2000)
      WRITE (Z,2010)
      WRITE (Z,2011)
      WRITE (Z,2012)
C
      UN    = SQRT ( UMDTCR + UMDTCS )
      RAN   = SQRT ( UMDTCR )
      SYS   = SQRT ( UMDTCS )
      AUN   = UN  * MDOTC
      ARAN  = RAN * MDOTC
      ASYS  = SYS * MDOTC
      PCUN  = UN  * 100.
      PCRAN = RAN * 100.
      PCSYS = SYS * 100.
C
      IF ( IU .EQ. 1 ) THEN
        WRITE (Z,5000) MDOTC,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
        WRITE (Z,5001)
      ELSE
        WRITE (Z,6000) MDOTC,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
        WRITE (Z,5001)
      END IF
C
      UN    = SQRT ( UYFCR + UYFCS )
      RAN   = SQRT ( UYFCR )
      SYS   = SQRT ( UYFCS )
      AUN   = UN  * YFC
      ARAN  = RAN * YFC
      ASYS  = SYS * YFC
      PCUN  = UN  * 100.
      PCRAN = RAN * 100.
      PCSYS = SYS * 100.
C
      IF ( IU .EQ. 1 ) THEN
        WRITE (Z,5010) YFC,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
        WRITE (Z,5011)
      ELSE
        WRITE (Z,6010) YFC,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
        WRITE (Z,5011)
      END IF
C
      UN    = SQRT ( UPICR + UPICS )
      RAN   = SQRT ( UPICR )
      SYS   = SQRT ( UPICS )
      AUN   = UN  * POWIC
      ARAN  = RAN * POWIC
      ASYS  = SYS * POWIC
      PCUN  = UN  * 100.
      PCRAN = RAN * 100.
      PCSYS = SYS * 100.
C
      IF ( IU .EQ. 1 ) THEN
        WRITE (Z,5030) POWIC,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
        WRITE (Z,5031)
      ELSE
        WRITE (Z,6030) POWIC,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
        WRITE (Z,5031)
```

```
      END IF
C
      UN     = SQRT ( UPOCR + UPOCS )
      RAN    = SQRT ( UPOCR )
      SYS    = SQRT ( UPOCS )
      AUN    = UN  * POWOC
      ARAN   = RAN * POWOC
      ASYS   = SYS * POWOC
      PCUN   = UN  * 100.
      PCRAN  = RAN * 100.
      PCSYS  = SYS * 100.
C
      IF ( IU .EQ. 1 ) THEN
        WRITE (Z,5020) POWOC,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
        WRITE (Z,5021)
      ELSE
        WRITE (Z,6020) POWOC,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
        WRITE (Z,5021)
      END IF
C
      UN     = SQRT ( UETACR + UETACS )
      RAN    = SQRT ( UETACR )
      SYS    = SQRT ( UETACS )
      AUN    = UN  * ETAC
      ARAN   = RAN * ETAC
      ASYS   = SYS * ETAC
      PCUN   = UN  * 100.
      PCRAN  = RAN * 100.
      PCSYS  = SYS * 100.
C
      WRITE (Z,5040) ETAC,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
      WRITE (Z,5041)
C
      WRITE (Z,5050) KRHOC
      WRITE (Z,5051)
C
      WRITE (Z,5050) KRHO/KRHOC
      WRITE (Z,5052)
      WRITE(Z,2020)
C
      RETURN
C
C*********************************************************************C
C*********************************************************************C
C
 1000 FORMAT(7(/))
 2000 FORMAT(31X,'MASS FLOW RATE / SPECIFIC ENERGY APPROACH WITH ABSOLUT
     1E UNCERTAINTIES',////)
 2010 FORMAT(4X,'QUANTITY',10X,'UNITS',12X,'COMPUTED',9X,'TOTAL'
     1,8X,'PERCENT',6X,'RANDOM',7X,'PERCENT',4X,'SYSTEMATIC'
     2,5X,'PERCENT')
 2011 FORMAT(40X,'VALUE',11X,'UNCERT',8X,'TOTAL',7X,'UNCERT'
     1,7X,'RANDOM',7X,'UNCERT',6X,'SYSTEMATIC')
 2012 FORMAT(69X,'UNCERT',20X,'UNCERT',21X,'UNCERT',//)
 2020 FORMAT(4(/),2(132('*'),/))
 5080 FORMAT('1',2(132('*'),/),/29X,'PERFORMANCE RESULTS CONVERTED TO',
     1          F6.0,' RPM AND',F7.5,' LBM/CU FT INLET DENSITY',//,
     2          2(132('*'),/))
 5000 FORMAT(3X,'MASS FLOW',9X,'LBM/S',F20.2,3X,6(F13.3))
 5001 FORMAT(5X,'RATE',//)
 5010 FORMAT(3X,'FAN SPECIFIC',6X,'FT*LB/LBM',F16.2,3X,6(F13.3))
 5011 FORMAT(6X,'ENERGY',//)
 5020 FORMAT(3X,'FAN OUTPUT',8X,'HP',F23.2,3X,6(F13.3))
 5021 FORMAT(5X,'POWER'//)
 5030 FORMAT(3X,'FAN INPUT',9X,'HP',F23.2,3X,6(F13.3))
 5031 FORMAT(5X,'POWER'//)
 5050 FORMAT(3X,'COMPRESS.',9X,'NONE',F21.5,3X,6(F13.3))
 5051 FORMAT(5X,'COE.'//)
 5040 FORMAT(3X,'FAN',15X,'PER',F21.4,4X,6(F13.3))
 5041 FORMAT(3X,'EFFICIENCY',8X,'UNIT'//)
 5052 FORMAT(3X,'COE. RATIO')
 5060 FORMAT(3X,'FAN MEAN',10X,'LBM/CU FT',F16.5,3X,6(F13.3))
 5061 FORMAT(3X,'DENSITY',//)
 6000 FORMAT(3X,'MASS FLOW',9X,'KG/S',F21.2,3X,6(F13.3))
 6010 FORMAT(3X,'FAN SPECIFIC',6X,'J/KG',F21.3,3X,6(F13.3))
 6020 FORMAT(3X,'FAN OUTPUT',8X,'KW',F23.2,3X,6(F13.3))
```

```
      6030 FORMAT(3X,'FAN INPUT',9X,'KW',F23.2,3X,6(F13.3))
      6060 FORMAT(3X,'FAN MEAN',10X,'KG/CU M',F16.5,3X,6(F13.3))
      6080 FORMAT('1',2(132('*'),/),/30X,'PERFORMANCE RESULTS CONVERTED TO',
     1             F6.2,' FPS AND',F7.4,' KG/CU M INLET DENSITY',//,
     2             2(132('*'),/))
C
           END

@PRT,L LABSRC.MASNRG
```

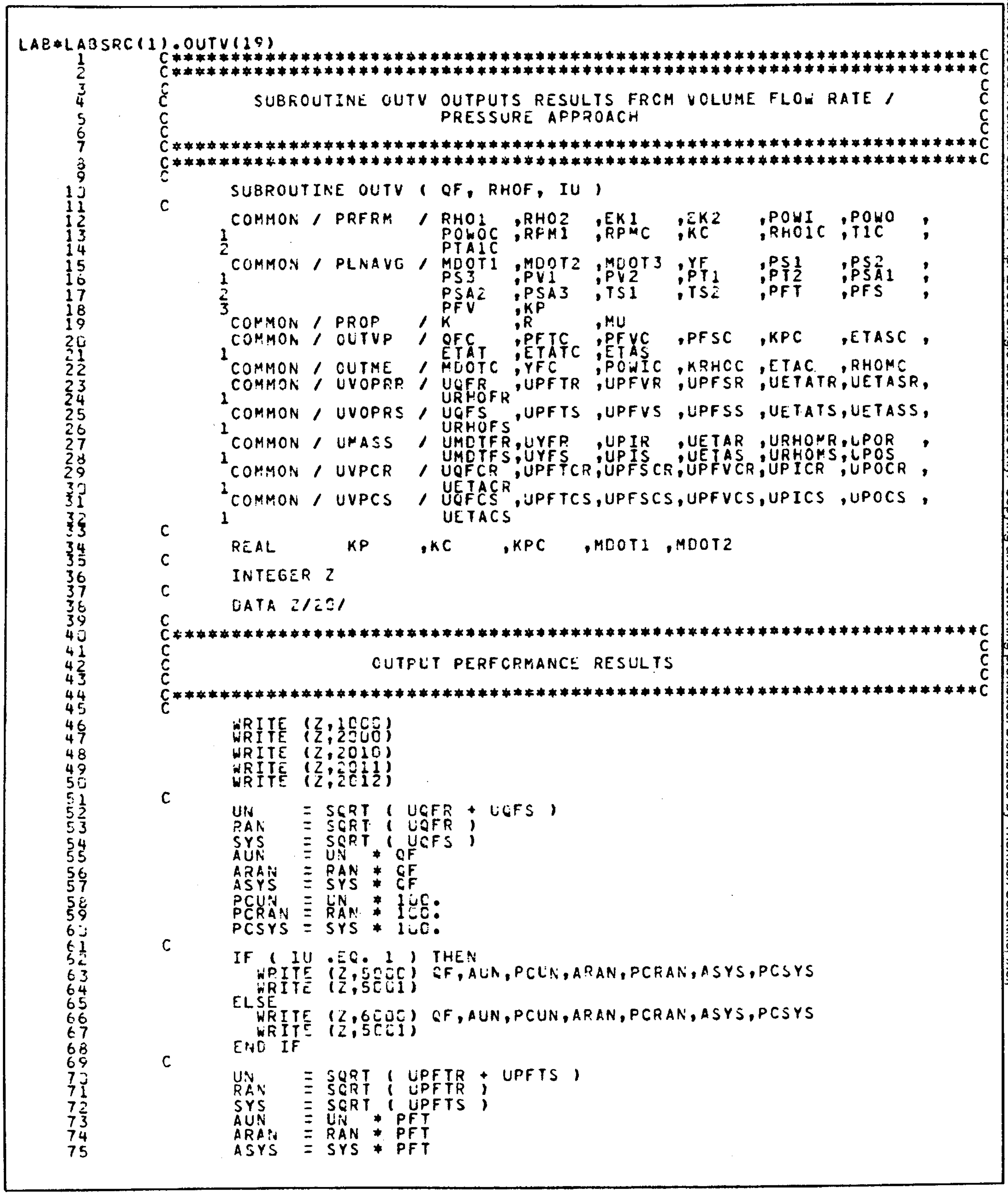


```
LAB*LABSRC(1).MASNRG(25)
C********************************************************************C
C********************************************************************C
C                                                                    C
C       SUBROUTINE MASNRG DETERMINES FAN PERFORMANCE USING           C
C            MASS FLOW RATE/SPECIFIC ENERGY APPROACH                 C
C                                                                    C
C********************************************************************C
C********************************************************************C
C
      SUBROUTINE MASNRG ( MDOT,C11,C16,RHOM,KRHO,ETA,GC,AREA )
C
      REAL        MDOT    ,KRHO    ,KC      ,MDOTC   ,KRHOC    ,
     1            MDOT1   ,MDOT2   ,MDOT3   ,KP      ,K
C
      COMMON / PRFRM  / RHO1  ,RHO2  ,EK1   ,EK2   ,POWI  ,POWO  ,
     1                  POWOC ,RPM1  ,RPMC  ,KC    ,RHO1C ,T1C   ,
     2                  PTA1C
      COMMON / PRFRM1/ ALPHA1,ALPHA2
      COMMON / PLNAVG / MDOT1 ,MDOT2 ,MDOT3 ,YF    ,PS1   ,PS2   ,
     1                  PS3   ,PV1   ,PV2   ,PT1   ,PT2   ,PSA1  ,
     2                  PSA2  ,PSA3  ,TS1   ,TS2   ,PFT   ,PFS   ,
     3                  PFV   ,KP
      COMMON / OUTME / MDOTC ,YFC   ,POWIC ,KRHOC ,ETAC  ,RHOMC
      COMMON / PROP  / K     ,R     ,MU
C
      DIMENSION AREA(3)
C
C********************************************************************C
C                                                                    C
C       CALCULATE PERFORMANCE                                        C
C                                                                    C
C********************************************************************C
C
      RHOM = ( RHO1 + RHO2 ) / 2.
      YF   = C11 * ( PS2 - PS1 ) / RHOM + MDOT**2. / ( 2. * GC ) *
     1       ((( ALPHA2 / (( RHO2**2. * AREA(2)**2. )) - ALPHA1 /
     2       (( RHO1**2. * AREA(1)**2. )) )))
      POWO = MDOT * YF / C16
      KRHO = RHO1 / RHOM
      ETA  = POWO / POWI
C
C********************************************************************C
C                                                                    C
C             CONVERT PERFORMANCE TO SPECIFIED CONDITIONS            C
C                                                                    C
C********************************************************************C
C
      B     = ( RPMC / RPM1 )**2. * TS1 / T1C
      KRHOC = 1. - B * ( 1. - KRHO )  * (((( ETA * KC -
     1        ( KC - 1 ) * (( 1. + B * ( 1. + KRHO ) )) )))) /
     2        (((( ETA * K - ( K - 1. ) * (( 1. + ( 1. + KRHO ) )) ))))
      RHOMC = RHO1C / KRHOC
      MDOTC = MDOT * RHO1C / RHO1 * RPMC / RPM1 * KRHO / KRHOC
      YFC   = YF * ( RPMC / RPM1 )**2.
      POWIC = POWI * ( RPMC / RPM1 )**3. * RHO1C / RHO1 * KRHO / KRHOC
      POWOC = POWO * ( RPMC / RPM1 )**3. * RHO1C / RHO1 * KRHO / KRHOC
      ETAC  = ETA
C
      RETURN
C
      END

@PRT,L LABSRC.VOLPRS
```

```
LAB*LABSRC(1).VOLPRS(3)
C**************************************************************C
C**************************************************************C
C                                                              C
C       SUBROUTINE VOLPRS DETERMINES FAN PERFORMANCE USING     C
C              VOLUME FLOW RATE/PRESSURE APPROACH              C
C                                                              C
C**************************************************************C
C**************************************************************C
C
      SUBROUTINE VOLPRS ( PTA1,CP1,MDOT,C2,C11,C17,JC,QF,RHOF )
C
      COMMON / PRFRM  / RHO1  ,RHO2  ,EK1   ,EK2   ,POWI  ,POWO  ,
     1                  POWOC ,RPM1  ,RPMC  ,KC    ,RHO1C ,T1C   ,
     2                  PTA1C
      COMMON / PLNAVG / MDOT1 ,MDOT2 ,MDOT3 ,YF    ,PS1   ,PS2   ,
     1                  PS3   ,PV1   ,PV2   ,PT1   ,PT2   ,PSA1  ,
     2                  PSA2  ,PSA3  ,TS1   ,TS2   ,PFT   ,PFS   ,
     3                  PFV   ,KP
      COMMON / PROP   / K     ,R     ,MU
      COMMON / OUTVP  / QFC   ,PFTC  ,PFVC  ,PFSC  ,KPC   ,ETASC ,
     1                  ETAT  ,ETATC ,ETAS
      COMMON / OUTME  / MDOTC ,YFC   ,POWIC ,KRHOC ,ETAC  ,RHOMC
C
      REAL      MDOT  ,JC    ,KP    ,KC     ,KPC    ,KPKPC  ,
     1          MDOT1 ,MDOT2 ,KRHOC ,K
C
C**************************************************************C
C                                                              C
C                    CALCULATE PERFORMANCE                     C
C                                                              C
C**************************************************************C
C
      RHOF    = RHO1 * PTA1 / (((( PSA1 * (( 1. + EK1 /
     1          ( JC  * CP1 * TS1 ) )) ))))
      QF      = C2 * MDOT / RHOF
      PFT     = PT2  - PT1
      PFV     = RHO2 * EK2  / C11
      PFS     = PFT  - PFV
C
C**************************************************************C
C                                                              C
C           CONVERT PERFORMANCE TO SPECIFIED CONDITIONS        C
C                                                              C
C**************************************************************C
C
      Z       = ( K - 1. ) / K * POWI * C17 / ( QF * PTA1 )
      X       = PFT / PTA1
      KP      = Z * ALOG( 1. + X ) / ((( X * ALOG( 1. + Z ) )))
      POWO    = QF * PFT * KP / C17
      ETAT    = POWO / POWI
      ETAS    = ETAT * PFS / PFT
      ZC      = Z * K / ( K - 1. ) * ( KC - 1. ) / KC * PTA1 / PTA1C *
     .          ( RPMC / RPM1 )**2. * RHO1C / RHOF
      A       = ALOG( 1. + X ) * ALOG( 1. + ZC ) / ALOG( 1. + Z ) *
     .          ( K - 1. ) / K * KC / ( KC - 1. )
      XC      = EXP( A ) - 1.
      KPKPC   = Z / ZC * XC / X * K / ( K - 1. ) * ( KC - 1. ) / KC
      KPC     = KP / KPKPC
      QFC     = QF * RPMC / RPM1 * KPKPC
      PFTC    = PFT * RHO1C / RHOF * ( RPMC / RPM1 )**2 * KPKPC
      PFVC    = PFV * ( RPMC / RPM1 )**2 * RHO1C / RHOF
      PFSC    = PFTC - PFVC
      POWIC   = POWI * RHO1C / RHOF * ( RPMC / RPM1 )**3. * KPKPC
      POWOC   = POWO * RHO1C / RHOF * ( RPMC / RPM1 )**3. * KPKPC
      ETATC   = ETAT
      ETASC   = ETAT * PFSC / PFTC
C
      RETURN
C
      END

@PRT,L LABSRC.OUTV
```



```
LAB*LABSRC(1).OUTV(19)
C**********************************************************************C
C**********************************************************************C
C                                                                      C
C      SUBROUTINE OUTV OUTPUTS RESULTS FROM VOLUME FLOW RATE /         C
C                          PRESSURE APPROACH                           C
C                                                                      C
C**********************************************************************C
C**********************************************************************C
C
      SUBROUTINE OUTV ( QF, RHOF, IU )
C
      COMMON / PRFRM  / RHO1  ,RHO2  ,EK1   ,EK2   ,POWI  ,POWO  ,
     1                  POWOC ,RPM1  ,RPMC  ,KC    ,RHO1C ,T1C   ,
     2                  PTA1C
      COMMON / PLNAVG / MDOT1 ,MDOT2 ,MDOT3 ,YF    ,PS1   ,PS2   ,
     1                  PS3   ,PV1   ,PV2   ,PT1   ,PT2   ,PSA1  ,
     2                  PSA2  ,PSA3  ,TS1   ,TS2   ,PFT   ,PFS   ,
     3                  PFV   ,KP
      COMMON / PROP   / K     ,R     ,MU
      COMMON / OUTVP  / QFC   ,PFTC  ,PFVC  ,PFSC  ,KPC   ,ETASC ,
     1                  ETAT  ,ETATC ,ETAS
      COMMON / OUTME  / MDOTC ,YFC   ,POWIC ,KRHCC ,ETAC  ,RHOMC
      COMMON / UVOPRR / UQFR  ,UPFTR ,UPFVR ,UPFSR ,UETATR,UETASR,
     1                  URHOFR
      COMMON / UVOPRS / UQFS  ,UPFTS ,UPFVS ,UPFSS ,UETATS,UETASS,
     1                  URHOFS
      COMMON / UMASS  / UMDTFR,UYFR  ,UPIR  ,UETAR ,URHOMR,UPOR  ,
     1                  UMDTFS,UYFS  ,UPIS  ,UETAS ,URHOMS,UPOS
      COMMON / UVPCR  / UQFCR ,UPFTCR,UPFSCR,UPFVCR,UPICR ,UPOCR ,
     1                  UETACR
      COMMON / UVPCS  / UQFCS ,UPFTCS,UPFSCS,UPFVCS,UPICS ,UPOCS ,
     1                  UETACS
C
      REAL      KP    ,KC    ,KPC   ,MDOT1 ,MDOT2
C
      INTEGER Z
C
      DATA Z/20/
C
C**********************************************************************C
C                                                                      C
C                     OUTPUT PERFORMANCE RESULTS                       C
C                                                                      C
C**********************************************************************C
C
      WRITE (Z,1000)
      WRITE (Z,2000)
      WRITE (Z,2010)
      WRITE (Z,2011)
      WRITE (Z,2012)
C
      UN     = SQRT ( UQFR + UQFS )
      RAN    = SQRT ( UQFR )
      SYS    = SQRT ( UQFS )
      AUN    = UN  * QF
      ARAN   = RAN * QF
      ASYS   = SYS * QF
      PCUN   = UN  * 100.
      PCRAN  = RAN * 100.
      PCSYS  = SYS * 100.
C
      IF ( IU .EQ. 1 ) THEN
         WRITE (Z,5000) QF,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
         WRITE (Z,5001)
      ELSE
         WRITE (Z,6000) QF,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
         WRITE (Z,5001)
      END IF
C
      UN     = SQRT ( UPFTR + UPFTS )
      RAN    = SQRT ( UPFTR )
      SYS    = SQRT ( UPFTS )
      AUN    = UN  * PFT
      ARAN   = RAN * PFT
      ASYS   = SYS * PFT
```

```
      PCUN  = UN  * 100.
      PCRAN = RAN * 100.
      PCSYS = SYS * 100.
C
      IF ( IU .EQ. 1 ) THEN
         WRITE (Z,5010) PFT,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
         WRITE (Z,5011)
      ELSE
         WRITE (Z,6010) PFT,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
         WRITE (Z,5011)
      END IF
C
      UN    = SQRT ( UPFSR + UPFSS )
      RAN   = SQRT ( UPFSR )
      SYS   = SQRT ( UPFSS )
      AUN   = UN  * PFS
      ARAN  = RAN * PFS
      ASYS  = SYS * PFS
      PCUN  = UN  * 100.
      PCRAN = RAN * 100.
      PCSYS = SYS * 100.
C
      IF ( IU .EQ. 1 ) THEN
         WRITE (Z,5020) PFS,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
         WRITE (Z,5021)
      ELSE
         WRITE (Z,6020) PFS,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
         WRITE (Z,5021)
      END IF
C
      UN    = SQRT ( UPFVR + UPFVS )
      RAN   = SQRT ( UPFVR )
      SYS   = SQRT ( UPFVS )
      AUN   = UN  * PFV
      ARAN  = RAN * PFV
      ASYS  = SYS * PFV
      PCUN  = UN  * 100.
      PCRAN = RAN * 100.
      PCSYS = SYS * 100.
C
      IF ( IU .EQ. 1 ) THEN
         WRITE (Z,5030) PFV,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
         WRITE (Z,5031)
      ELSE
         WRITE (Z,6030) PFV,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
         WRITE (Z,5031)
      END IF
C
      UN    = SQRT ( UPIR + UPIS )
      RAN   = SQRT ( UPIR )
      SYS   = SQRT ( UPIS )
      AUN   = UN  * POWI
      ARAN  = RAN * POWI
      ASYS  = SYS * POWI
      PCUN  = UN  * 100.
      PCRAN = RAN * 100.
      PCSYS = SYS * 100.
C
      IF ( IU .EQ. 1 ) THEN
         WRITE (Z,5050) POWI,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
         WRITE (Z,5051)
      ELSE
         WRITE (Z,6050) POWI,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
         WRITE (Z,5051)
      END IF
C
      UN    = SQRT ( UPOR + UPOS )
      RAN   = SQRT ( UPOR )
      SYS   = SQRT ( UPOS )
      AUN   = UN  * POWO
      ARAN  = RAN * POWO
      ASYS  = SYS * POWO
      PCUN  = UN  * 100.
      PCRAN = RAN * 100.
      PCSYS = SYS * 100.
C
```

```
      IF ( IU .EQ. 1 ) THEN
        WRITE (Z,5060) POWO,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
        WRITE (Z,5061)
      ELSE
        WRITE (Z,6060) POWC,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
        WRITE (Z,5061)
      END IF
C
      UN     = SQRT ( UETATR + UETATS )
      RAN    = SQRT ( UETATR )
      SYS    = SQRT ( UETATS )
      AUN    = UN  * ETAT
      ARAN   = RAN * ETAT
      ASYS   = SYS * ETAT
      PCUN   = UN  * 100.
      PCRAN  = RAN * 100.
      PCSYS  = SYS * 100.
C
      WRITE (Z,5070) ETAT,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
      WRITE (Z,5071)
C
      UN     = SQRT ( UETASR + UETASS )
      RAN    = SQRT ( UETASR )
      SYS    = SQRT ( UETASS )
      AUN    = UN  * ETAS
      ARAN   = RAN * ETAS
      ASYS   = SYS * ETAS
      PCUN   = UN  * 100.
      PCRAN  = RAN * 100.
      PCSYS  = SYS * 100.
C
      WRITE (Z,5080) ETAS,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
      WRITE (Z,5081)
C
      UN     = SQRT ( URHOFR + URHOFS )
      RAN    = SQRT ( URHOFR )
      SYS    = SQRT ( URHOFS )
      AUN    = UN  * RHOF
      ARAN   = RAN * RHOF
      ASYS   = SYS * RHOF
      PCUN   = UN  * 100.
      PCRAN  = RAN * 100.
      PCSYS  = SYS * 100.
C
      IF ( IU .EQ. 1 ) THEN
        WRITE (Z,5090) RHOF,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
      ELSE
        WRITE (Z,6090) RHOF,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
      END IF
C
      WRITE (Z,5040) KP
      WRITE (Z,5041)
C
      WRITE (Z,2020)
C
C**********************************************************************C
C                                                                      C
C                   OUTPUT CONVERSION RESULTS                          C
C                                                                      C
C**********************************************************************C
C
      IF ( IU .EQ. 1 ) WRITE(Z,5100) RPMC , RHO1C
      IF ( IU .EQ. 2 ) WRITE(Z,6100) RPMC , RHO1C
C
      WRITE (Z,1000)
      WRITE (Z,2000)
      WRITE (Z,2010)
      WRITE (Z,2011)
      WRITE (Z,2012)
C
      UN     = SQRT ( UQFCR + UQFCS )
      RAN    = SQRT ( UQFCR )
      SYS    = SQRT ( UQFCS )
      AUN    = UN  * QFC
      ARAN   = RAN * QFC
      ASYS   = SYS * QFC
```

```
      PCUN  = UN   * 100.
      PCRAN = RAN  * 100.
      PCSYS = SYS  * 100.
C
      IF ( IU .EQ. 1 ) THEN
         WRITE (Z,5000) QFC,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
         WRITE (Z,5001)
      ELSE
         WRITE (Z,6000) QFC,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
         WRITE (Z,5001)
      END IF
C
      UN    = SQRT ( UPFTCR + UPFTCS )
      RAN   = SQRT ( UPFTCR )
      SYS   = SQRT ( UPFTCS )
      AUN   = UN   * PFTC
      ARAN  = RAN  * PFTC
      ASYS  = SYS  * PFTC
      PCUN  = UN   * 100.
      PCRAN = RAN  * 100.
      PCSYS = SYS  * 100.
C
      IF ( IU .EQ. 1 ) THEN
         WRITE (Z,5010) PFTC,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
         WRITE (Z,5011)
      ELSE
         WRITE (Z,6010) PFTC,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
         WRITE (Z,5011)
      END IF
C
      UN    = SQRT ( UPFSCR + UPFTCS )
      RAN   = SQRT ( UPFSCR )
      SYS   = SQRT ( UPFSCS )
      AUN   = UN   * PFSC
      ARAN  = RAN  * PFSC
      ASYS  = SYS  * PFSC
      PCUN  = UN   * 100.
      PCRAN = RAN  * 100.
      PCSYS = SYS  * 100.
C
      IF ( IU .EQ. 1 ) THEN
         WRITE (Z,5020) PFSC,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
         WRITE (Z,5021)
      ELSE
         WRITE (Z,6020) PFSC,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
         WRITE (Z,5021)
      END IF
C
      UN    = SQRT ( UPFVCR + UPFTCS )
      RAN   = SQRT ( UPFVCR )
      SYS   = SQRT ( UPFVCS )
      AUN   = UN   * PFVC
      ARAN  = RAN  * PFVC
      ASYS  = SYS  * PFVC
      PCUN  = UN   * 100.
      PCRAN = RAN  * 100.
      PCSYS = SYS  * 100.
C
      IF ( IU .EQ. 1 ) THEN
         WRITE (Z,5030) PFVC,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
         WRITE (Z,5031)
      ELSE
         WRITE (Z,6030) PFVC,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
         WRITE (Z,5031)
      END IF
C
C
      UN    = SQRT ( UPICR + UPICS )
      AUN   = UN   * POWIC
      RAN   = SQRT ( UPICR )
      ARAN  = RAN  * POWIC
      PCUN  = UN   * 100.
      PCRAN = RAN  * 100.
      SYS   = SQRT ( UPICS )
      ASYS  = SYS  * POWIC
      PCSYS = SYS  * 100.
```

```
C
      IF ( IU .EQ. 1 ) THEN
        WRITE (Z,5050) POWIC,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
        WRITE (Z,5051)
      ELSE
        WRITE (Z,6050) POWIC,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
        WRITE (Z,5051)
      END IF
C
      UN    = SQRT ( UPOCR + UPOCS )
      RAN   = SQRT ( UPOCR )
      SYS   = SQRT ( UPOCS )
      AUN   = UN  * POWOC
      ARAN  = RAN * POWOC
      ASYS  = SYS * POWOC
      PCUN  = UN  * 100.
      PCRAN = RAN * 100.
      PCSYS = SYS * 100.
C
      IF ( IU .EQ. 1 ) THEN
        WRITE (Z,5060) POWOC,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
        WRITE (Z,5061)
      ELSE
        WRITE (Z,6060) POWOC,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
        WRITE (Z,5061)
      END IF
C
      UN    = SQRT ( UETACR + UETACS )
      RAN   = SQRT ( UETACR )
      SYS   = SQRT ( UETACS )
      AUN   = UN  * ETATC
      ARAN  = RAN * ETATC
      ASYS  = SYS * ETATC
      PCUN  = UN  * 100.
      PCRAN = RAN * 100.
      PCSYS = SYS * 100.
C
      WRITE (Z,5070) ETATC,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
      WRITE (Z,5071)
C
      WRITE (Z,5080) ETASC,AUN,PCUN,ARAN,PCRAN,ASYS,PCSYS
      WRITE (Z,5081)
C
      WRITE (Z,5040) KPC
      WRITE (Z,5041)
C
      WRITE (Z,5040) KP/KPC
      WRITE (Z,5042)
C
      WRITE(Z,2020)
C
      RETURN
C
C**********************************************************************C
C**********************************************************************C
C
 1000 FORMAT(7(/))
 2000 FORMAT(34X,'VOLUME FLOW RATE / PRESSURE APPROACH WITH ABSOLUTE UNC
     1ERTAINTIES',////)
 2010 FORMAT(4X,'QUANTITY',10X,'UNITS',13X,'COMPUTED',7X,'TOTAL'
     1,8X,'PERCENT',7X,'RANDOM',7X,'PERCENT',5X,'SYSTEMATIC'
     2,5X,'PERCENT')
 2011 FORMAT(41X,'VALUE',9X,'UNCERT',8X,'TOTAL',8X,'UNCERT'
     1,7X,'RANDOM',8X,'UNCERT',6X,'SYSTEMATIC')
 2012 FORMAT(68X,'UNCERT',21X,'UNCERT',22X,'UNCERT',//)
 2020 FORMAT(4(/),2(132('*'),/))
 5000 FORMAT(4X,'VOLUME',10X,'CU FT/MIN',F16.0,F14.1,F13.3,F14.1,
     1   F12.3,F14.1,F13.3)
 5001 FORMAT(4X,'FLOW RATE',//)
 5010 FORMAT(4X,'FAN TOTAL',7X,'IN WG',F21.2,F15.3,F13.3,F14.3,
     1   F12.3,F14.3,F13.3)
 5011 FORMAT(4X,'PRESSURE',//)
 5020 FORMAT(4X,'FAN STATIC',6X,'IN WG',F21.2,F15.3,F13.3,F14.3,
     1   F12.3,F14.3,F13.3)
 5021 FORMAT(4X,'PRESSURE',//)
 5030 FORMAT(4X,'FAN VELOCITY',4X,'IN WG',F21.2,F15.3,F13.3,F14.3,
```

```
     1  F12.3,F14.3,F13.3)
5031 FORMAT(4X,'PRESSURE',//)
5040 FORMAT(4X,'COMPRESS.',7X,'NONE',F23.5)
5041 FORMAT(4X,'COE.',//)
5042 FORMAT(4X,'COE. RATIO')
5050 FORMAT(4X,'FAN INPUT',7X,'HP',F25.2,F14.3,F13.3,F14.3,F12.3,
     1  F14.3,F13.3)
5051 FORMAT(4X,'POWER',//)
5060 FORMAT(4X,'FAN OUTPUT',6X,'HP',F25.2,F14.3,F13.3,F14.3,F12.3,
     1  F14.3,F13.3)
5061 FORMAT(4X,'POWER',//)
5070 FORMAT(4X,'FAN TOTAL',7X,'PER',F23.4,F15.5,F13.3,F14.3,F12.3,
     1  F14.3,F13.3)
5071 FORMAT(4X,'EFFICIENCY',6X,'UNIT',//)
5080 FORMAT(4X,'FAN STATIC',6X,'PER',F23.4,F15.5,F13.3,F14.3,F12.3,
     1  F14.3,F13.3)
5081 FORMAT(4X,'EFFICIENCY',6X,'UNIT',//)
5090 FORMAT(4X,'FAN DENSITY',5X,'LBM/CU FT',F18.5,F14.5,F13.3,
     1  F14.3,F12.3,F14.3,F13.3,//)
5100 FORMAT('1',2(132('*'),/),/29X,'PERFORMANCE RESULTS CONVERTED TO',
     1          F6.0,' RPM AND',F7.5,' LBM/CU FT INLET DENSITY',//,
     2          2(132('*'),/))
6100 FORMAT('1',2(132('*'),/),/30X,'PERFORMANCE RESULTS CONVERTED TO',
     1          F6.2,' REV/S AND',F7.4,' KG/CU M INLET DENSITY',//,
     2          2(132('*'),/))
6000 FORMAT(4X,'VOLUME',10X,'CU M/S',F21.0,F14.1,F13.3,F14.1,
     1  F12.3,F14.1,F13.3)
6010 FORMAT(4X,'FAN TOTAL',7X,'K PA',F23.3,F14.3,F13.3,F14.3,
     1  F12.3,F14.3,F13.3)
6020 FORMAT(4X,'FAN STATIC',6X,'K PA',F23.3,F14.3,F13.3,F14.3,
     1  F12.3,F14.3,F13.3)
6030 FORMAT(4X,'FAN VELOCITY',4X,'K PA',F23.3,F14.3,F13.3,F14.3,
     1  F12.3,F14.3,F13.3)
6050 FORMAT(4X,'FAN INPUT',7X,'KW',F25.2,F14.3,F13.3,F14.3,F12.3,
     1  F14.3,F13.3)
6060 FORMAT(4X,'FAN OUTPUT',6X,'KW',F25.2,F14.3,F13.3,F14.3,F12.3,
     1  F14.3,F13.3)
6090 FORMAT(4X,'FAN DENSITY',5X,'KG/CU M',F23.5,F14.5,F13.3,
     1  F14.3,F12.3,F14.3,F13.3)
C
      END
```

APPENDIX C

SAMPLE COMPUTER OUTPUT

The following sample output is based on a four-point traverse. Obviously, no real test will have as few points as this, but additional points are not necessary to illustrate the calculations and the results. Input data and intermediate calculations, as well as final results, are given. Both actual and converted results are shown. The results are given for both the mass flow rate — specific energy approach and the volume flow rate — pressure approach. The same measurements were used tc obtain the results for the two different approaches.

```
**********************************************************
**********************************************************

     TEST-G. HAND CALCULATED TEST TO VERIFY PROGRAM. DATA FROM TEST-B.

**********************************************************
**********************************************************


                  CONTROL PARAMETERS
     --------------------------------------

 ALL INPUT IN U.S. CUSTOMARY UNITS ........... IL = 1

 INPUT STATIC AND DYNAMIC PRESSURES ........ IPR = 2

 OUTLET MASS FLOW RATE USED .............. IMASS = 2

 MASS FLOW/SPEC. ENG. AND VOL. FLOW/PRES.. ICALC = 3

 AIR IS THE TEST GAS ...................... IAIF = 1

 TORQUE METER ............................. IPOW = 3


**********************************************************


                  AIR MOISTURE DATA
            --------------------------

          DRY BULB TEMPERATURE       71.40  F

          WET BULB TEMPERATURE       53.00  F


 SPECIFIC HUMIDITY ..........   .00430  LBM VAPOR/LBM DRY GAS


**********************************************************
**********************************************************
```

```
*******************************************************
*******************************************************


         SPECIFIED OPERATING CONDITIONS
      --------------------------------------

      SPEED OF ROTATION ..............  915.      RPM
      ABSOLUTE TOTAL PRESSURE ........  407.510   IN. WA
      INLET TEMPERATURE ..............   70.      F
      INLET DENSITY..................     .07500 LBM/CU FT
      SPECIFIC HEAT RATIO ...........     1.40


*******************************************************


                MEASURED CONDITIONS
      --------------------------------------

 MEASURED SPEED OF ROTATION ..........  922.00    RPM


 FAN INPUT POWER .....................  344.00    HP


 ATMOSPHERIC PRESSURE ................   29.561   IN. HG


*******************************************************
*******************************************************
```

```
          ****************************************************************************
          ****************************************************************************
                                   MEASUREMENT UNCERTAINTIES
          ****************************************************************************
          ****************************************************************************


                                          A B S O L U T E                           R E L A T I V E
   PARAMETER           UNITS           RANDOM      SYSTEMATIC                RANDOM      SYSTEMATIC
   ------------------------------------------------------------------------------------------------

AREA                 SQ FT                                                    .007          .007
GAS CONSTANT         FT*LB/LBM.R                                              .000          .002
TEMPERATURE          F                   .500        2.000
VELOCITY PRESSURE    IN. WG                                                   .025          .011
STATIC PRESSURE      IN. WG                                                   .015          .011
BAROMETRIC PRESSURE  IN. HG              .010         .050
YAW ANGLE            DEG                2.000        2.000
PITCH ANGLE          DEG                2.000        2.000
MOTOR EFFICIENCY     DECIMAL                                                  .001          .010
WATTS                                                                         .001          .010
VOLTS                                                                         .001          .010
AMPERES                                                                       .001          .010
TORQUE               LB*FT                                                    .010          .010
FAN SPEED            RPM                 .000        1.000
TURBINE POWER        HP                                                       .010          .010
NO. OF PTS. FACTOR                                                            .000          .000


          ****************************************************************************
          ****************************************************************************
```

```
************************************************************
************************************************************

                  INPUT DATA AT FAN INLET

************************************************************
************************************************************


THE NUMBER OF PORTS ......................... NF =  1


NUMBER OF TRAVERSE POINTS PER PORT .......... NT =  1


TRAVERSE FROM ONE SIDE


TRAVERSE PLANE DIMENSIONS ....  12.000 X  12.000 IN.


PROBE DIAMETER..............................  1.000 IN.


EFFECTS OF PROBE BLOCKAGE CALCULATED ... NO
```

```
************************************************************
************************************************************
RANDOM RELATIVE UNCERTAINTIES IN THE STEADY OPERATION FACTORS
************************************************************
************************************************************

          QUANTITY                 UNCERTAINTY

             MASS FLOW RATE            UFSMR  = .010
             VOLUME FLOW RATE          UFSCR  = .010
             SPECIFIC ENERGY           UFSYR  = .008
             TOTAL PRESSURE            UFSPTR = .006
             DENSITY                   UFSROR = .003
             SPEED                     UFSNR  = .001
             POWER                     UFSPR  = .007

************************************************************
************************************************************
```

```
POINT        TOTAL        STATIC       VELOCITY         TEMPERATURE        YAW     PITCH        PROBE        PROBE
            PRESSURE     PRESSURE     PRESSURE              (F)           (DEG)   PRESSURE     BLOCKAGE        ID
           (IN. WG)     (IN. WG)     (IN. WG)                                    (IN. WG)     (SQ FT)
-----------------------------------------------------------------------------------------------------------------------

 NCNE         .CGO         .CCC         .COC              71.4C            .C      .000         .000C           2
```

```
*****************************************************
*****************************************************
          AVERAGE VALUES AT INLET PLANE
     ---------------------------------------

  MASS FLOW RATE                     .CO LBM/S

  STATIC PRESSURE                   .CCC IN. WG

  VELOCITY PRESSURE                 .CCO IN. WG

  TOTAL PRESSURE                    .COG IN. WG

  TEMPERATURE                   531.1C R

  DENSITY                        .07347 LBM/CU FT

  SPECIFIC KINETIC ENERGY            .0G FT*LB/LBM

  KINETIC ENERGY CORR FACTOR    .0C0C0

  ABSOLUTE STATIC PRESSURE      402.621 IN. WA

  ABSOLUTE TOTAL PRESSURE       402.621 IN. WA

*****************************************************
*****************************************************


   OPEN INLET FAN --- NO TRAVERSE MADE AT INLET
```

```
*************************************************************
*************************************************************

                  INPUT DATA AT FAN OUTLET

*************************************************************
*************************************************************


THE NUMBER OF PORTS ......................... NF =  2


NUMBER OF TRAVERSE POINTS PER PORT .......... NT =  2


TRAVERSE FROM ONE SIDE


TRAVERSE PLANE DIMENSIONS ....  58.25C X  6C.375 IN.


PROBE DIAMETER..............................  1.000 IN.


EFFECTS OF PROBE BLOCKAGE CALCULATED ... YES
```

```
POINT       TOTAL        STATIC       VELOCITY                                        PITCH          PROBE        PROBE
           PRESSURE     PRESSURE      PRESSURE      TEMPERATURE        YAW          PRESSURE       BLOCKAGE        ID
           (IN. WG)     (IN. WG)      (IN. WG)          (F)           (DEG)         (IN. WG)       (SQ FT)
-----------------------------------------------------------------------------------------------------------------------

 A1         21.320       20.300         1.020            76.50         -15.0           .300          .1011          2
  2         21.060       20.150          .910            76.50          -2.0           .350          .3034          2

 B1         20.760       20.200          .560            77.00         -24.0          -.050          .1011          2
  2         21.200       20.250          .950            77.00           4.0           .050          .3034          2
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                                          RESULTS AT OUTLET PLANE

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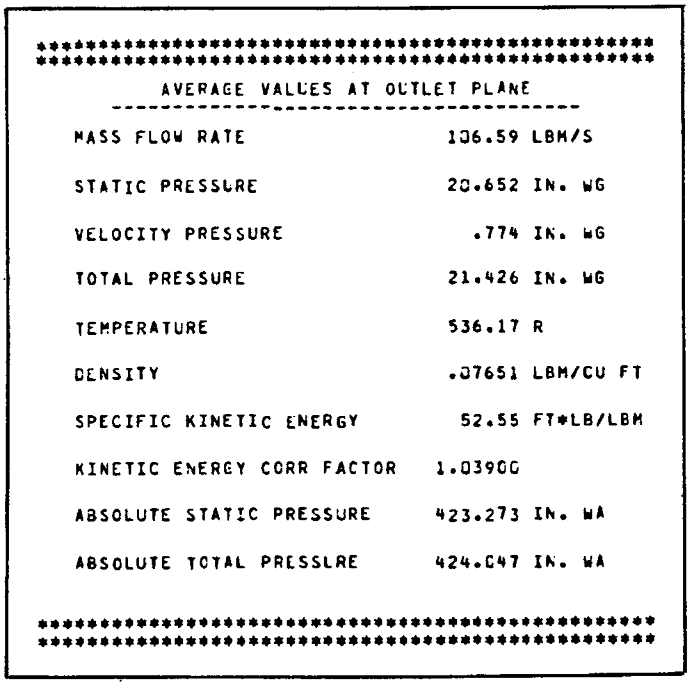
POINT   PT(J)     PS(J)    PV(J)   TS(J)    RHO(J)     1 - EP   1 + ET    PROBE RE      KVJC      KTJ      VELOCITY    YAW     PITCH     ITER
                 (IN. WG)           (R)   (LBF/CU FT)                                                        (FPM)    (DEG)    (DEG)

A1     21.781    20.737   1.043   535.88   .07657     .99912  1.00060   34971.000   1.02381   1.02165   4049.56   -15.00   21.785      1
 2     21.536    20.604    .932   535.91   .07654     .99921  1.00053   33040.055   1.02463   1.02260   3827.42    -2.00   26.192      1

B1     21.174    20.583    .591   536.52   .07645     .99950  1.00034   26308.502   1.05662   1.01996   3051.21   -24.00   -2.329      1
 2     21.622    20.664    .957   536.41   .07648     .99919  1.00055   33477.146   1.00843   1.01991   3881.06     4.00    7.199      1
```



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**************************************************
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          AVERAGE VALUES AT OUTLET PLANE
       ------------------------------------
   MASS FLOW RATE                 106.59 LBM/S

   STATIC PRESSURE                20.652 IN. WG

   VELOCITY PRESSURE                .774 IN. WG

   TOTAL PRESSURE                 21.426 IN. WG

   TEMPERATURE                    536.17 R

   DENSITY                        .07651 LBM/CU FT

   SPECIFIC KINETIC ENERGY         52.55 FT*LB/LBM

   KINETIC ENERGY CORR FACTOR    1.03900

   ABSOLUTE STATIC PRESSURE      423.273 IN. WA

   ABSOLUTE TOTAL PRESSURE       424.047 IN. WA

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                                         PERFORMANCE RESULTS
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                    MASS FLOW RATE / SPECIFIC ENERGY APPROACH WITH AESCLUTE LNCERTAINTIES

 QUANTITY        UNITS          COMPLTED     TOTAL      PERCENT    RANDOM    PERCENT   SYSTEMATIC    PERCENT
                                 VALUE       LNCERT      TOTAL     LNCERT     RANDOM     UNCERT     SYSTEMATIC
                                                         LNCERT               UNCERT                  UNCERT

MASS FLOW       LBM/S           1C6.59        1.895      1.778      1.583      1.485      1.043        .978
  RATE

FAN SPECIFIC    FT*LB/LBM      1482.67       18.116      1.222     15.847      1.C69      8.779        .592
   ENERGY

FAN INPUT       HP              344.JC        5.441      1.582      4.199      1.221      3.46C       1.C06
  POWER

FAN OUTPUT      HP              287.34        6.469      2.251      5.478      1.9C6      3.44C       1.197
  POWER

FAN             PER             .8353         .C23       2.751       .C19      2.264       .C13       1.564
EFFICIENCY      UNIT

FAN MEAN        LBM/CU FT       .C7499        .CCC        .335       .CCC       .22C       .CCC        .253
DENSITY

COMPRESS.       NONE            .97974
  COE.


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              PERFORMANCE RESULTS CONVERTED TO  915. RPM AND .07500 LBM/CU FT INLET DENSITY
***************************************************************************************
***************************************************************************************



                    MASS FLOW RATE / SPECIFIC ENERGY APPROACH WITH ABSOLUTE UNCERTAINTIES

  QUANTITY        UNITS          COMPUTED      TOTAL     PERCENT    RANDOM    PERCENT   SYSTEMATIC   PERCENT
                                   VALUE       UNCERT     TOTAL     UNCERT    RANDOM      UNCERT    SYSTEMATIC
                                                          UNCERT              UNCERT                  UNCERT

 MASS FLOW       LBM/S            107.11        1.999     1.867      1.626     1.518       1.163      1.086
   RATE

 FAN SPECIFIC    FT*LB/LBM       1460.24       18.121     1.241     15.608     1.069       9.208       .631
     ENERGY

 FAN INPUT       HP               340.45        5.816     1.708      4.293     1.261       3.923      1.152
    POWER

 FAN OUTPUT      HP               284.38        6.660     2.342      5.496     1.933       3.761      1.323
    POWER

 FAN             PER              .8353          .023     2.751       .019     2.264        .013      1.564
 EFFICIENCY      UNIT

 COMPRESS.       NONE             .98774
   COE.

 COMPRESS.       NONE             .99190
 COE. RATIO

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                                          PERFORMANCE RESULTS
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*****************************************************************************************************



                        VOLUME FLOW RATE / PRESSURE APPROACH WITH ABSOLUTE UNCERTAINTIES

QUANTITY        UNITS          COMPUTED     TOTAL      PERCENT     RANDOM     PERCENT    SYSTEMATIC    PERCENT
                                 VALUE      UNCERT      TOTAL      UNCERT     RANDOM       UNCERT     SYSTEMATIC
                                                        UNCERT                UNCERT                    UNCERT

VOLUME         CU FT/MIN        87048.      1639.2      1.883      1335.7      1.534        950.2      1.092
FLOW RATE

FAN TOTAL      IN WG             21.43        .258      1.204        .231      1.080         .114       .533
PRESSURE

FAN STATIC     IN WG             20.65        .259      1.253        .232      1.123         .115       .555
PRESSURE

FAN VELOCITY   IN WG               .77        .018      2.363        .014      1.849         .011      1.471
PRESSURE

FAN INPUT      HP               344.00       5.441      1.582       4.199      1.221        3.460      1.006
POWER

FAN OUTPUT     HP               288.52       6.604      2.289       5.528      1.916        3.613      1.252
POWER

FAN TOTAL      PER               .8387      .02334      2.782        .019      2.272         .013      1.606
EFFICIENCY     UNIT

FAN STATIC     PER               .8084      .02249      2.762        .018      2.272         .013      1.606
EFFICIENCY     UNIT

FAN DENSITY    LBM/CU FT        .07347      .00341       .557        .000       .316         .000       .459

COMPRESS.      NONE             .98294
COE.



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                         PERFORMANCE RESULTS CONVERTED TO  915. RPM AND .07500 LBM/CU FT INLET DENSITY
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                              VOLUME FLOW RATE / PRESSURE APPROACH WITH ABSOLUTE UNCERTAINTIES

QUANTITY          UNITS               COMPUTED       TOTAL        PERCENT       RANDOM       PERCENT     SYSTEMATIC     PERCENT
                                        VALUE        UNCERT        TOTAL        UNCERT       RANDOM        UNCERT      SYSTEMATIC
                                                                   UNCERT                    UNCERT                      UNCERT

VOLUME          CU FT/MIN              86376.        1629.2        1.886        1325.3       1.534         947.5        1.097
FLOW RATE

FAN TOTAL       IN WG                  21.54           .290        1.345          .242       1.126          .158         .736
PRESSURE

FAN STATIC      IN WG                  20.76           .286        1.379          .242       1.167         1.992        9.597
PRESSURE

FAN VELOCITY    IN WG                    .78           .016        2.015          .015       1.876          .012        1.556
PRESSURE

FAN INPUT       HP                    343.18          5.862        1.708         4.327       1.261         3.955        1.152
POWER

FAN OUTPUT      HP                    287.83          6.845        2.378         5.590       1.942         3.951        1.373
POWER

FAN TOTAL       PER                    .8387         .02334        2.782          .019       2.272          .013        1.606
EFFICIENCY      UNIT

FAN STATIC      PER                    .8084         .02334        2.782          .019       2.272          .013        1.606
EFFICIENCY      UNIT

COMPRESS.       NONE                   .98307
COE.

COMPRESS.       NONE                   .99987
COE. RATIO


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APPENDIX D
DERIVATIONS OF UNCERTAINTY EQUATIONS

This Appendix deals with the propagation of uncertainties into the results. Included are derivations for four of the uncertainty equations that appear in Par. 5.12. The other equations in Par. 5.12 can be derived in a manner similar to one of the four examples. All of the derivations follow the approach suggested in Ref. (2).

D1 UNCERTAINTY IN $\dot{m}_x$, THE MASS FLOW RATE AT PLANE x

The equation for $\dot{m}_x$ is given in Section 5 as

$$\dot{m}_x = \frac{A_x}{C_2}\frac{1}{n}\sum_{j=1}^{n}(\rho_j V_j \cos\psi_j \cos\phi_j)_x \tag{5.6-1}$$

Not all of the variables in this equation are direct test measurements. We can get closer to measurements by substituting for ρ_j and V_j.

$$\rho_j = \frac{C_{11}p_{saj}}{RT_{sj}} = \frac{C_{11}(p_{sj} + C_{13}p_b)}{RT_{sj}} \tag{5.4-5}$$

$$V_j = C_{12}\sqrt{\frac{p_{vj}}{\rho_j}} \tag{5.5-1}$$

We can also improve this analysis by adding two factors, F_n and F_{sm}, to the original equation. Both the number of points factor F_n and the steadiness factor F_{sm} are assumed equal to unity; therefore, they will not change the original equation. However, they will provide a basis for evaluating the uncertainties due to number of points and unsteadiness. Substituting for ρ_j and V_j and adding F_n and F_{sm} gives

$$\dot{m}_x = \frac{A_x}{C_2}\frac{1}{n}F_nF_{sm}\sum_{j=1}^{n}\left(C_{11}^{1/2}C_{12}\frac{(p_{sj} + C_{13}p_b)^{1/2}}{R^{1/2}T_{sj}^{1/2}}p_{vj}^{1/2}\cos\psi_j\cos\phi_j\right)_x \tag{D.1-1}$$

It will be helpful to introduce A_j which is equal to A_x/n and substitute

$$\dot{m}_x = \frac{C_{11}^{1/2}C_{12}}{C_2}F_nF_{sm}\sum_{j=1}^{n}\left(A_j\frac{(p_{sj} + C_{13}p_b)^{1/2}}{R^{1/2}T_{sj}^{1/2}}p_{vj}^{1/2}\cos\psi_j\cos\phi_j\right)_x \tag{D.1-2}$$

Defining the flow through A_j as $\dot{m}_j$,

$$\dot{m}_j = \frac{C_{11}^{1/2}C_{12}}{C_2}\left(A_j\frac{(p_{sj}+C_{13}p_b)^{1/2}}{R^{1/2}T_{sj}^{1/2}}\,p_{vj}^{1/2}\cos\psi_j\cos\phi_j\right) \tag{D.1-3}$$

The constants C_{11}, C_{12}, and C_2 can be considered exact and, therefore, ignored in the uncertainty analysis. It follows that

$$\dot{m}_x = F_nF_{sm}\sum_{j=1}^{n}\dot{m}_j \tag{D.1-4}$$

Differentiating

$$d\dot{m}_x = \frac{\partial\dot{m}_x}{\partial F_n}dF_n + \frac{\partial\dot{m}_x}{\partial F_{sm}}dF_{sm} + \frac{\partial\dot{m}_x}{\partial\sum_{j=1}^{n}\dot{m}_j}\,d\sum_{j=1}^{n}\dot{m}_j$$

$$\frac{\partial\dot{m}_x}{\partial F_n} = F_{sm}\sum_{j=1}^{n}\dot{m}_j = \frac{\dot{m}_x}{F_n}$$

$$\frac{\partial\dot{m}_x}{\partial F_{sm}} = F_n\sum_{j=1}^{n}\dot{m}_j = \frac{\dot{m}_x}{F_{sm}}$$

$$\frac{\partial m_x}{\partial\sum_{j=1}^{n}\dot{m}_j} = F_nF_{sm} = \frac{\dot{m}_x}{\sum_{j=1}^{n}\dot{m}_j} \tag{D.1-5}$$

Kline and McClintock [Ref. (2)] recommended a second power equation for combining uncertainties.

$$(d\dot{m}_x)^2 = \left(\frac{\dot{m}_x}{F_n}dF_n\right)^2 + \left(\frac{\dot{m}_x}{F_{sm}}dF_{sm}\right)^2 + \left(\frac{\dot{m}_x}{\sum_{j=1}^{n}\dot{m}_j}\,d\sum_{j=1}^{n}\dot{m}_j\right)^2 + \cancelto{0}{\text{cross product terms}} \tag{D.1-6}$$

Assuming complete independence of the individual terms, the cross product terms are all zero. Similarly,

$$\sum_{j=1}^{n}\dot{m}_i = \dot{m}_1 + \dot{m}_2 + \cdots + \dot{m}_n$$

$$d\sum_{j=1}^{n}\dot{m}_j = d\dot{m}_1 + d\dot{m}_2 + \cdots + d\dot{m}_n$$

$$\left(d\sum_{j=1}^{n}\dot{m}_j\right)^2 = (d\dot{m}_1)^2 + (d\dot{m}_2)^2 + \cdots + (d\dot{m}_n)^2 + \cancelto{0}{\text{cross product terms}} \tag{D.1-7}$$

Hence,

$$(d\dot{m}_x)^2 = \left(\frac{\dot{m}_x}{F_n}\, dF_n\right)^2 + \left(\frac{\dot{m}_x}{F_{sm}}\, dF_{sm}\right)^2 + \left(\frac{\dot{m}_x}{\sum\limits_{j=1}^{n} \dot{m}_j}\right)^2 \sum_{j=1}^{n} (d\dot{m}_j)^2 \qquad \text{(D.1-8)}$$

Dividing by $(\dot{m}_x)^2$,

$$\left(\frac{d\dot{m}_x}{\dot{m}_x}\right)^2 = \left(\frac{dF_n}{F_n}\right)^2 + \left(\frac{dF_{sm}}{F_{sm}}\right)^2 + \frac{\sum\limits_{j=1}^{n} (d\dot{m}_j)^2}{\left(\sum\limits_{j=1}^{n} \dot{m}_j\right)^2} \qquad \text{(D.1-9)}$$

In the manner of Kline and McClintock [Ref. (2)], let

$$U_{m_x} = d\dot{m}_x \qquad u_{m_x} = \frac{d\dot{m}_x}{\dot{m}_x} \qquad U_{F_n} = dF_n \qquad u_{F_n} = \frac{dF_n}{F_n}$$

etc., where U is the absolute uncertainty and u is the relative or per unit uncertainty in the subscripted quantity. It is also useful to denote the partial derivative of a result with respect to a particular variable as the sensitivity factor θ. For example,

$$\theta_{F_n} = \frac{\partial \dot{m}_x}{\partial F_n}$$

etc.

To develop a compact notation, let

$$\theta_{i,j} = \frac{\partial \dot{m}_j}{\partial v_{i,j}} \qquad \text{for variables } v_{i,j} \text{ in } \dot{m}_j$$

The variables $v_{i,j}$ in m_j are: $A_j, p_{sj}, p_b, R, T_{sj}, p_{vj}, \psi_j$, and ϕ_j. If $i = 1, v_{i,j}$ is A_j; $i = 2, v_{i,j}$ is p_{sj}; $i = 3, v_{i,j}$ is p_b; $i = 4, v_{i,j}$ is R; $i = 5, v_{i,j}$ is T_{sj}; $i = 6, v_{i,j}$ is p_{vj}; $i = 7, v_{i,j}$ is ψ_j; and $i = 8$ $v_{i,j}$ is ϕ_j. The various sensitivity factors are:

$$\theta_{A_j} = \frac{\partial \dot{m}_j}{\partial A_j} = \frac{\dot{m}_j}{A_j}$$

$$\theta_{p_{sj}} = \frac{\partial \dot{m}_j}{\partial p_{sj}} = \frac{\dot{m}_j}{2(p_{sj} + C_{13} p_b)}$$

$$\theta_{p_b} = \frac{\partial \dot{m}_j}{\partial p_b} = \frac{\dot{m}_j}{2(p_{sj} + C_{13} p_b)}$$

$$\theta_R = \frac{\partial \dot{m}_j}{\partial_R} = \frac{\dot{m}_j}{-2R}$$

$$\theta_{T_{sj}} = \frac{\partial \dot{m}_j}{\partial T_{sj}} = \frac{\dot{m}_j}{-2T_{sj}}$$

$$\theta_{p_{vj}} = \frac{\partial \dot{m}_j}{\partial p_{vj}} = \frac{\dot{m}_j}{2p_{vj}}$$

$$\theta_{\psi_j} = \frac{\partial \dot{m}_j}{\partial \psi_j} = -\tan \psi_j \, \dot{m}_j$$

$$\theta_{\phi_j} = \frac{\partial \dot{m}_j}{\partial \phi_j} = -\tan \phi_j \, \dot{m}_j$$

All of these sensitivity factors have the general form

$$\theta_{i,j} = \frac{\dot{m}_j}{g(v_{i,j})} \text{ where } g(v_{i,j}) \text{ is a function of } v_{i,j}$$

We can also let

$$\sum_{j=1}^{n} (d\dot{m}_j)^2 = \sum_{j=1}^{n} U_{\dot{m}_j}^2 \qquad \text{(D.1-10)}$$

However,

$$U_{\dot{m}_j}^2 = \sum_{i=1}^{k} (\theta_{i,j} U_i)^2 \qquad \text{(D.1-11)}$$

where U_i is the uncertainty in the variable i, and where $i = A_j, p_{sj}, p_b$, etc. It follows that

$$\sum_{j=1}^{n} U_{\dot{m}_j} = \sum_{j=1}^{n} \sum_{i=1}^{k} (\theta_{i,j} U_i)^2 \qquad \text{(D.1-12)}$$

Also that

$$\sum_{j=1}^{n} U_{\dot{m}_j} = \sum_{j=1}^{k} \sum_{i=1}^{n} \left(\frac{\dot{m}_j U_i}{g(v_{i,j})}\right)^2 = \sum_{j=1}^{n} (\dot{m}_j)^2 \sum_{i=1}^{k} \left(\frac{U_i}{g(v_{i,j})}\right)^2 \qquad \text{(D.1-13)}$$

Rearranging the equation for $\dot{m}_x$ (D.1-4) gives

$$\sum_{j=1}^{n} (\dot{m}_j)^2 = \frac{\dot{m}_x^2}{F_n^2 F_{sm}^2}$$

Also

$$\sum_{i=1}^{k} \left(\frac{U_i}{g(v_{i,j})}\right)^2 = \frac{U_{A_j}^2}{A_j} + \frac{1}{4}\left(\frac{U_{p_{sj}}^2 + C_{13}^2 U_{p_b}^2}{p_{saj}^2}\right)$$

$$+ \frac{1}{4}\left[\left(\frac{U_R}{R}\right)^2 + \left(\frac{U_{T_{sj}}}{T_{sj}}\right)^2 + \left(\frac{U_{p_{vj}}}{p_{vj}}\right)^2\right]$$

$$+ \left(\frac{\tan^2 \psi_j U_{\psi_j}^2 + \tan^2 \phi_j U_{\phi_j}^2}{C_{19}}\right) \qquad \text{(D.1-14)}$$

Therefore, by substituting in (D.1-9)

$$\left(\frac{U_{\dot{m}_x}}{\dot{m}_x}\right)^2 = \left(\frac{U_{I_n}}{F_n}\right)^2 + \left(\frac{U_{I_{sm}}}{F_{sm}}\right)^2 + \frac{F_n^2 F_{sm}^2}{\dot{m}_x^2} \sum_{j=1}^{n} (\dot{m}_j)^2$$

$$\left\{\frac{U_{A_j}^2}{A_j} + \frac{1}{4}\left(\frac{U_{p_{sj}}^2 + C_{13}^2 U_{p_b}^2}{p_{sj}^2}\right) + \frac{1}{4}\left[\left(\frac{U_R}{R}\right)^2 + \left(\frac{U_{T_{sj}}}{T_{sj}}\right)^2 + \left(\frac{U_{p_{vj}}}{p_{vj}}\right)^2\right] + \left(\frac{\tan^2 \psi_j U_{\psi_j}^2 + \tan^2 \phi_j U_{\phi_j}^2}{C_{19}}\right)\right\} \quad \text{(D.1-15)}$$

Setting F_n and F_{sm} equal to unity, rearranging, and substituting relative uncertainties where possible,

$$u_{\dot{m}_x}^2 = u_{I_n}^2 + u_{I_{sm}}^2 + u_{A_x}^2 + \sum_{j=1}^{n} \left(\frac{\dot{m}_j}{\dot{m}_x}\right)^2 \left[\left(\frac{U_{p_{sj}}^2 + C_{13}^2 U_{p_b}^2}{p_{sj}^2}\right)\right.$$

$$\left. + \left(\frac{\tan^2 \psi_j U_{\psi_j}^2 + \tan^2 \phi_j U_{\phi_j}^2}{57.30^2}\right) + \frac{1}{4}\left(u_R^2 + u_{T_{sj}}^2 + u_{p_{vj}}^2\right)\right] \quad \text{(D.1-16)}$$

This is Eq. (5.12-3).

D2 UNCERTAINTY IN p_{sx}, THE AVERAGE STATIC PRESSURE AT PLANE x

The equation for p_{sx} is given in Section 5 as

$$p_{sx} = \frac{\sum_{j=1}^{n} (p_{sj} V_j \cos \psi_j \cos \phi_j)_x}{\sum_{j=1}^{n} (V_j \cos \psi_j \cos \phi_j)_x} \quad \text{(5.7-1)}$$

The $V_j \cos \psi_j \cos \phi_j$ terms in both the numerator and denominator are weighting factors in the averaging process. We will assume that the contributions of these weighting factors to uncertainty are negligible and approximate Eq. (5.7-1) by

$$p_{sx} \cong \frac{1}{n} \sum_{j=1}^{n} p_{sj} \quad \text{(D.2-1)}$$

only for the purpose of uncertainty evaluation.

Differentiating

$$d_{p_{sx}} = \frac{1}{n} d \sum_{j=1}^{n} p_{sj} \quad \text{(D.2-2)}$$

Noting that

$$d \sum_{j=1}^{n} p_{sj} = \sum_{j=1}^{n} dp_{sj}$$

and that

$$\left(d\sum_{j=1}^{n} p_{sj}\right)^2 = \sum_{j=1}^{n} (dp_{sj})^2$$

if we assume the cross product terms to be zero (because of independence), we find

$$(dp_{sx})^2 = \frac{1}{n^2}\sum_{j=1}^{n}(dp_{sj})^2 \qquad \text{(D.2-3)}$$

Dividing by p_{sx}^2

$$\left(\frac{dp_{sx}}{p_{sx}}\right)^2 = \frac{1}{n^2}\,\frac{\sum_{j=1}^{n}(dp_{sj})^2}{p_{sx}^2} \qquad \text{(D.2-4)}$$

Multiplying by p_{sj}^2/p_{sj}^2

$$\left(\frac{dp_{sx}}{p_{sx}}\right)^2 = \frac{1}{n^2}\sum_{j=1}^{n}\left(\frac{p_{sj}}{p_{sx}}\right)^2\left(\frac{dp_{sj}}{p_{sj}}\right)^2 \qquad \text{(D.2-5)}$$

Since $dp_{sj}/p_{sj} = U_{p_{sj}}$, the final equation is

$$u_{p_{sx}}^2 = \frac{1}{n^2}\sum_{j=1}^{n}\left(\frac{p_{sj}}{p_{sx}}\right)^2 u_{p_{sj}}^2 \qquad \text{(D.2-6)}$$

This is Eq. (5.12-9).

D3 UNCERTAINTY IN P_I FOR A CALIBRATED AC MOTOR

The equation for P_I is given in Section 5 as

$$P_I = \frac{10^3 W\eta_M}{C_{14}} \qquad \text{(5.8-1)}$$

Differentiating

$$dP_I = (Wd\eta_M + \eta_M dW)\,\frac{10^3}{C_{14}} \qquad \text{(D.3-1)}$$

Substituting for W and η_M

$$dP_I = \left(\frac{P_I}{\eta_M}d\eta_M = \frac{P_I}{W}dW\right) \qquad \text{(D.3-2)}$$

Dividing by P_I, squaring, and setting cross product terms to zero

$$\left(\frac{dP_I}{P_I}\right)^2 = \left[\left(\frac{d\eta_M}{\eta_M}\right)^2 + \left(\frac{dW}{W}\right)^2\right] \tag{D.3-3}$$

In terms of relative uncertainties, the result including the effect of unsteadiness is

$$u_{P_I}^2 = u_{F_{SP}}^2 + u_{\eta_M}^2 + u_W^2 \tag{D.3-4}$$

This is Eq. (5.12-16).

D4 UNCERTAINTY IN ρ_m, THE FAN MEAN DENSITY

The equation for ρ_m is given in Section 5 as

$$\rho_m = \frac{\rho_1 + \rho_2}{2} \tag{5.10-1}$$

Differentiating

$$d\rho_m = \frac{1}{2}(d\rho_1 + d\rho_2) \tag{D.4-1}$$

Squaring and dropping cross product terms

$$d\rho_m^2 = \frac{1}{4}(d\rho_1^2 + d\rho_2^2)$$

Dividing by ρ_m^2

$$\left(\frac{d\rho_m}{\rho_m}\right)^2 = \frac{d\rho_1^2 + d\rho_2^2}{(\rho_1 + \rho_2)^2} \tag{D.4-2}$$

Writing in terms of uncertainties

$$u_{\rho_m}^2 = \frac{U_{\rho_1}^2 + U_{\rho_2}^2}{(\rho_1 + \rho_2)^2} \tag{D.4-3}$$

This is Eq. (5.12-22).

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APPENDIX E

ASSIGNING VALUES TO PRIMARY UNCERTAINTIES

The equations in Par. 5.12 give the uncertainties of the various results of the test in terms of the uncertainties in the test measurements and in certain other factors. These measurement and factor uncertainties, herein called *primary uncertainties,* should reflect the circumstances of the test. Some of the circumstances that affect the primary uncertainties are discussed in this Appendix. Typical values of the primary uncertainties are also suggested here. Values are given for both the systematic and the random components of the uncertainties where appropriate.

E1 NUMBER OF POINTS FACTOR (F_n)

The factor F_n was introduced in Appendix D in the derivation of the uncertainty in $\dot{m}_x$. The factor F_n itself is assumed equal to unity and is dropped from the final equations for $\dot{m}_x$ and for $u_{\dot{m}_x}$. The relative uncertainty in F_n is called $u^S_{F_n}$, is systematic, and is believed to have a value of 0.01 or 1% if the specifications regarding number of points are followed. The uncertainty increases rapidly as fewer and fewer points are used. Increasing the number of points probably does not improve the uncertainty very rapidly. There is no random uncertainty in F_n.

E2 STEADY OPERATION FACTOR FOR X (F_{sX})

The factor F_{sm} was introduced in Appendix D in the derivation of the uncertainty in $\dot{m}_x$. Similar factors F_{sX} for other performance variables X are also required. In every case, the factor itself is assumed equal to unity and is dropped from the final equations for X and for u_X. The relative uncertainty in F_{sm} is random, is called $u^R_{F_{sm}}$, and is evaluated from the reference measurements for the velocity pressure p_{vR}, the appropriate temperature T_R, and the appropriate static pressure p_{saR}. The evaluation is obtained as follows:

(*a*) obtain averages for p_{vR}, T_R, and p_{saR} measurements for each window of time;
(*b*) calculate $\dot{m}_R = (p_{saR} \cdot p_{vR}/T_R)^{1/2}$ for each window of time;
(*c*) calculate the mean and the standard deviation for all $\dot{m}_R$ (i.e., for all windows of time);
(*d*) multiply the standard deviation by 2;
(e) divide by the mean; and
(*f*) call the result $u^R_{F_{sm}}$.

Other steady operation factors are required and a similar procedure can be used. Table E1 lists the factors, the reference measurements, and the combinations required to determine $u^R_{F_{sX}}$. There is no systematic uncertainty in F_{sX}.

E3 TEST MEASUREMENTS

Typical values for both the random and the systematic components of the uncertainties in the various test measurements are shown in Table E2.

TABLE E1

Factor	Uncertainty	Combination of Reference Measurements
F_{sm}	$u^R{}_{F_{sm}}$	$\dot{m}_R = p_{saR}^{1/2}\, p_{vR}^{1/2}\, T_R^{-1/2}$
F_{sQ}	$u^R{}_{F_{sQ}}$	$Q_R = p_{vR}^{1/2} T_R^{1/2} p_{saR}^{-1/2}$
F_{sy}	$u^R{}_{F_{sy}}$	$y_R = p_{saR}{}^{-1} p_{tR} T_R$
F_{spt}	$u^R{}_{F_{spt}}$	$p_{tR} = p_{tR}$
$F_{s\rho}$	$u^R{}_{F_{s\rho}}$	$\rho_R = p_{saR} T_R{}^{-1}$
F_{sN}	$u^R{}_{F_{sN}}$	$N_R = N_R$
$F_{s\mathrm{P}}$	$u^R{}_{F_{s\mathrm{P}}}$	$\mathrm{P}_R = I_R$ or W_R

TABLE E2

Measurement	Random Uncertainty	Systematic Uncertainty
A_x	$u^R{}_{A_x} = 0.007$	$u^S{}_{A_x} = 0.007$
R	$u^R{}_R =$ nil	$u^S{}_R = 0.002$
T_{sj}	$U^R{}_{T_{sj}} = 0.5$°F	$U^S{}_{T_{sj}} = 2$°F
p_{vj}	$u^R{}_{p_{vj}} = 0.025$	$u^S{}_{p_{vj}} = 0.011$
p_{sj}	$u^R{}_{p_{sj}} = 0.015$	$u^S{}_{p_{sj}} = 0.011$
p_b	$U^R{}_{p_b} = 0.01$ in. Hg	$U^S{}_{p_b} = 0.05$ in. Hg
ψ_j	$U^R{}_{\psi_j} = 2°$	$U^S{}_{\psi_j} = 2°$
ϕ_j	$U^R{}_{\phi_j} = 2°$	$U^S{}_{\phi_j} = 2°$
η_M	$u^R{}_{\eta M} = 0.001$	$u^S{}_{\eta M} = 0.010$
W	$u^R{}_W = \begin{cases} 0.001 \text{ digital} \\ 0.010 \text{ analog} \end{cases}$	$u^S{}_W = 0.010$
E	$u^R{}_E = \begin{cases} 0.001 \text{ digital} \\ 0.010 \text{ analog} \end{cases}$	$u^S{}_E = 0.010$
I	$u^R{}_I = \begin{cases} 0.001 \text{ digital} \\ 0.010 \text{ analog} \end{cases}$	$u^S{}_I = 0.010$
τ	$u^R{}_\tau = 0.010$	$u^S{}_\tau = 0.010$
N	$\left.\begin{matrix} U^R{}_N = \\ u^R{}_N = \end{matrix}\right\}$ nil (electronic)	$U^S{}_N = 1$ rpm $u^S{}_N = 0.001$
P_t	$u^R{}_{\mathrm{P}_t} = 0.010$	$u^S{}_{\mathrm{P}_t} = 0.010$
n	$U^R{}_n = 1$ count	$U^S{}_n =$ nil
t	$U^R{}_t = 2$ sec − slip	$U^S{}_t = 1$ sec

GENERAL NOTE:
These values should only be used if the actual circumstances support their use.

The various random uncertainties that are listed in Table E2 are based on estimates of the fluctuations in the measured variable during a typical fan test (excluding fluctuations due to unsteady operation as reflected in the steady operation factor). These fluctuations are due in part to the fact that the fan has a finite number of blades. The extent of the fluctuations will be influenced by the damping that operates on the signal and therefore by the choice of instruments.

The various systematic uncertainties that are listed in Table E2 are based on the assumption that instruments will be selected for the test in accordance with the specifications in this Code. The values shown are based on estimates of the residual uncertainty after calibration, on estimates of the effects of temperature and other changes not included in the calibration, and on estimates of operator bias.

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APPENDIX F
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