AIAA AEROSPACE MICRO-LESSON

Easily digestible Aerospace Principles revealed for K-12 Students and Educators. These lessons will be sent on a bi-weekly basis and allow grade-level focused learning. - AIAA STEM K-12 Committee.

AVIATION ODDITIES

Most of us have a clear idea of what an airplane looks like; the word conjures up images of airliners and fighter jets, or perhaps old-fashioned biplanes and general aviation stalwarts like Cessna Skyhawks and Piper Cherokees. These planes all share generally similar layouts: long, relatively slender fuselages, wings mounted on the left and right sides, and stabilizers (vertical and horizontal fins) mounted at the tail. This has been the "standard" configuration for aircraft for over a hundred years (probably dating back to Glenn Curtiss' "Headless Pusher," one of the first aircraft to go into production), but over the years there have been a dizzying variety of different configurations for airplanes, ranging from the unexpected to the downright bizarre.

Next Generation Science Standards (NGSS):
* Discipline: Engineering, technology, and applications of science.
* Crosscutting Concept: Structure and function.
* Science & Engineering Practice: Constructing explanations and designing solutions.

GRADES K-2

NGSS: Engineering Design: Ask questions, make observations, and gather information about a situation people want to change to define a simple problem that can be solved through the development of a new or improved object or tool.

What does an airplane need in order to fly? First, it needs enough lift to counteract its weight and keep it in the air. Then it needs some means to keep its front end pointing forward. Finally, it needs something to hold everything together so that it does not fall apart. If an airplane is designed for a specific mission purpose (like carrying passengers or doing science experiments), it needs to fulfill that purpose as well. How it accomplishes these things is left as an exercise for the designer. Over the years, designers have been very creative in their solutions to these problems.

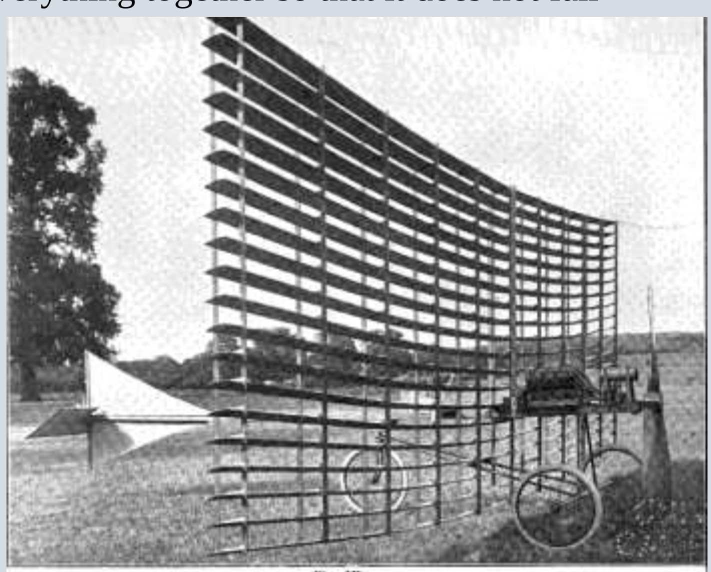


Fig. IV.

In the early days of flight, before the invention or discovery of relatively strong and lightweight metals, the strength of the

GRADES K-2 (CONTINUED)

material connecting the wings to the fuselage was a limiting factor. One way around this limitation was to use more than one pair of wings. Many early airplanes were biplanes, with one pair of wings above the other, or triplanes, with three pairs of wings stacked one over the other. Using multiple wings distributed the total amount of load which each wing had to carry, making the job of designing an effective structure much easier. Some early experimental airplanes took this idea to an extreme, as you can see in the picture to the previous page—and this is not the most extreme example! As you'd imagine, these outlandish designs were not very successful–they produced a lot more drag, and the air flowing around the closely-stacked wings often caused each one to interfere with its neighbors. An easy way to demonstrate this is to look at an old triplane compared to a monoplane (single-winged plane) of the same era. Which one looks like it would go faster? This is a bit simplistic, but it's a useful exercise; most people have some instinctive sense of what is fast (aerodynamically efficient) and what is slow (high drag).

These effects are not so noticeable when there are only two wings, so biplanes and triplanes can still fly quite well. Triplanes became obsolete during the first world war, as they simply created too much air resistance to fly fast enough to keep up with newer planes, but biplanes were used commonly throughout World War Two (though only in a training role by war's end), and are still very popular today for recreational flying. Biplanes are often popular for aerobatic flight displays at airshows because their short, stubby wings make them quite maneuverable.

GRADES 3-5

NGSS: Engineering Design: Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.

Why do aircraft designers sometimes pursue highly unconventional designs? The reasons, unsurprisingly, are often quite complicated–and sometimes engineers with different needs can end up with similarly unusual aircraft. For example, consider the P-38 Lightning, a successful long-range fighter airplane during the Second World War. The P-38 was one of the earliest examples of a twin-boom design, with a small nacelle suspended between two long, skinny fuselages. The pilot would sit in the central nacelle, with the two engines mounted in the outer booms. The aircraft's designers at the Lockheed Corporation, Hall

GRADES 3-5 (CONTINUED)

Hibbard and Kelly Johnson, selected this unorthodox layout because it allowed them to minimize drag: the slender booms provided just enough space to fit two engines with superchargers and the small cockpit nacelle gave the aircraft a sleek overall profile and a relatively low weight. For these reasons, the P-38 became the first fighter aircraft to reach 650 kph (400 mph) in level flight.

Another interesting example of a twin-boom airplane is the White Knight, designed by legendary aeronautical engineer Burt Rutan. The White Knight, much like the P-38 Lightning, has long, spindly boom fuselages and a shorter nacelle suspended in the middle of the wing. However, in this case, the impetus for the design was not speed but space: the unusual design of the aircraft created plenty of room for the White Knight to carry its cargo, the pioneering spaceplane SpaceShipOne.

Another fascinating example of convergent designs is the so-called "flying wing". These airplanes look like nothing else, because they are exactly as the name describes–simply a wing, with no fuselage or tail surfaces. Engineers in both the United States and Germany researched flying wings during the Second World War, but it was not until decades later that a flying wing design was put into construction. Poetically named, the first (and to date, only) flying wing design to enter significant production was the B-2 "Spirit," built by Northrop, the company founded by Jack Northrop—America's original flying wing pioneer during World War II. The Northrop engineers were drawn to the flying wing design because of its incredibly low radar cross section; its single surface makes it very easy to hide from enemy radar.

Other flying wing designs to leave the drawing board in recent decades include the Pathfinder/Centurion/Helios series of unmanned, solar-powered aircraft. You may note that these aircraft have small protrusions on the underside of the wing, but these are mostly there to store batteries and payloads and to hold the wheels. These research vehicles were built to test the mechanics of long-duration solar flight in the upper atmosphere, so clearly the designers weren't worried about radar cross-section. In fact, they chose the flying wing configuration because in theory, it offers the highest possible aerodynamic performance for an airplane due to its extremely low drag.

These are just two examples of something which crops up quite often in engineering: designs which, for a variety of related and unrelated reasons, converge somewhat to give similar final products.

GRADES 6-8

NGSS: Engineering Design: Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

In their quest to build flying machines, people have tried some very funny-looking designs. There have been all kinds of peculiar examples, but perhaps nothing has seen as much experimentation as the most fundamental part of a plane–the wing. The air flowing around the wings creates the lift force that keeps the airplane up. Most airplanes have two wings, one on the left and one on the right. Slow airplanes usually have wings that stick out straight. Airplanes which need to fly more quickly usually have the wings angled back; most passenger jets and military airplanes have wings like this. Airplanes which need to fly very quickly usually have wings that are swept back even further–in fact, they are swept so far back that they are usually shaped like a triangle which extends all the way to the back of the plane; this is called a "delta wing," named after the Greek capital letter "delta." A great example of this is the F-106 Delta Dart, but you can see similar wing shapes on the SR-71 "Blackbird" and the Space Shuttle. This variation in wing shapes is dictated by the laws of aerodynamics: as planes start to travel faster and faster, they need these specialized wing shapes to help them slice through the air efficiently.

But this does not exhaust the possibilities for wing shapes. In 1934, an inventor named Steven Nemeth unveiled the "Parasol," an airplane with a circular wing. (The link also has videos of two other aircraft with circular wings, the "Flying Pancake" and the "Avrocar.") In the 1970s, NASA experimented with a wing that was shaped like a horizontal "X." This wing was actually added to an airplane that already had its own wings and tail; the purpose of the X-wing was to measure how the air would flow around it. With radio-controlled model airplanes, one can get even more creative!

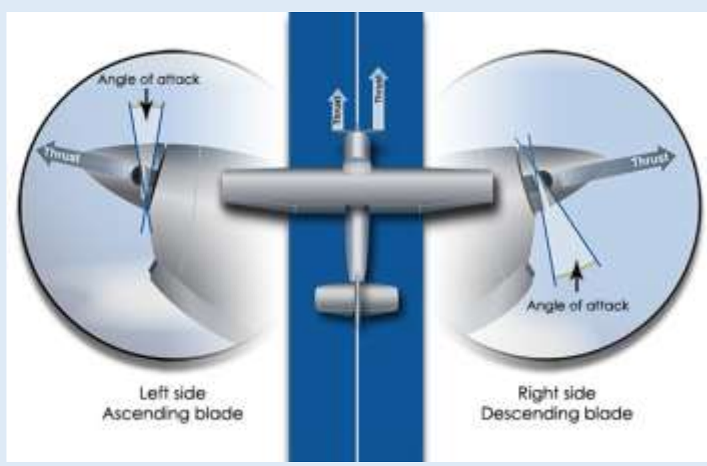
GRADES 6-8 (CONTINUED)

There are many different shapes of wings that will allow an airplane to fly. The bigger question is: will they allow the airplane to fly well? Or, even better: what advantages does an airplane gain from having an unconventional wing? For most applications, the advantages of a specialized wing are outweighed by the negatives. Some wings produce too much drag, some are unstable, and others are simply too expensive and too complicated to produce. However, some designs which used to be impractical have become more feasible as our ability to manufacture complicated shapes has increased. A great example is the forward-swept wing. While the technology was studied during the second world war and found to be relatively impractical because it is unstable, modern computers and high-tech composite materials allowed NASA to fly successful prototypes in the 1980s and early 1990s.

GRADES 9-12

NGSS: Engineering Design: Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

You've *probably* never designed an airplane, but if you did, you would probably try to keep it symmetric – i.e. the same on the left and the right. You might imagine that symmetry helps to keep an airplane moving straight forward, but the reality is not quite so simple. A single propeller on the nose of an airplane will cause the air passing through it to spin, going upward on one side and downward on the other. This creates asymmetrical loads on the wings and tail, which gives the plane a natural turning tendency. The torque needed to turn the propeller will also tend to roll the airplane in the opposite direction. In addition, the propeller itself produces a turning tendency because as the aircraft climbs or descends, one blade of the propeller is always meeting the oncoming air at a steeper angle than the other (you can see this for yourself based on the geometry of the plane when viewed from the side, as shown in the diagram to the right). Since propellers are basically spinning wings, this blade produces more thrust, resulting in the plane trying to turn left as it climbs and right as it



GRADES 9-12 (CONTINUED)

descends – this effect is known by pilots as "P-factor". To compensate for these tendencies, many aircraft are designed with some degree of asymmetry. One slightly extreme example is the Macchi Folgore (an Italian fighter aircraft from the second world war), which had a left wing 20 cm longer than its right for that very reason.

In the 1930s, the German airplane designer Richard Vogt designed the BV-141 reconnaissance aircraft. "Reconnaissance" is another word for "spying" and allowing the crew to look in many different directions, especially downward, was a major consideration. The BV-141 had a crew nacelle to the right of the midpoint of the wing, an engine nacelle to the left of the midpoint, and a very asymmetrical tail mounted behind the engine.

In the 1990s, Burt Rutan (already well known for his unconventional aircraft designs such as the Voyager–another twin-boom aircraft like those discussed above–and scores of aircraft designed for recreational home builders) designed an asymmetric twin-engined airplane called the Boomerang. His first concern in designing the airplane was safety: how will the airplane fly if one engine fails? With a symmetric airplane, there is suddenly a lot of unbalanced drag on one side (from the failed engine) and extra thrust on the other side (because the airplane needs to keep its airspeed up). The Boomerang can lose an engine and not suffer as great a consequence.

While asymmetric aircraft like these look somewhat unnatural to us, it's fairly easy to estimate their design parameters using the basic physics of moments. To a first approximation, each wing produces a lift force that acts roughly in the middle of the wing and each nacelle/fuselage produces a weight force that acts at its center of mass. For extra realism, we can even include some amount of torque produced by the engine(s). If we sum the moments produced by each of these elements, we can figure out what length each wing has to be to balance an asymmetric layout of fuselage elements (i.e. create a net moment of zero about the aircraft's roll axis).

Sixty Years Ago in the Space Race:

April 5: The United States Air Force successfully launched an Atlas ICBM from Cape Canaveral. The missile flew 600 miles downrange.

April 14: After four months in orbit, the Soviet Sputnik II spacecraft re-entered the Earth's atmosphere and burned up.