APPLICATION NOTE • AN-0019

Airspeed and Altitude Calculation

Using the ISA Atmosphere Model and the Pitot-Static Equations, from Basic Incompressible Flow to Compressible, High-Speed / High-Altitude Corrections

Reference device: All Sensors AUAV Series Dual Pressure Sensor | Related datasheet: DS-0432

1. Purpose and Scope

The All Sensors AUAV Series dual pressure sensor reports three quantities during flight: absolute pressure (static, ambient pressure), differential pressure (dynamic, or "impact" pressure from a pitot-static probe), and temperature. This note explains how those three sensor outputs are converted into two quantities that matter to a UAV flight controller: pressure altitude and true airspeed.

The note is organized in two stages of increasing detail:

- Part A – a simplified, incompressible-flow model suitable for small, low-speed UAVs (multirotors and slow fixed-wing aircraft flying well below about 100 knots, at altitudes within a few thousand feet of the ground).
- Part B – the full compressible-flow (isentropic) equations required for faster or higher-flying UAVs, where the simplified model in Part A starts to under-report airspeed by a significant margin.

Each stage includes a fully worked numerical example using realistic sensor output values, so the reader can check their own firmware implementation against the same numbers.

2. What the Sensor Gives You

The AUAV combines two independent pressure channels in one package:

- Absolute channel – measures the true ambient (static) air pressure, Pabs, referenced to a near-vacuum inside the sensor. This is the same quantity a barometer measures, and it is what changes as the vehicle climbs or descends.
- Differential channel – measures the pressure difference between two ports, Pdiff. When one port is connected to a forward-facing pitot tube and the other to a static port (or to the ambient side of the same probe), Pdiff is the dynamic pressure created by the aircraft moving through the air.
- Temperature – each channel also returns a temperature reading used internally for compensation; this same value doubles as the outside air temperature (OAT) input needed for the density and speed-of-sound calculations below.

Once these three values are converted to engineering units (pascals and kelvin) using the transfer functions in the AUAV product datasheet, they become the only inputs needed for everything that follows.

> *Sign and plumbing convention used throughout this note: static (ambient) pressure Ps ≈ Pabs, and total (pitot) pressure Pt = Ps + Pdiff. Confirm this matches your own pneumatic plumbing before using these equations — if the pitot line and static line are swapped, Pdiff will be reported with the opposite sign.*

3. Part A — Simplified Model for Low-Speed UAVs

Part A assumes two simplifications that are reasonable for typical hobby and light commercial drones: (1) air is treated as incompressible, i.e. its density does not change appreciably as it slows down at the pitot tube, and (2) the atmosphere below about 11 km follows the standard, single-layer ISA troposphere model. Both assumptions are good to well under 1% error for airspeeds below roughly 100 knots (about 51 m/s, Mach 0.15) at altitudes below a few thousand meters.

3.1 Pressure Altitude (ISA Troposphere Model)

The International Standard Atmosphere (ISA) defines how pressure, temperature, and density fall off with height under “average” conditions. In the troposphere (0 to 11,000 m), ISA assumes a constant temperature lapse rate, and this relationship can be inverted to solve for altitude directly from a measured absolute pressure:

$$h = 44330\left[1 - \left(\frac{P_{abs}}{P_0}\right)^{\frac{1}{5.255}}\right]$$

where h is pressure altitude in meters, Pabs is the measured absolute pressure in pascals, and P0 = 101,325 Pa, the standard ISA sea-level reference pressure. The constants 44,330 and 5.255 come directly from the ISA sea-level temperature (288.15 K), lapse rate (6.5 K/km), and the properties of air, and do not need to be re-derived for this application.

> *This equation gives pressure altitude — height above the 1013.25 mbar reference level — not height above the local ground or above mean sea level on a specific day. For height above the launch point, subtract the pressure altitude computed from a ground-level reading taken just before takeoff.*

3.2 Local Air Density

Airspeed depends on how dense the air is, and density changes with both altitude and temperature. Rather than assuming the standard ISA temperature at a given altitude, the AUAV's own temperature reading, T (in kelvin), should be used together with the measured absolute pressure to get the true local density from the ideal gas law:

$$\rho = \frac{P_{abs}}{R \times T}$$

where ρ (rho) is air density in kg/m³, and R = 287.05 J/(kg·K) is the specific gas constant for dry air. Using the sensor's own temperature reading, rather than a fixed assumed value, is the single biggest accuracy improvement available in this whole process — density, and therefore airspeed, is directly proportional to it.

3.3 Indicated / True Airspeed (Incompressible Bernoulli / Pitot Equation)

A pitot-static probe measures dynamic pressure, the pressure rise caused by bringing moving air to rest at the tube's tip. For low speeds, Bernoulli's equation for incompressible flow relates this directly to velocity:

$$V = \sqrt{\frac{2 \times P_{diff}}{\rho}}$$

where V is true airspeed in m/s and Pdiff is the differential (dynamic) pressure reading from the AUAV, in pascals. This is the equation used almost universally in low-cost UAV autopilots, and it is accurate as long as the vehicle stays well below about Mach 0.3.

3.4 Worked Example — Low-Speed Fixed-Wing UAV

Assume the AUAV reports the following compensated values during a low-altitude cruise leg:

Quantity	Symbol	Value
Absolute pressure	Pabs	95,000 Pa (950.0 mbar)
Differential pressure	Pdiff	150 Pa
Temperature	T	288.15 K (15.0 °C)

Step 1 — Pressure altitude

$$h = 44330\left[1 - \left(\frac{95{,}000}{101{,}325}\right)^{\frac{1}{5.255}}\right] = 44330 \times [1 - 0.9876] \approx 540\,m\ (\approx 1{,}772\,ft)$$

Step 2 — Local air density

$$\rho = \frac{95{,}000}{287.05 \times 288.15} \approx 1.148\,kg/m^3$$

Step 3 — True airspeed

$$V = \sqrt{\frac{2 \times 150}{1.148}} = \sqrt{261.2} \approx 16.2\,m/s\ (\approx 31.4\,kt, \approx 36.2\,mph)$$

> *Result: a UAV at this pressure altitude and dynamic pressure is flying at approximately 540 m pressure altitude and 16.2 m/s (about 32 knots) true airspeed — a typical cruise condition for a small fixed-wing UAV, well inside the range where the simplified model is accurate to a fraction of a percent.*

4. Part B — Compressible-Flow Model for Higher-Speed / Higher-Altitude UAVs

As airspeed rises above roughly Mach 0.3 (about 100 m/s at sea level), or as a UAV climbs into thinner, colder air, the incompressible assumption in Part A begins to under-predict airspeed — the air is measurably compressed as it slows at the pitot tip, which raises the measured Pdiff for a given true speed. Turbine-powered or high-performance fixed-wing UAVs, and any aircraft operating above a few kilometers of altitude, should use the compressible correction shown below instead.

4.1 Mach Number from Measured Pressures (Rayleigh Pitot-Tube Equation)

For subsonic compressible flow, the relationship between the ratio of total to static pressure and Mach number is given by the isentropic (Rayleigh) pitot equation, using k = 1.4 for the ratio of specific heats of air:

$$\frac{P_{diff}}{P_s} = (1 + 0.2 \times M^2)^{3.5} - 1$$

Here Ps is static (absolute) pressure, equal to Pabs from the AUAV's absolute channel, and Pdiff is the dynamic/impact pressure from the differential channel, exactly as before — only the equation relating them to speed has changed. Solved directly for Mach number:

$$M = \sqrt{\left\{5 \times \left[\left(\frac{P_{diff}}{P_s} + 1\right)^{\frac{2}{7}} - 1\right]\right\}}$$

This relation is valid for all subsonic Mach numbers (M < 1) and reduces back to the simplified Part A formula in the limit of small Pdiff/Ps — it is a strict superset, not a different model.

4.2 True Airspeed from Mach Number

Once Mach number is known, true airspeed follows from the local speed of sound, which itself depends only on the measured air temperature:

$$a = \sqrt{k \times R \times T}, \qquad V = M \times a$$

where a is the local speed of sound in m/s, k = 1.4, R = 287.05 J/(kg·K), T is the measured static temperature in kelvin, and V is true airspeed in m/s.

4.3 Altitude and Density

The pressure-altitude equation from Section 3.1 remains valid up to 11 km using the same constants, and the ideal gas law in Section 3.2 remains the correct way to get local density if it is needed for other calculations (e.g. dynamic pressure loading, engine performance) — compressibility affects the pitot relationship between Pdiff and speed, not the basic altitude or density equations themselves.

4.4 Worked Example — High-Speed, High-Altitude UAV

Assume a faster, higher-flying UAV (e.g. a small turbine-powered platform) reports:

Quantity	Symbol	Value
Absolute pressure	Pabs (= Ps)	54,000 Pa (540.0 mbar)
Differential pressure	Pdiff	9,000 Pa
Temperature	T	250.0 K (−23.15 °C)

Step 1 — Pressure altitude (same equation as Part A)

$$h = 44330\left[1 - \left(\frac{54{,}000}{101{,}325}\right)^{\frac{1}{5.255}}\right] \approx 5{,}001\,m \ (\approx 16{,}406\,ft)$$

Step 2 — Mach number from the Rayleigh pitot relation

$$M = \sqrt{\left\{5 \times \left[(9{,}000/54{,}000 + 1)^{\frac{2}{7}} - 1\right]\right\}} = \sqrt{5 \times 0.0450} \approx 0.474$$

Step 3 — Local speed of sound and true airspeed

$$a = \sqrt{1.4 \times 287.05 \times 250} \approx 317.0\,m/s \qquad V = 0.474 \times 317.0 \approx 150.4\,m/s \ (\approx 292\,kt, \approx 337\,mph)$$

4.5 Why the Correction Matters: A Direct Comparison

Applying the simplified, incompressible equation from Part A (Section 3.3) to this same set of readings, using the same local density from the ideal gas law (ρ = Pabs/(R×T) ≈ 0.753 kg/m³), gives:

$$V_{incompressible} = \sqrt{\frac{2 \times 9{,}000}{0.753}} \approx 154.6\,m/s \ \ vs. \ \ V_{compressible} \approx 150.4\,m/s$$

> *At this flight condition the simplified model over-reads true airspeed by about 4 m/s, roughly 2.8% — small here, but the error grows rapidly (and always in the same direction) as Mach number increases further, which is why the compressible correction is required once a UAV's cruise speed or altitude moves meaningfully beyond the Part A operating envelope.*

5. Summary of Equations

Quantity	Simplified (Part A)	Compressible (Part B)
Pressure altitude	$h = 44330\left[1 - \left(\frac{P_{abs}}{P_0}\right)^{\frac{1}{5.255}}\right]$	same equation (valid to 11 km)
Air density	$\rho = \frac{P_{abs}}{R \times T}$	same equation, used for other purposes

Quantity	Simplified (Part A)	Compressible (Part B)
Speed relation	$V = \sqrt{\frac{2 \times P_{diff}}{\rho}}$	$M = \sqrt{\left\{5\left[\left(\frac{P_{diff}}{P_s}+1\right)^{\frac{2}{7}}-1\right]\right\}}$, $V = M\sqrt{k\,R\,T}$
Valid range	M ≲ 0.3 (≈ 100 m/s at sea level)	all subsonic speeds, M < 1

6. Practical Notes for Implementation

- Always adjust the AUAV's raw digital counts using the Extended Compensation coefficients (A, B, C, D, Es, TC50H, TC50L) stored in the sensor's EEPROM, as described in the AUAV product datasheet, before converting to engineering units (Pa and K) with the pressure and temperature output transfer functions. Skipping this step leaves residual linearity and temperature-dependent errors in the reading that will propagate directly into the altitude and airspeed results.
- Use the sensor's own temperature reading in the density and speed-of-sound equations rather than an assumed standard-atmosphere value — this is the largest single source of avoidable error in both Part A and Part B.
- Re-zero or record a ground-level Pabs reading immediately before flight if height above the launch point (rather than standard pressure altitude) is required.
- For vehicles that operate across a wide speed envelope (e.g. a VTOL that hovers and then transitions to fast forward flight), it is reasonable to implement the full compressible equations from Part B everywhere — they remain accurate at low speed and simply cost a few extra floating-point operations per update.
- Above 11 km altitude, the single-layer troposphere formula in Section 3.1 is no longer valid; a multi-layer ISA model is required, which is outside the scope of this note but follows the same general approach.

7. References

1. All Sensors AUAV Series Dual Pressure Sensor Product Datasheet (device-specific; refer to the datasheet for the exact AUAV variant in use). For standard products, see DS-0432.

2. U.S. Standard Atmosphere, 1976 (ISA reference model, troposphere layer).

3. Anderson, J.D., Fundamentals of Aerodynamics — Rayleigh Pitot-tube (isentropic subsonic) equation.

Appendix A: Altitude / Pressure Reference Tables

The tables below tabulate the pressure-altitude relationship from Section 3.1 for quick lookup or firmware unit-test reference, without needing to evaluate the equation by hand:

$$h = 44330\left[1 - \left(\frac{P_{abs}}{P_0}\right)^{\frac{1}{5.255}}\right]$$

The sea-level reference row (Pabs = 101,325 Pa, h = 0) is highlighted in each table.

A.1 Altitude at Selected Absolute Pressure Values

Altitude computed for round-number static (absolute) pressure values.

Pabs (Pa)	Altitude (m)	Altitude (ft)
110000	−698.4	−2292
101325	**0.0**	**0**
100000	110.9	364
95000	540.4	1774
90000	988.7	3244
80000	1949.3	6397
70000	3012.7	9887
60000	4207.1	13806
50000	5575.3	18296
40000	7186.6	23584
30000	9165.4	30078

A.2 Absolute Pressure at Round-Number Altitudes (Meters)

Pabs computed for round-number altitude values in meters, for reference when working in metric units.

Pabs (Pa)	Altitude (m)	Altitude (ft)
107476	−500	−1641
101325	**0**	**0**
100130	100	328
95462	500	1641
89876	1000	3282
84559	1500	4923
79499	2000	6563
70113	3000	9845

Pabs (Pa)	Altitude (m)	Altitude (ft)
54026	5000	16408
41067	7000	22972
26442	10000	32817

A.3 Absolute Pressure at Round-Number Altitudes (Feet)

Pabs computed for round-number altitude values in feet, for reference when working with flight levels or imperial units.

Pabs (Pa)	Altitude (m)	Altitude (ft)
105039	−304.7	−1000
101325	**0**	**0**
101288	3.0	10
100960	30.5	100
99508	152.4	500
97718	304.7	1000
94216	609.4	2000
84314	1523.6	5000
69693	3047.2	10000
46580	6094.4	20000
30107	9141.6	30000

Appendix B: Airspeed Reference Tables

The tables below tabulate true airspeed for a range of differential (dynamic) pressure readings and outside air temperatures, at a fixed sea-level static pressure of Pabs = 101,325 Pa, for quick lookup or firmware unit-test reference.

B.1 Incompressible (Simplified) Model — Section 3.3

Computed from the incompressible pitot relation, with local density from the ideal gas law:

$$V = \sqrt{\frac{2 \times P_{diff}}{\rho}}, \qquad \rho = \frac{P_{abs}}{R \times T}$$

Values are true airspeed in m/s.

Pdiff (Pa) \ T (°C)	–40	–20	0	20	40	60	80
50	8.13	8.47	8.80	9.11	9.42	9.71	10.00
100	11.49	11.98	12.44	12.89	13.32	13.74	14.15
250	18.17	18.94	19.67	20.38	21.06	21.72	22.37
500	25.70	26.78	27.82	28.82	29.78	30.72	31.63
1000	36.35	37.87	39.34	40.75	42.12	43.45	44.73
2000	51.40	53.56	55.64	57.64	59.57	61.44	63.26
3000	62.95	65.60	68.14	70.59	72.96	75.25	77.48
5000	81.27	84.69	87.97	91.13	94.19	97.15	100.02
7000	96.16	100.20	104.08	107.83	111.45	114.95	118.35

All values verified by direct computation to match within rounding at 2 decimal places. This table is valid only while the incompressible assumption holds (airspeed below roughly Mach 0.3, about 100–115 m/s depending on temperature); see Appendix B.2 for the compressible-flow equivalent at higher speeds.

B.2 Compressible-Flow Model — Sections 4.1–4.2

Computed from the Rayleigh subsonic pitot relation, followed by the speed-of-sound relation:

$$M = \sqrt{\left\{5\left[\left(\frac{P_{diff}}{P_s}+1\right)^{\frac{2}{7}}-1\right]\right\}}, \qquad V = M\sqrt{k\,R\,T}$$

at the same sea-level static pressure (Ps = Pabs = 101,325 Pa) and the same temperatures as Appendix B.1. Rows extend in 5,000 Pa steps beyond 10,000 Pa up to the point where the 80 °C column reaches 300 m/s, to illustrate the growing deviation from the incompressible model at higher differential pressures.

Pdiff (Pa) \ T (°C)	–40	–20	0	20	40	60	80
50	8.13	8.47	8.80	9.11	9.42	9.71	10.00
100	11.49	11.97	12.44	12.89	13.32	13.74	14.14
250	18.16	18.93	19.66	20.37	21.05	21.71	22.36
500	25.68	26.76	27.79	28.79	29.76	30.69	31.60
1000	36.28	37.81	39.27	40.68	42.05	43.37	44.65
2000	51.22	53.37	55.44	57.43	59.36	61.23	63.04
3000	62.62	65.26	67.78	70.22	72.58	74.86	77.07
5000	80.57	83.96	87.21	90.35	93.38	96.31	99.16
7000	95.01	99.00	102.84	106.54	110.11	113.58	116.94
10000	113.00	117.75	122.31	126.71	130.96	135.08	139.07
15000	137.29	143.06	148.60	153.94	159.11	164.11	168.96
20000	157.30	163.91	170.26	176.38	182.30	188.03	193.59
25000	174.55	181.88	188.93	195.72	202.29	208.65	214.82
30000	189.82	197.79	205.46	212.85	219.99	226.91	233.62
35000	203.58	212.14	220.36	228.28	235.94	243.36	250.56
40000	216.15	225.23	233.96	242.37	250.51	258.38	266.02
45000	227.74	237.31	246.50	255.37	263.93	272.23	280.29
50000	238.50	248.52	258.15	267.44	276.41	285.10	293.53
55000	248.57	259.01	269.05	278.72	288.08	297.13	305.92

Comparing Appendix B.1 and B.2 at Pdiff = 7,000 Pa and 80 °C: the incompressible model gives 118.35 m/s versus 116.94 m/s here — about a 1.2% difference. At Pdiff = 55,000 Pa and 80 °C, the gap widens substantially (the incompressible formula is not physically valid at this dynamic pressure and is omitted here); this is the same deviation illustrated in Section 4.5, just tabulated across the full temperature range.