AOE 2104 Introduction to Aerospace Engineering

1. Introduction

The three basic disciplines in aerospace engineering are: fluid dynamics, structures, and flight dynamics and control. This course will give you an introduction of each of these disciplines in the context of aircraft and spacecraft applications. However, prior to looking into any of these disciplines we will take a look at the original aircraft used for powered flight and see if we can think like the Wright brothers did in developing their design. Since you have little background in aerodynamics, structures, and flight mechanics, you are at the same level as the Wright brothers were when they started. Here we will take you through some of the ideas that the brothers thought were correct. Later we will see that everything is not as it appears.

1.1 History -Prior to Wright Brothers

Previous to Sir George Caley (1773 - 1857), powered flight was attempted by mimicking the flight of birds, by the flapping of wings (ornithopters). Caley, however, in 1799, managed to separate the concept of lift from the concept of propulsion, using a fixed wing to generate the lift, and a separate mechanism for generating propulsion (thrust). Caley had a wide variety of interests and invented the caterpillar tractor (tracked vehicle), was a member of Parliament, published papers on optics and railroad safety devices, and made a major contribution to aeronautics. He examined model helicopters that in turn led him to develop a whirling arm apparatus for testing lifting surfaces (or airfoils) and measuring the forces on these surfaces. Caley built a small glider that had a single wing and tail, a full size glider that had multi-wings and a tail, and finally, in 1853 flew the worlds first human-carrying glider (with Caley's coachman on board - who subsequently served notice) It should be noted that one of his designs (1852) included a wing incidence angle, and adjustable cruciform tail, a pilot operated elevator and rudder, a fuselage, a three wheel undercarriage., and finally a tubular beam and box beam construction - features not seen until the Wright brothers designs

The next real contributor to help develop powered flight was Otto Lilienthal (1848-1896) who designed the first controlled gliders in history. Lilienthal developed monoplane gliders that used cambered airfoil shapes, incorporated horizontal and vertical tail planes for stability, and that were controlled by shifting ones weight in much the same way as a hang glider pilot does nowadays. Lilienthal had the philosophy that one must get up in the air and fly around in order to get the feel of an airplane before an engine was attached. Unfortunately, Lilienthal was killed when his glider main wing stalled, and dove into the ground. This accident had a profound effect on the Wright brother's design.

In the United States, Octave Chanute (1832 - 1910) published a book *Progress in Flying Machines* (1984) where he gathered all the aeronautical information that he could find. Chanute designed hang gliders similar to Lilienthal's but improved on the structural rigging of the craft that the Wright brothers subsequently used in their vehicle.

The other contributor to the long process to develop powered flight was Samuel P. Langley (1834-1906), who developed and flew a powered model aircraft configured with two tandem wings. These models powered first with steam and then with gasoline, managed to fly over 3/4 of a mile. When expanded to a full size aircraft, the vehicle was launched with a man on board and subsequently crashed (twice) in the Potomac River. The likely culprit responsible for the crash was a structural failure. However, it is likely the vehicle would have had difficulty flying since the pilot had zero flight experience, and the vehicle had no real control.

1.2 The Wright Brothers Experiment

Wilbur (1867 - 1912) and Orville (Bubbo) (1871 - 1948) Wright started thinking about flight when they were 11 and 7 years old respectively when they received a helicopter-like toy that flew up to the ceiling. They built a number of copies of this toy and even tried to scale it up, but were unsuccessful. It was, however, the death of Otto Lilienthal that focused their attention and according to Orville, "We at once set to work to devise a more efficient means of maintaining the equilibrium." They wrote to the Smithsonian in the spring of 1899 and received information including documents by Chanute, Langley, and Lilienthal amongst others.

There were three key contribution that the Wright brothers made that allowed them to succeed in achieving powered flight:

1. They recognized that the most important problem was one of control - one had to be able to guide and steer the airplane and return it safely to earth.

2. They recognized the importance of integrating diverse technologies into a single successful airframe.

3 They recognized that in order to develop a successful airplane it must include progressive flight research and flight testing following an incremental path from theoretical understanding through ground-based research methods, early flight tests with sub-scale models, and finally flight with full-size piloted machines.

The four challenges that faced the brothers were:

1. Designing and building a suitable structure
2. Finding or building a powerplant
3. Ensuring it would generate sufficient lift
4. Providing some means for control

The first was "solved" by Chanute, the second was in the process of being solved by the introduction of the gasoline engine. The last two were the challenging problems to be solved. The two schools of approach were to emphasize power and lift (Langley) or emphasize soaring flight (Lilienthal and Chanute). The Wrights opted for the latter approach. The accident of Lilienthal made the brothers to reject the idea of moving the body for control and focused on moving surfaces for control The airplane must be controlled for climbing and descending flight, yawing, and rolling or banking, and combinations of these.

The longitudinal control or pitch control was provided by a “horizontal rudder” in the front of the plane operated through a lever by the pilot. The roll control was the most difficult and was finally done by warping the wings so that the lift would be different from the left to the right wing causing a roll. It was this development that allowed the aircraft to bank and turn. The brothers selected a forward control surface, what is now called a canard surface because they were concerned about the possibility of crashing due to a wing stall as happened to Lilienthal. By putting the smaller control surface in front, the small surface would stall first, and the nose would drop some but the wing would not stall and hence the aircraft would maintain lift, and fall in a controlled fashion to the earth. In addition, in the event of a crash, the forward structure acted as a shock absorber, protecting the pilot. All these properties of the canard are good. However, there is one significantly bad side effect of a canard, the problem of stability. The Wright brothers did not appreciate the concept of stability and consequently developed an unstable aircraft. This fact, in itself is not a “show stopper” since the brothers also learned to fly canard configured gliders and could correct for the instabilities.

Continued experiments on their gliders led them to conclude that most of the aerodynamic data that they had received from previous investigators was wrong, the lift being generated was less than 1/2 that predicted by the data. It was during this 1901 flight that the vehicle pitched up and crashed, but in a controlled manner, (as the canard design hoped for) that prevented injury of the pilot and little damage to the vehicle. In addition to the lack of lift, the brothers also found that the wing warping for bank control was acting strangely, the vehicle would turn as expected, and then reverse itself. In addition, around this time the brothers found their glider, flown as a kite, behaved well when flown backward. However because of the fear of a Lilienthal type accident they still opted to keep the canard configuration.

As a result of the discrepancy of the data, the brothers set out to do some systematic wind tunnel tests (they designed and built their own wind tunnel along with the measuring devices) to determine the true properties of various shaped lifting surfaces. Subsequently the new data was used to design new wings. The 1902 gilder had a wing with twice the aspect ratio of the 1901 glider. Eventually they discovered that by making the vertical tail, a movable rudder, the turn reversal and subsequent spiral into the ground could be controlled. With these changes, the 1902 glider was flown 375 flights in 6 days, gliding up to 622 feet at a time.

The following year they added an engine (they built) and a propeller that they designed with the understanding that a propeller is a wing that spins. The rest is history. Wilbur took the first flight and over controlled the horizontal rudder and landed 60 feet down range and broke a few elevator supports. After rebuilding, Orville flew it to 100 feet in 12 seconds. The successful flight was the culmination of some hard work and down to earth engineering.

1.2 Units, Dimensions, and Conversions

In order to evaluate and discuss terms used in aerospace engineering it is necessary that discuss the issue of units and dimensions. These ideas are fundamental for all analysis and must be understood in order to obtain qualitative results. In all problems, units and dimensions must be consistent.

Dimensions: Dimensions are qualitative in nature and designate a type of unit, not related in any way to a value. In this course we will use four fundamental dimensions:

[M]	mass
[L]	length
[T]	time
[θ]	temperature

such a system is usually called MLT system of dimensions. Note that the dimension [F] force ***is not included***. The force dimension can be derived from the three MLT dimensions using Newton's second law:

$$F = ma$$
$$[F] = [M][L\,T^{-2}] = [MLT^{-2}] \tag{1}$$

For example, we can express pressure, Force/unit area with the following dimensions:

$$[P] = [FL^{-2}] = [MLT^{-2}L^{-2}] = [ML^{-1}T^{-2}]$$

(Note; It is possible to build a system on the units FLT with M being the derived one. However that system will not be use here. The one use here is considered the more fundamental system)

Units: Units are qualitative in nature and will reflect a specific amount. There are several systems of units, but we will be concerned with only two: The US Customary and The Systeme International (SI). Unfortunately both are frequently used, with the US system primarily used in the US, and the SI system used throughout the world and in the US. The units and dimensions associated with these systems is given below:

Dimension	US	SI
[M]	slug (slug)	kilogram (kg)
[L]	foot (ft)	meter (m)
[T]	second (sec)	second (s)
[θ]	deg Rankine (deg Fahrenheit)+459.688)	deg Kelvin (deg Centigrade+273.16)
[F] (derivable)	pound (lb)	Newton (N)

Clearly, from Newton's second law:

$$1\ \text{lb} = 1\ \text{slug} \cdot 1\ \text{ft/sec}^2 \qquad\qquad 1\ \text{N} = 1\ \text{kg} \cdot 1\ \text{m/s}^2$$

These are called ***proper units*** since the force is directly related to the mass and acceleration, without any proportionality factors. Note that under no circumstances does the mass unit lb_m appear anywhere. It is not a proper unit and will not appear in the US or SI system of units!

Since we will deal with both sets of units, we need conversion factors and constants.

Constants:

Constant	US	SI
Perfect Gas Constant R	$1716.488 \dfrac{\text{ft lb}}{\text{slug °R}}$	$287.074 \dfrac{\text{Joules}}{\text{kg °K}}$
Gravitational Constant g_0	$32.174 \dfrac{\text{ft}}{\text{sec}^2}$	$9.807 \dfrac{m}{s^2}$

Conversions:

1 ft	=	0.3048 m	Units of length
1 ft^2	=	0.0929 m^2	Units of area
1 slug/ft^3	=	515.379 kg/m^3	Units of density
1 ft-lb	=	1.3558 Nm (Joules)	Units of energy

1 lb	=	4.4482 N	Units of force
1 slug	=	14.5939 kg	Units of density
1 HP	=	745.6999 Watts	Units of power
1 lb/ft^2	=	47.88026 N/m^2 (Pascal)	Units of Pressure
1 ft^3	=	0.02832 m^3	Units of Volume

In addition to the fundamental units, we often get information in terms of nautical miles and knots. The conversions for these (non-fundamental units) are:

		US		SI	
1 nautical mile	=	6076.1 ft	=	1852.0 m	
1 nautical mile/hour	=	1 knot			
1 knot	=	1.6878 ft/sec	=	0.5144 m/s	= 1.1508 miles/hour

These last values can be calculated from the basic unit relations given previously:

$$\frac{1\text{ nautical mile}}{\text{hr}} \cdot \frac{1\text{ hr}}{3600\text{ sec}} \cdot \frac{6076.1\text{ ft}}{1\text{ nautical mile}} = 1.6878\,\frac{\text{ft}}{\text{sec}}$$

and

$$1.6878\frac{\text{ft}}{\text{sec}} \cdot \frac{1852.0\text{ m}}{6076.1\text{ ft}} = 0.5144\text{ m/s}$$