

Air Data Computers

Air Data Computers have been with us for many years now and have become increasingly more important, never more so than now as the RVSM mandate deadline approaches. The conventional aneroid pressure altimeter has been around for decades and is surprisingly accurate for a mechanical instrument. This instrument however will slowly lose accuracy with increasing altitude. This scale error is why they will not meet today's stringent RVSM accuracy requirements. The history of RVSM goes back further than you think, it was first proposed in the mid 1950's and again in 1973 and both times was rejected. With RVSM going into effect this month it will provide six new flight levels, increase airspace capacity and most likely save hundreds of millions in fuel burn each year.

Electrically driven altimeters when paired with current generation air data computers provide a much improved and more accurate system. The air data computer has become most important in maintaining optimum performance of the aircraft in this ever-demanding environment we call the national airspace system. These computers have made it possible to actually implement the RVSM mandate that we now face as well as providing additional information to other aircraft systems.

The Beginning

Initially the main air data sensing application that concerned us was for an altitude hold capability with the autopilot. This "Altitude Capsule", a simple aneroid just like an altimeter is interfaced to a locking solenoid that allows an error signal to be generated as the diaphragm changes with altitude. All these capsules used gears, cams, potentiometers and solenoids to maintain a given altitude when commanded. In those days if the aircraft held within +/-100ft that was considered nominal but then the accuracy would also vary at different altitudes. These mechanically sensing instruments have at times been problems for us all, for failing to maintain proper pressure rates on them during normal routine maintenance would cause undue stress or even failure. Let's look at the airspeed indicator as an example. We have found that by keeping the airspeed "alive" while performing any pitot-static system checks is the only way to insure the integrity of the instrument as well as provide a visual reference of the applied pressure differential in the system. Several type airspeeds in Learjet's for example would tend to drop a pin positioned internally between the aneroid and the bi-metal calibration arm when subjected to abnormal rates. The dislocation of this pin then would cause the instrument to read high above 120kts. This of course required a tear down of the airspeed in order to re-install the pin. Today's air data computers with solid state transducers that are integrated with electrical instruments or digital displays have eliminated these mechanical concerns. Solid state pressure sensors and digital instruments are much more forgiving. Current generation air data computers have evolved into a separate amplifier that provides a multitude of functions and information.

The first generation of a Central Air Data Computer (CADC) evolved out of the Navy F14A Tomcat program in the 1967-1969 time period. This computer employed Quartz Sensors, 20 bit Analog to Digital and Digital to Analog devices and a microprocessor chipset designed by American Microsystems. Although this computer also was designed to manage some of the control surfaces of the aircraft it was a major achievement in its time.

The Sensor

The heart of any air data computer is the pressure sensor itself. The accuracy of the entire system is based on the sensor. The two types of pressure sensors used are absolute sensor for the static port and a differential sensor for the pitot system. There are three common sensor designs employed and they are: bonded strain gauge, deposited or ion implanted piezoresistive elements and capacitive. These pressure transducers are simply an Electro-mechanical device for translating fluid pressure values into voltages across a high-impedance. The piezoresistive sensor design employs a fully active Wheatstone Bridge. Applied pressure presents a distributed load to the diaphragm, which provides bending stresses. This stress creates a strain proportional to the applied pressure, which results in a bridge imbalance. With an applied voltage across the bridge the unbalance produces a millivolt output. The capacitive type is believed to provide the highest sensitivity, least aging effects and provide very accurate low pressure sensing. This capacitive sensing technique measures atmospheric pressure through the change in voltage across the capacitive element, one plate of which deflects slightly with changes in applied pressure. The sensitivity of a transducer is defined as the ratio of its electrical output to its mechanical input. These transducers are very accurate but they do have some imperfections in that their calibration curves do not represent a straight line (linear) relationship between the pressure applied and its output. The air data computer can correct for this by storing the correction curve parameters in permanent memory in the form of a look-up table or put into flash memory for example to allow for re-writing the curve as aging occurs. This curve is critical to masking out the non-linearity and achieving maximum accuracy. The predictability and repeatability of the transducer's performance, regardless of type used will greatly effect system performance. Controlling the transducer's temperature will help insure this consistent performance. In order to appreciate the sensitivities required let's look at what the SAE has defined as accuracy's required by the air data system. An earlier SAE specification calls for a tolerance of $\pm 25\text{ft}(\pm 0.012\text{psi})$ at 5,000ft and $\pm 125\text{ft}(\pm 0.010\text{psi})$ at 50,000ft. The Collins ADC-3000 system for example lists a resolution of one foot and lists an accuracy of $\pm 40\text{ft}$ at FL410 to maintain RVSM envelope tolerances. One common method used digitize the sensor output is to allow it to control a voltage controlled oscillator (VCO). The oscillator output then is a digital value from which all other computations can take place. The more common technique now is an analog to digital interface directly to the microprocessor. The microprocessor then can monitor and control the transducer temperature to insure a predictable output.

Air Data Functions

The modern air data computers and their associated instrumentation are used to measure a number of critical air mass properties. The computer must track pressure changes as the aircraft climbs, descends, accelerates, decelerates and then accurately predict for example capture points for the autopilot. The atmospheric pressure or force per unit area of the air in the earth's atmosphere will decrease monotonically with the distance above the surface. There are three critical measurements for the computer. The two fundamental pressure measurements required is impact pressure (Q_c) as measured at the pitot tube and the ambient static air pressure (Q_s) sensed at the static ports.

Ideally you want undisturbed pitot-static pressure to arrive at the computer however some influences do exist. Placement and sizing of the Pitot-Static probes and ports is also critically important in order to help minimize these influences. The CIA found out after they lost an A-12 aircraft on May 24, 1963 just how critical this can be. The computer must be capable of providing a stable and extremely accurate measurement over long sustained periods of flight. Pressure Altitude is the altitude referenced to a standard sea level pressure of 29.92Hg. Since barometric pressure varies locally as a function of the weather conditions a local correction to the measured pressure is required. This Baro-Corrected or Baro-Altitude is referenced to the local pressure and this is used below FL180. The pilot controls the amount of correction applied to the measured pressure altitude simply by dialing in the local pressure on the altimeter or the display control panel. This correction is sent to the air data computer in one of several forms; analog voltage, synchro format or digitally. The final measurement that must be considered and one that influences many calculations is the air temperature. The Total Air Temperature (TAT) probe is one method while a simple outside air temperature (OAT) probe is another. Let's look at the total air temperature method. The probe compresses the impacting air to zero speed and the resulting temperature causes a change in the resistance of the sensing element. The air data then converts this resistance to temperature. The TAT probe design could be of two types: aspirated and non-aspirated. The air temperature is used to calibrate the impact pressure as well as in determining air density. The air density will effect the force of the air. This measured temperature will vary from the standard lapse rate of $.65^{\circ} \text{C} / 100 \text{ meters}$ and this value will vary up or down depending on location and the local weather. These three measurements provide the following computed air data output signals which supply primary and secondary instruments: Pressure Altitude, Baro-Corrected Altitude, Vertical Speed, Mach Number, Total Air Temperature, Calibrated Airspeed, True Airspeed, Digitized Pressure Altitude (Gillham), Altitude Hold, Airspeed Hold, Mach Hold and Flight Control Gain Scheduling.

System Corrections

Static Source Error Correction (SSEC) plays an important role in the overall accuracy of the air data system by making corrections to pressure altitude. The purpose of SSEC is to produce a minimum residual static system error. All aircraft have some imperfections in the static system as it is plumbed through the airframe to include defects at the static ports caused by aerodynamic effects of the aircraft in flight. This correction is important in any high performance and jet aircraft. In order to correct for these imperfections certain calibrations need to be made within the air data computer. The Airplane Flight Manual Performance Section for a specific airplane will have in it a table or chart showing the actual corrections in altimetry for that airframe. This information developed by the airframe manufacturer can be pre-programmed in memory by the air data manufacturer and selected with program straps that identify the particular airframe. Program modules are another format used to implement this correction. The current useful weight and angle of attack may also influence the SSEC as the fluid dynamics around the static ports may differ. This is an important factor in minimizing the overall Altimetry System Error (ASE) in the aircraft. We should remember that because this is a dynamic correction that it must be disabled for example when complying with altimeter certification. Pitot Source Error Correction (PSEC) may also be compensated for in a similar manner on some airframes.

Measuring Airspeed

As with measuring altitude, measuring airspeed is basically straightforward and deals with measuring the impact pressure. Indicated airspeed (IAS) is merely a reference to pitot minus static pressure. There are however several other factors to be concerned with. In dealing with impact pressure (Qc) we must also be aware of the compressibility that occurs around the airframe and pitot tube. The compressibility of the air mass as the aircraft moves through the air also creates a drag coefficient, as a result of this the air temperature must be known to solve for heat at a specific pressure. NASA has a technical note, D-822 that shows the relationship of Impact Pressure (Qc) for values of Calibrated Airspeed and serves as a good reference. The aircraft's airspeed indicators are calibrated at standard sea-level conditions and there the measured airspeed is True Airspeed (TAS). The net pressure and density at all other altitudes will deviate and therefore the air data computer must calculate a correction for them to maintain an accurate True Airspeed at these altitudes. True airspeed is the actual airspeed of the aircraft through the air or Mach number times the speed of sound. As the speed of sound is a function of static air temperature (SAT), here again air temperature is required. If the air mass at altitude is relatively stationary, then true airspeed represents groundspeed also. True airspeed is the speed of choice for any navigation system and has become a required input. The GPS navigator and Flight Management systems use true airspeed to compute winds aloft thus enabling the crew to fly at more fuel-efficient altitudes and also for solving equations relating to ground coordinates.

Common Terms

Pt **Total Pressure:** the sum of local atmospheric pressures plus dynamic pressures. Algebraically then, total pressure equals the sum of static pressure (Ps) plus Impact pressure (Qc)

$$Pt = Ps + Qc$$

Ps **static pressure:** the absolute pressure of still air surrounding a body; the atmospheric pressure at the flight level of the aircraft.

Qc **impact pressure:** a calculated value, it is the difference between total pressure and static pressure; it is the pressure created by the forward motion of the aircraft.

TAT **total air temperature:** the temperature of an airflow measured as the airflow is brought to rest without removal or addition of heat; impact temperature.

OAT **outside air temperature:** the temperature of the static outside temperature without the effects of airspeed.

Conclusions

We have seen certainly in the last decade the need for more information to be available to the crew in the cockpit. The growth of GPS, Flight Management systems and the newer cockpit display technologies has demanded a growth in previously existing systems as well. Existing ADC80 series computers, for example, can be brought into RVSM compliance through SB32 and updating the SSEC by STC. This enormous growth dictates also an integration of data far beyond what most of us envisioned twenty years ago. The air data computer performs critically important functions that enhance the safety, reliability and performance of the aircraft.

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