Basic avionics

Avionics is a rather broad subject. The word avionics is short for **aviation electronics**. But it actually encompasses much more than electronics. What exactly does avionics entail? How does it work? And how did it come to be? That is what this summary is all about. We start by examining the history of avionics, and some of the first systems that were developed.

1 History of avionics

The development of Avionics started as early as the 18th century. In 1783, the Montgolfier brothers used a **barometer** to measure altitude. The famous Wright brothers used avionics as well: an **anemometer** to measure airspeed. Soon after that, aircraft were equipped with **magnetic compasses** to measure heading, **angle of attack vanes** to measure attitude, **fuel-quantity gauges** to measure fuel levels, and so on. Yet in the early days, navigation was still done visually.

At the end of the 1920s, avionics had progressed so much, that the first blind flight and landing was performed: navigation was done solely based on **gyroscopes** and **radio navigation aids**. Over the 1930s, **radio navigation** and **landing aids** were further developed, and implemented on aircraft.

In the 1940s, the second world war started. This resulted in the development of **radar** for aircraft detection. Also, communication became more important. **VHF** and **UHF** communication was developed. But with all these systems, the pilot really had a hard time. The two decades after WW2 therefore mainly resulted in a reduction of the pilot workload. Systems like **autopilots**, **automated warning systems** and **integrated flight instruments** were developed. This was also the time where the **basic T** was implemented in aircraft.

The oil crisis of the 1970s changed the way of flying. Efficiency became an important topic. **Digital computers** were developed, aiding pilots in flying and navigating their airplane as efficiently as possible. Thanks to the development of **multi-function displays**, information could also be displayed in a much more flexible way. This resulted in so-called **glass cockpits**: cockpits with a lot of displays.

Today, glass cockpits are quite common. But we also have systems like **GPS navigation** and **digital communication links**. And many more advanced systems are yet to come. What will the future bring us? Only time will tell.

2 Pressure based systems

We can use pressure to measure things like altitude, vertical airspeed and airspeed itself. How do we do this?

2.1 Measuring altitude and vertical speed

Let's examine the **international standard atmosphere** (ISA). At **mean sea level** (MSL), we have $p_0 = 101325Pa$, $\rho_0 = 1.225kg/m^3$ and $T_0 = 288.15K$, $R = 287.05m^2/s^2K$. Up to a height of h = 11km (the **troposphere**), the temperature changes by by $\lambda = -6.5K/km$.

To calculate with this atmosphere, we define the **geopotential height** $H = \frac{g}{g_0}h$, with $g_0 = 9.81$. This implies that

$$\frac{p}{p_0} = \left(\frac{T}{T_0}\right)^{-\frac{g_0}{\lambda R}} = \left(1 + \frac{\lambda H}{T_0}\right)^{-\frac{g_0}{\lambda R}} \quad \text{or} \quad H = \frac{T_0}{\lambda} \left(\left(\frac{p}{p_0}\right)^{-\frac{\lambda R}{g_0}} - 1\right). \quad (2.1)$$

So, based on the pressure, we can find the **pressure altitude**. The pressure can simply be measured using an **aneroid**: a static air pressure meter.

It should be noted that the pressure altitude is not equal to the real attitude. So what's the use of using it? Well, the pressure altitude is mainly used for vertical separation of aircraft. During normal flight, all aircraft have set their altimeter to the ISA MSL pressure. (This is called **QNE**.) They may not know their exact altitude. But if they agree to fly on different pressure altitudes, collisions will at least be prevented.

But the pressure altitude can also be used during landing. Let's suppose that an aircraft comes close to an airport. The pilot then simply inserts the local pressure of the airport, converted to MSL, into his altimeter. (This is called **QNH**. The height at which the pilot does this – the **transition level** – differs per airport.) Now the pressure altitude approximately equals the actual altitude. So the pilot can use his altimeter for landing the airplane.

When we can measure height, we can also measure vertical speed. This time, we use a **variometer**, which measures pressure rates dp/dt. Based on this rate, we can find the vertical speed, using

$$\frac{dH}{dt} = -\frac{RT}{g_0 p} \frac{dp}{dt}.$$
(2.2)

2.2 Measuring airspeed

To measure the airspeed, we can use a **pitot tube**. This tube measures the difference between the **total pressure** p_t and the **static pressure** p. Bernoulli's law states that

$$p_t = p + q = p + \frac{1}{2}\rho V_t^2 \qquad \Rightarrow \qquad V_t = \sqrt{\frac{2(p_t - p)}{\rho}}.$$
 (2.3)

In this equation, q is the **dynamic pressure** and V_t is the **true airspeed** (TAS). However, we usually do not know the density ρ when we're flying. So, instead, we use ρ_0 as density. Of course, this does not give us the true airspeed V_t anymore. Instead, it gives us the **equivalent airspeed** (EAS) $V_e = V_t \sqrt{\rho/\rho_0}$. There's just one problem. The above method only works for incompressible flows. (So for roughly M < 0.3.) For higher velocities, we can use the isentropic relations to find that

$$p_t = p\left(1 + \left(\frac{\gamma - 1}{2}\right)M^2\right)^{\frac{\gamma}{\gamma - 1}} \qquad \text{or} \qquad M^2 = \frac{2}{\gamma - 1}\left(\left(\frac{p_t}{p}\right)^{\frac{\gamma - 1}{\gamma}} - 1\right). \tag{2.4}$$

In this equation, the Mach number M is defined such that $V_t = Ma$. a is the speed of sound and satisfies $a^2 = \gamma RT$.

Again, there's a problem. To find a, we need the **static air temperature** (SAT) T. One way to find it, is to measure the **total air temperature** (TAT) T_t . Then, we use the relation

$$T_t = T\left(1 + \frac{\gamma - 1}{2}\eta M^2\right). \tag{2.5}$$

In this equation, η is the **recovery factor**. (Theoretically, it's 1, but in real life, it's closer to 0.9.) However, in airplanes, usually another method is used. Instead of using the real speed of sound a, we use $a_0 = \sqrt{\gamma RT_0} = 340.3 m/s$. This gives us the **calibrated airspeed** (CAS) $V_c = Ma_0$. Again, V_c is not equal to V_t . But, for incompressible flows, we at least do have $V_c = V_e$.