



AEROSPACE STANDARD

AIR1900™**REV. B**

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Superseding AIR1900A

(R) Guide to Temperature Monitoring in Aircraft Gas Turbine Engines

RATIONALE

This update of AIR1900 to revision B has been made to incorporate the contents of AIR1900A with three other documents to create a single comprehensive report covering temperature monitoring. The details of the other three documents are as follows:

- ARP464 - Mount - Thermocouple
- ARP465B - Flange - Thermocouple
- ARP485A - Temperature Measuring Devices Nomenclature

Due to the availability of similar and more up-to-date information in the public domain, together with the extensive effort required, the original material has not been brought up to date.

Upon publication, the three superseded documents—ARP464, ARP465B, and ARP485A—will be cancelled. This strategy was agreed to by the SAE E-32 Committee to reduce the number of documents it is required to maintain.

FOREWORD

This document, originally prepared in 1991, was reviewed by industry and committee members between 2008 and 2010. Changes were made in 2015 to incorporate the content of ARP464, ARP465B, and ARP485A, thus rendering those three documents obsolete. These changes combine mechanical and installation considerations, nomenclature and a general overview of temperature measurement for engine monitoring systems in various areas of aircraft gas turbine engines.

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1. SCOPE

This SAE Aerospace Information Report (AIR) provides an overview of temperature measurement techniques for various locations of aircraft gas turbine engines while focusing on current usage and methods, systems, selection criteria, and types of hardware.

1.1 Purpose

The purpose of this document is to provide information and guidance on the selection and use of aircraft turbine engine temperature monitoring systems and elements.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AIR46	The Preparation and Use of Thermocouples for Aircraft Gas Turbine Engines
AIR1828	Guide to Engine Lubrication System Monitoring
AIR1873	Guide to Limited Engine Monitoring Systems for Aircraft Gas Turbine Engines
ARP755	Aircraft Propulsion System Performance Station Designation and Nomenclature
ARP1217	Instrumentation Requirements for Turboshift Engine Performance Requirements
ARP1587	Aircraft Gas Turbine Engine Health Management System Guide
AS793	Total Temperature Measuring Instruments (Turbine Powered Subsonic Aircraft)
AS8005	Minimum Performance Standard, Temperature Instruments

2.1.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

STP470B-EB Manual on the Use of Thermocouples in Temperature Measurement

2.1.3 NIST Publications

Available from NIST, 100 Bureau Drive, Stop 1070, Gaithersburg, MD 20899-1070, Tel: 301-975-6478, www.nist.gov.

ITS-90 Thermocouple Database

2.1.4 Other Publications

Anixter. (2013). Chapter 7: Electrical characteristics. *Technical information handbook: Wire and cable* (85-102).

Beynon, T.G.R. (1982). Radiation thermometry applied to the development and control of gas turbine engines. *Temperature*, 471-477.

Beynon, T.G.R. (2015). Turbine pyrometry: An equipment manufacturer's view (Paper No. 81-GT-136). *American Society of Mechanical Engineers*, <https://doi.org/10.1115/81-GT-136>.

Doebelin, E.O. (1966). *Measurement systems: Application and design*. McGraw Hill.

Douglas, J. (1980). High speed turbine blade pyrometry in extreme environments. *Measurement methods in rotating components in turbo machinery*. American Society of Mechanical Engineers.

Moffat, R.J. (1962). Gas temperature measurement. In C.M. Herzfeld (Ed.), *Temperature—Its measurement and control in science and industry* (Vol. 3, part 2, 553-571).

Shambrook, K.P. (1982). Signal processing techniques for temperature measurement. *Temperature—Its measurement and control in science and industry* (1167-1172).

Stringfellow, K. (1982). Improving the accuracy of thermocouple temperature measuring circuits (Report No. PNR90148). *Rolls-Royce Ltd.*

Sydenham, P. (1982). Basic electronics for instrumentation. *Instrument Society of America*.

Trenkle, F. and Reinhardt, M. (1973). *In-flight temperature measurements* (Vol. 2). NATO Advisory Group for Aerospace Research and Development.

2.2 Definitions/Glossary

General temperature measurement related terms are defined first, followed by nomenclature specific to temperature measuring devices, particularly thermocouples, as applied to aircraft turbines for use by:

- a. Power plant manufacturers.
- b. Airframe manufacturers.
- c. Procurement organizations.
- d. Equipment organizations.
- e. Service and maintenance personnel.
- f. Other interested organizations.

2.2.1 BIMETALLIC ELEMENT

A temperature sensitive device composed of two materials having different thermal coefficients of expansion resulting in a proportional movement of the free segment of the device with changes in temperature.

2.2.2 COCKPIT INDICATOR

An instrument used to translate the EMF from a temperature measurement system into a visual indication of the temperature to the measuring junction or junctions.

2.2.3 TEMPERATURE INDICATOR

A temperature indicator is a device which responds to a signal from a temperature measuring system to provide a reproducible indication of the signal level.

2.2.4 NULL BALANCE INDICATOR

A null balance indicator is a cockpit indicator which provides a visual indication by means of a potentiometer circuit whose accuracy is not affected by external resistance.

2.2.5 CONDUCTION ERROR

The difference between the gas temperature and the sensed temperature caused by conduction of heat along the thermocouple assembly support tubes and leads and mounting surface or adjacent components.

2.2.6 LIMITING ZONE TEMPERATURE

The maximum permissible zone operating temperature.

2.2.7 MEASURING JUNCTION

That junction of a thermocouple sensing system immersed in or in contact with the medium whose temperature is to be observed. That junction may be separated from the measured medium by insulation and/or a protective sheath.

2.2.7.1 Types of Junctions

- a. Twisted
- b. Looped
- c. "V"
- d. "U"
- e. Stirrup
- f. Pencil

See Appendix A.

2.2.8 RADIATION ERROR

The difference between the gas temperature and the sensed temperature caused by radiant heat transfer between the sensing element and surrounding areas.

2.2.9 RADIATION PYROMETER TEMPERATURE MEASUREMENT SYSTEM

A system depending for its indication on the wavelength and intensity of radiation from the medium to the measuring element of the pyrometer.

2.2.10 RECOVERY FACTOR

That ratio of the difference in indicated temperature and static temperature to the difference in total temperature and static temperature, expressed in (k).

2.2.10.1 RECOVERY RATIO

Recovery ratio is the ratio of the measured temperature versus true air temperature as recorded in a wind tunnel or open jet facility.

$$R = \frac{T_{\text{indicated}}}{T_T} \quad (\text{Eq. 1})$$

2.2.11 REFERENCE JUNCTION

That union of two dissimilar metal wires that is maintained at a known signal level and is used to determine an absolute temperature indication from the relative temperature measured at the measuring junction.

2.2.12 RESISTANCE TEMPERATURE DEVICE

A temperature sensitive device composed of a material whose resistance increases in a reproducible manner as the temperature increases with negligible hysteresis. Typically, wire wound on to a mandrel or screen printed onto a substrate.

2.2.13 RESISTANCE SPOOL

A variable resistance used to adjust the resistance of the thermocouple measurement system to predetermined values under given conditions.

2.2.14 STAGNATION TEMPERATURE

This term is sometimes used as an alternative to total temperature. Though they are different concepts thermodynamically, they are numerically the same for ideal gasses.

2.2.15 STANDARD RESPONSE TIME

The time required for a temperature measuring element to register 63.2% of a step change in temperature of a gas stream flowing at a rate of 29.295 kg/m²/s (6 lb/ft²/s), also referred to as "standard time constant."

2.2.16 STANDARD STEADY-STATE REPRODUCIBILITY FACTOR

The ratio, expressed in percent, between the indicated gas temperature and a standard indicated temperature under predetermined gas temperature, radiation, and conduction losses and mass flow conditions over the range of in-flight engine operations.

2.2.17 STATIC TEMPERATURE (GAS AND THERMAL EQUILIBRIUM)

A measurable property that is directly proportional to the mean kinetic energy of the particles. In a moving gas, the static temperature would be indicated by an instrument moving in the same direction and at the same velocity as the gas.

2.2.18 SUPPORT TUBE

The support tube is the portion of the thermocouple assembly immersed in the medium to be measured and provides support for the measuring junction and lead wires.

2.2.19 TEMPERATURE

A measure of the average energy of motion, or kinetic energy, of particles in matter expressed in terms of units designated on a standard scale.

2.2.20 TEMPERATURE MEASUREMENT

The observation of the relative heat energy present as it affects engine performance and/or life, i.e., bearing, compressor inlet, turbine in or out, blade temperature, and any other pertinent material or gas temperature.

2.2.21 TEMPERATURE MEASUREMENT SYSTEM

A system consisting of one or more measuring elements to quantitatively measure temperature by heat transfer including a means of transmitting the resultant single output to and including the indicator, and if applicable, to the engine control device.

2.2.21.1 TEMPERATURE INDICATING SYSTEM

That part of the temperature measurement system extending physically from the engine-airframe interface up to and including the aircraft cockpit indicator.

2.2.21.2 TEMPERATURE SENSING SYSTEM

That part of the temperature measurement system extending physically from and including the temperature measuring element to the engine-airframe interface and, if applicable, to the engine control.

2.2.22 TEMPERATURE MEASURING ELEMENT

That element or portion of a temperature measuring system that yields a measurable signal that is reproducible as a function of temperature.

2.2.22.1 PROBE

A probe is an immersion type temperature measuring element.

2.2.22.2 CONTACT ELEMENT

A contact element is a temperature measuring element used in intimate contact with the solid-state body to be measured.

2.2.22.3 REMOTE MEASURING ELEMENT

A remote measuring element is a temperature measuring device removed from the medium to be measured.

2.2.23 COMPENSATED REFERENCE JUNCTION

A junction maintained at a known signal output level by circuitry designed to compensate for changes in ambient temperatures, which is used to determine an absolute temperature indication from the relative temperature measured at the measuring junction.

2.2.24 INDICATING LEAD

That portion of the thermocouple indicating system from the engine / airframe disconnect to the reference junction.

2.2.25 THERMISTOR

A temperature sensitive device composed of a material whose resistance decreases in a reproducible manner as the temperature increases with negligible hysteresis.

2.2.26 THERMOCOUPLE ASSEMBLY

That part of the thermocouple sensing system including all components from the measuring junction to the electrical connector or to the harness junction box as is the case with the integral harness.

2.2.27 THERMOCOUPLE ASSEMBLY EXTENSION LEAD

An assembly that physically supports, protects, and insulates the conductors extending from the thermocouple assembly to a point within the thermocouple harness.

2.2.28 THERMOCOUPLE BOSS

The means of attaching a thermocouple assembly to the engine case.

2.2.29 THERMOCOUPLE CALIBRATION

The plot of the EMF output of a temperature measuring junction versus known temperatures.

2.2.29.1 THERMOCOUPLE CALIBRATION UNCERTAINTY

The ratio, expressed in percentage, of the difference between the EMF output of a temperature measuring junction at a given temperature and the specified EMF for that temperature, to that specified EMF.

$$\text{Measurement Uncertainty (\%)} = \frac{(\text{EMF}_{\text{test}} - \text{EMF}_{\text{ref}})}{\text{EMF}_{\text{ref}}} \times 100 \quad (\text{Eq. 2})$$

2.2.30 THERMOCOUPLE HARNESS

An assembly that physically supports, protects, and insulates the conductors extending from the thermocouple assemblies to the thermocouple output harness connector.

2.2.31 Thermocouple Harness Construction

2.2.31.1 RIGID THERMOCOUPLE HARNESS

An assembly in which the lead supporting and protective structure is firm and non-flexible and requires application of appreciable force in order to obtain deflection. Typically composed of a metal sheathed material.

2.2.31.2 FLEXIBLE THERMOCOUPLE HARNESS

An assembly in which the lead supporting and protective structure is easily bent and adapts itself readily to change of shape.

2.2.31.3 THERMOCOUPLE HARNESS CIRCUITRY

The complete electrical path designed to conduct the output EMFs generated by the individual temperature measuring junctions into a single useable value.

2.2.31.4 COMMON JUNCTION CIRCUIT

A circuit in which each temperature measuring junction is paralleled by means of individual leads to a common point.

2.2.31.5 EQUAL RESISTANCE BRANCH CIRCUIT

A circuit in which the temperature measuring junctions are paired in parallel and symmetrically arranged about junction points, so that equal resistance paths are maintained around each loop. This is the simplest and most accurate system provided the branch circuits are of equal resistance.

2.2.31.6 LADDER CIRCUIT

Temperature measuring junctions geometrically and electrically paralleled to two bus bars.

2.2.31.7 OPEN LADDER CIRCUIT

A parallel circuit in which the bus bars are electrically discontinuous. Without resistance compensation, this type of circuit is no longer preferred for jet engine environments.

2.2.31.8 CLOSED LADDER CIRCUIT

A parallel circuit in which the bus bars are electrically continuous. Without resistance compensation, this type of circuit is no longer preferred for jet engine environments.

2.2.31.9 RESISTANCE COMPENSATED LADDER CIRCUIT

A parallel circuit in which compensating resistors have been inserted so that the output voltage of the circuit will equal the arithmetical average of the voltages of the several individual measuring junctions.

2.2.31.10 THERMOCOUPLE TYPE TEMPERATURE MEASUREMENT SYSTEM

A thermocouple and associated supporting structure, electrical insulation up to and including the indicator and, if applicable, to the control device. This system as applied to exhaust gas temperature measurement may include one or more thermocouple assemblies, a thermocouple harness, thermocouple harness lead, reference junction, resistance spool, and indicator.

2.2.32 THERMOCOUPLES

A pair of dissimilar electrically conducting materials joined together so that a difference in temperature at the junction generates an EMF across the ends not joined. Typical combinations of wire are as follows:

Table 1 - Thermocouple wire combinations

Type	+ (positive polarity)	- (negative polarity)
E	Nickel chromium (Kp)	Constantan
J	Iron	Constantan
T	Copper	Constantan
K	Nickel chromium (Kp)	Nickel aluminium or nickel silicon (Kn)
R, S, B	Platinum/rhodium	Platinum
	Iridium/rhodium	Iridium

2.2.33 THERMOMETER

An immersion or contact type device whose operation is based on thermal equilibrium between the sensitive measuring element and the medium to be measured. Types of thermometers include thermocouples, resistance bulbs, thermistors, bimetallic elements, vapor pressure elements, etc.

2.2.34 TOTAL TEMPERATURE (GAS AND THERMAL EQUILIBRIUM)

The temperature indicated by an error free instrument having a fixed position in the gas stream and is the sum of the static temperature and the temperature rise due to the conversion of kinetic energy to heat, as the compression occurs at the sensing element.

2.2.35 TRANSIENT REPRODUCIBILITY FACTOR

The ratio expressed in percent between the indicated standard response time and that standard response time predetermined for the configuration tested.

2.2.36 TYPES OF THERMOCOUPLE ASSEMBLIES

2.2.36.1 BARE OR EXPOSED JUNCTION

Has no shielding or support tube covering of any type over the measuring junction.

2.2.36.2 STAGNATION

Designed to measure a temperature which approximates the total temperature value.

2.2.36.3 SAMPLING

Has means for sampling gases at two or more points and for mixing these at the measuring junction so as to give a useful representative value.

2.2.36.4 ASPIRATED

Constructed so that the rate of heat transfer to the measuring junction is increased by causing the gas to flow over the junction at a rate which is higher than the free stream velocity.

2.2.36.5 SONIC

Designed so that the gas can be made to flow over the measuring junction at Mach 1.

2.2.36.6 SHIELDED

The measuring junction is partially or completely enclosed by a housing, the purpose being to reduce the free stream velocity and capture a higher percentage of the kinetic energy, as well as reduce the radiation error and provide mechanical protection.

2.2.37 VAPOR PRESSURE ELEMENT

A temperature sensitive device with a signal proportional to pressure of vapor in coexistence with its liquid phase and independent of the specific volume.

2.3 Acronyms

ECU	Engine control unit
EGT	Exhaust gas temperature
EMF	Electromotive force
EMU	Engine monitoring unit
FOD	Foreign object damage
HP	High pressure
IP	Intermediate pressure
Kn	Negative thermo element for type K thermocouples
Kp	Positive thermo element for type K thermocouples
LP	Low pressure
MIC	Mineral insulated cable
MTBF	Mean time between failures
MTBO	Mean time between overhauls
MTBUR	Mean time between unscheduled removals

RTD	Resistance temperature detector
TBT	Turbine blade temperature
TET	Turbine entry temperature
UTR	Uniform temperature reference

3. BACKGROUND

3.1 Need

Temperature is one of the most critical and widely measured variables in the monitoring of aircraft gas turbine engines. The measurement of temperature is accomplished by a variety of sensor types used in a number of locations (i.e., thermodynamic stations) in an engine. Furthermore, signal processing is often accomplished differently and used for a number of purposes by different engine manufacturers. This document will attempt to provide a common reference point for considerations of:

- a. Sensor type.
- b. Location.
- c. Signal transmission.
- d. Signal processing.
- e. Signal uses.
- f. Selection criteria.
- g. Accuracy.
- h. Potential problems.

3.2 Airframe Measurements

It is possible to take certain temperature measurements on the aircraft physically in regions other than the engine. For example, it is possible to make a total temperature measurement on the fuselage and to have this represent the engine inlet total temperature. However, there is an increasing tendency to make engine temperature measurements independent of those made on the airframe. This document will, therefore, concern itself primarily with measurements made on the engine.

3.3 Heat Transfer

The measurement of temperature depends upon the balance of three physical phenomena: convection, conduction, and radiation. This document will not address the theory of these phenomena. The reader is referred to AIR46 and Moffat (1962) for more in-depth information.

4. TYPICAL USAGE

The requirements on the temperature measurement system are dependent not only on the current state of technology available to the user but also critically on the purpose for which it is intended.

4.1 Functions

Temperature measurements on the engine are used for four basic functions: control, diagnostics and condition monitoring, cockpit display, and performance measurement.

4.1.1 Control

The signal is used, in an active sense, in a feedback control loop to correct a number of physical variables. For example, temperature is used to limit fuel flow in order to prevent turbine blades from overheating. Furthermore, temperature is used to correct a number of other physical variables such as rotor speeds; scheduling variable geometry; surge schedules; and acceleration and deceleration schedules.

4.1.2 Diagnostics and Condition Monitoring

Temperature signals from one location can be used to compute the temperature of other locations in an engine. This means the signal is used, in a passive sense, to measure thermal behavior in various parts of the engine. The time history of the thermal behavior is usually recorded for later examination. For example, exhaust gas temperature (EGT) margin is computed in order to determine timing of shop visits and to preclude EGT exceedances, which disturb routine operations of aircraft (Beynon, 2015).

4.1.3 Cockpit Display

Temperature measurements, especially in the engine turbine section, are displayed to the flight crew for purposes of monitoring engine operation.

4.1.4 Performance Measurement

Temperature measurements are critical to the determination of several important aspects of engine performance, such as specific fuel consumption (SFC), efficiency, and turbine exhaust gas temperature.

4.2 Media

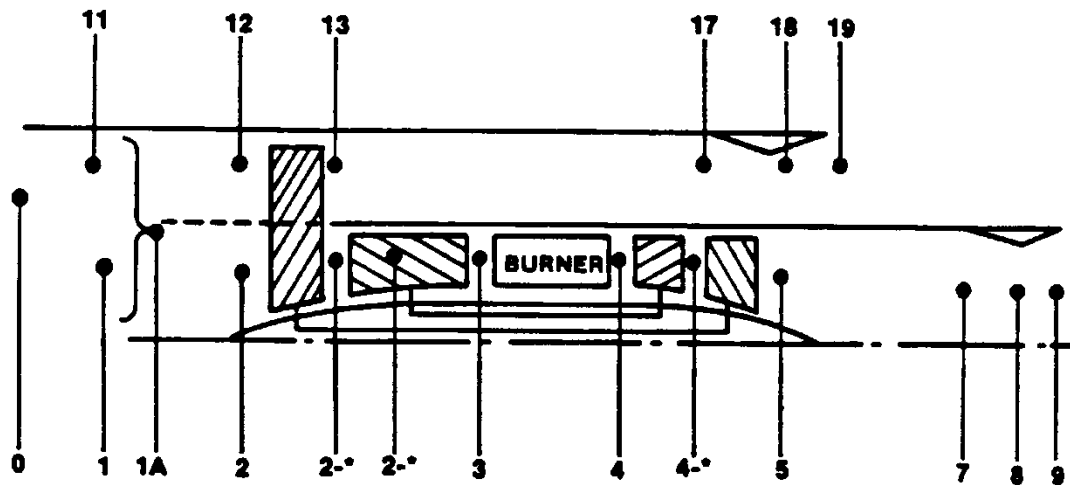
Temperature measurements of different media are required in an aircraft gas turbine engine. These media include:

- a. Gas paths.
- b. Turbine metal parts, such as blades.
- c. Liquids, including oil and fuel.

4.2.1 Gas Path

4.2.1.1 General

The purpose of a gas path temperature measurement generally dictates where it is made. Purposes include control, diagnostics and condition monitoring, cockpit display and performance measurement. Purposes specific to each location is discussed in the following paragraphs. The stations and their designation are described below and illustrated in [Figure 1](#).



*Intermediate stations are assigned a numeric or alpha identification, such as $T_{2.2}$.

Figure 1 - Thermodynamic stations for twin-spool turbofan (ARP755)

- T_1 = Inlet/engine interface temperature
- T_{12} = First compressor front face tip section temperature
- T_2 = First compressor front face temperature
- T_{13} = Temperature at end of compression of bypass flow
- T_{2x} = Temperature at intermediate stage in 1st compressor
- T_3 = Last compressor discharge temperature
- T_4 = Burner discharge temperature
- T_{4x} = High-pressure turbine discharge temperature
- T_5 = Last turbine discharge temperature
- T_7 = Engine/exhaust nozzle interface temperature

ARP755 describes gas turbine engine performance station identifications and nomenclature, and Section [2](#) provides temperature measuring devices nomenclature.

If there is no asymmetrical distribution of temperature at the given station, it is possible for a single temperature transducer to be used. However, practically speaking, asymmetric temperature distribution (both radially and circumferentially) occurs regularly and steps must be taken to deal with this fact. Testing is usually accomplished to establish temperature profiles and placement of probes is chosen at representative locations. Depending upon the location, either one, two or several probes are used to make circumferential measurements. In the case of turbine discharge (T_5) temperature, a rake of thermocouples is usually designed to make the chosen temperature measurement. The number of thermocouples in a rake can vary, but eight is a typical number.

4.2.1.1.1 T_1 , T_{12} , and T_2 Locations

Control functions often drive the need for these measurements. Schedules are often established for compressor speeds, fuel flows, and variable geometry. The schedules consist of nonlinear relationships between temperature and the variable being scheduled. Depending upon the temperature measured, the scheduled variable is controlled to a tolerance pre-established by the engine control software/hardware. These temperatures are used to correct shaft speeds and can also be used for condition monitoring to establish baseline temperatures from which T_{2x} and T_3 can be examined.

These temperatures are sometimes also selected for use in performance measurement. For example, depending upon the temperature selected, $NL/\sqrt{\theta}$ can be used to assess engine performance, where NL = low pressure compressor speed and θ = ratio of measured total (T_1 , T_{12} , or T_2) temperature to reference (sea level) ambient temperature.

In many civil (commercial) applications, T_1 is measured external to the engine and generally on the fuselage. Furthermore, unless there is significant disagreement between engine inlet total temperature and fuselage total temperature, the airframe (fuselage) total temperature is selected for the measurement. This is generally not the case for military engines, however. In these instances, the engine inlet sensor is selected. In the event of disagreement, either the fuselage temperature is selected or some other engine temperature is used in its place.

4.2.1.1.2 T_{2x} and T_3

These temperatures are usually used for key engine control functions such as scheduling of the variable stator vanes in boosters and compressors, managing blowout margins for combustor operability, detecting ice accretion or water ingestion or parameterizing models to use in voting in signal selection logic. They are also often selected for diagnostics and condition monitoring purposes. They can be used to identify trends, track efficiencies of low (T_{2x}) and high (T_3) pressure compressors through examination of their discharge temperatures in order to establish relationships between temperatures in the engine (between T_1 and T_{2x} , for example) under various engine operating conditions.

4.2.1.1.3 T_{4x} , T_5 and T_7

These temperatures are used for all purposes, including control, diagnostics and condition monitoring, cockpit display, and performance measurement.

4.2.1.2 Temperature Range

Typical temperature ranges for each measurement are given by thermodynamic station in [Table 2](#). They depend upon engine type (military, civil/commercial, corporate, helicopter) and flight envelope (maximum altitude and maximum Mach number). For ease of comparison, engine types are grouped as follows: high performance and low to medium performance. These are defined basically in terms of turbine entry temperature (TET) or station T_4 . For high-performance engines, maximum TET exceeds 1400 °C (2550 °F), whereas maximum TET falls below 1150 °C for low- to medium-performance engines. Temperature ranges are relatively independent of the purpose for which the sensor is to be used.

In general, there is a trend toward higher core temperatures, particularly T_3 , T_{4x} , T_5 , and T_7 . This is particularly true for high-performance engines where there is a need for increased performance (for example in military engines), increased efficiencies (in civil/commercial engines), or for both.

Table 2 - Normal operating temperature ranges

Station	High (°C)	Low/Medium (°C)
$T_1/T_{12}/T_2$	-55 to +175	-55 to +125
T_{2x}	-55 to +260	-55 to +200
T_3	0 to +650	0 to +500
T_{4x}	260 to +1200	260 to <1150
T_5/T_7	260 to +700	260 to +500

4.2.1.3 Accuracy

Accuracy requirements are established for the purpose for which the measurement is used. The measurement error includes several components, such as:

- a. Sensor related errors.
- b. Signal transmission errors.
- c. Signal processing errors.
- d. Signal display errors.

Typical accuracies are provided in [Table 3](#) and discussed further in related SAE documents cited in Section [2](#) (such as ARP1587 and AIR1873).

Table 3 - Measurement accuracy/uncertainty requirements

Location	Accuracy or Uncertainty (°C)
T ₁	±2.0
T ₁₂	±2.0
T ₂	±2.0
T _{2x}	±2.0
T ₃	±5.0 ¹
T _{4x}	±7.0 ¹
T ₅ /T ₇	±5.0 ¹

¹ At the design point only. This widens considerably at other temperatures.

4.2.2 Turbine Blade

4.2.2.1 Purpose

Turbine blade temperature (TBT) is measured to ensure blade temperature limits are not exceeded. Exceedance of established maximum allowable temperature will significantly reduce the creep life of a part. The purposes of the measurement include control, diagnostics, and condition monitoring.

Prior to the development of optical pyrometers, the direct measurement of TBT was not possible. Instead, an estimate could be made of TBT by the use of thermocouple temperature measurements in the HP turbine discharge (T₄₅) position or in the LP turbine discharge (T₅) location. This remains the dominant means of estimating TBT at the time this document was prepared. Specifically, T₄₅ or T₅ measurements are commonly used together with a predictable bias, to predict T₄, the turbine entry temperature. This is followed by an estimate of TBT based upon the estimate of T₄. This estimate must take into account cooling of the blades themselves by convective cooling, conduction, and radiation from the blades.

Nozzle guide vane temperature can also be targeted as a substitute to direct TBT measurement.

With the development of optical pyrometers, a direct measurement of TBT is now possible. The first stage turbine blades are often chosen for the measurement, although other stages can be selected as well.

It should be noted that a component's critical location may not be visible to the optical pyrometer due to mounting constraints (i.e., port location and direction, as well as mounting location temperatures and available physical space). In those cases, transfer functions might be employed to estimate the temperature at the critical location from the temperature measured elsewhere on the part.

4.2.2.2 Location

The most frequently chosen location for this measurement is the high-pressure turbine (HPT) blade. However, low-pressure turbine (LPT) blades may also be examined for diagnostics purposes.

4.2.2.3 Temperature Range

The typical operating temperature range is from 650 to 1150 °C but could approach 1500 °C for ceramic blades.

4.2.2.4 Accuracy

Accuracy requirements are meaningful only at the temperature design point selected. This may be any temperature over the operating range. At the design point, the maximum uncertainty will typically be ± 9 °C.

4.2.3 Liquids (Oil and Fuel Temperature)

4.2.3.1 Purpose

The purpose of this measurement is for condition monitoring or diagnostics.

4.2.3.2 Location

Measurement of the liquid temperature is usually accomplished by use of a probe immersed directly into the medium. Locations may vary but oil temperature sensor will typically be before the oil cooler, whereas the fuel temperature sensor is normally downstream of the fuel heater and upstream of the fuel filter.

4.2.3.3 Temperature Range

The temperature range is from -55 to 200 °C.

4.2.3.4 Accuracy

The maximum uncertainty for the condition monitoring, diagnostic purposes and cockpit display is typically less than ± 3.5 °C. These systems often do not require the high-level accuracy that is required for gas path sensors.

4.3 Sensor Types

There are many different technologies that have been used to measure temperature inside gas turbine engines. These include the following types:

- a. Thermocouples.
- b. Resistance temperature devices (RTDs).
- c. Optical.
- d. Thermistors.
- e. Gas/liquid filled thermometers.
- f. Acoustical.
- g. Beta emission.
- h. Resonating crystals.
- i. Spectroscopic.
- j. Color paints.