In the Name of God

Aircraft Structural Analysis

Ref. Books

- Aircraft Structures for Engineers - Vinay K. Goyal, 2012
- An Introduction to Aircraft Structural Analysis-T. H. G. Megson, 2010
- Mechanics of Aircraft Structures- C. T. Sun, 1998
- Introduction to the Theory of Thin-Walled Structures, Noel W. Murray, 1986

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Chapter 1: Learning about Aircraft Structures

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Instructional Objectives of Chapter 1

After completing this chapter, the reader should be able to:

1. Understand how aerospace structures have evolved with history.

2. Identify the main aerodynamic loads acting on airplanes.

3. Explain the major structural components of an aircraft and understand their function(s).

4. Understand the use of semi-monocoque structures in modern aircraft.

History of Aviation

Man has always wanted to overcome the challenges to move through air, water and ground. When man succeeded to travel through water and on ground, he dreamed to soar with the birds.

These dreams caused accidents due to structural failures. Icarus, from the Greek mythology, is famous for his death caused when the sun melt the wax holding his artificial wings together. Years later, inventors such as Leonardo Da Vinci, John Stringfellow, and Lawrence Hargrave designed intriguing flying machines long before the Wright brothers' famous flight at Kitty Hawk.

Pre-Wright Era: Early Aviation

- The first type of aircraft was a kite. It was designed in China during the fifth century by Mozi and Lu Ban. These first kites were made with silk using bamboo as the framework.

- During the thirteenth century, Roger Bacon, famous Franciscan friars, concluded that air could support a craft just like water supports boats.

- In June of 1783, in Annonay (France), the Montgoler brothers (Joseph and Jacques), were the first to succeed in launching a human to air. Their design consisted in a hot air balloon made of silk and lined with paper to trap the gas, called the Montgolere.

The 19th Century

- Lawrence Hargrave designed a box kite in 1893, followed by Alexander Graham Bell who experimented with box kites and wings built of multiple compound tetrahedral kites covered in silk (1907-1912).
- Jean Marie Le Bris designed a glider with movable wings.
- The greatest impact, during the ninth century, to the aviation industry was the integration of motors to aircraft.
- John Stringfellow designed a steam engine powered aircraft.
- Lawrence Hargrave designed a rigid-wing aircraft with fapping blades operated by compressed-air motor and the rotary engine, which powered many early aircraft up until about 1920.

Era of Strut-and-Wire Biplanes: 1900 to World War I

- The first heavier-than-air machine powered flight took place on December 17, 1903 (10:35am). It was the famous Wright Bothers, Orville and Wilbur, first flight.

Their mayor breakthrough was the invention of the “three axis-control”, which enabled the pilot to steer the aircraft effectively and maintain its equilibrium.

- On July 4, 1908, Glenn H. Curtiss flew the “June Bug” 5090 ft in 1 minute and 42.5 seconds.

- During the World War I, began the development of huge biplane bombers with two to four engines.

Before World War II

- In 1919, Captain E. F. White made a nonstop flight from Chicago to New York.
- In 1923, Lieutenants Oakley Kelly and John A. Macready made the first nonstop transcontinental flight from Roosevelt Field, Long Island to Rockwell Field.
- In 1924, Douglas World Cruiser was developed for the U.S. Army Air Service for an attempt to make the first flight around the world.
- One of the most successful designs during this period, was the Douglas DC-3 which became the first airliner to exclusively carry passengers, starting the modern era of passenger airline service.

Era of Propeller-Driven Airplane: During World War II

By the beginning of World War II, many towns and cities had built airports, and there were numerous qualified pilots. The war brought many innovations to aviation such as the first jet aircraft and the first liquid-fueled rockets. The largest operator of all international airlines in operation was Pan American Airways, serving 46 countries and colonies. Before World War II, only about 193,000 people were employed in the aviation industry; and after 1941, the number increased to almost 450,000.

Era of Jet-Propelled Airplane: After World War II until end of 20th Century

- In August of 1939, the Heinkel He 178 became the world's first aircraft to fly under turbojet power, thus becoming the first practical jet plane. The first operational turbojet aircraft, the Messerschmitt Me 262 and the Gloster Meteor, entered service towards the end of World War II in 1944.
- Civilian aircraft orders drastically increased from 6,844 in 1941 to 40,000 by the end of 1945. One of the minor military contractors was the Boeing Company who later became the largest aircraft manufacturer in the world. New aerodynamic designs, metals, and power plants would result in high-speed turbojet airplanes. These planes would later be able to y supersonically and make transoceanic flights regularly.

Design Philosophy

1. SAFE LIFE: Consists in designing each part for minimum weight and yet assuring they will last for a long time.

2. FAIL SAFE: Consists in designing the aircraft's components in such a coordination that if one unit fails, the other units will take on the load. In other words, the overall airframe (structure) is designed so that failure in one component doesn't cause the whole aircraft to fall apart.

Development of Aircraft Structures

Early aircraft were built from very lightweight materials such as bamboo, wood, and fabric. They design was similar to bridges, with beam and truss structures. As for an example, the wings on the Wright Flyer formed a truss: the two wings used wires and bars diagonally (at an angle) to strengthen the wing against aerodynamic forces.

In general, inside the wings we had truss structures. The bars inside were called spars. The wires used on the diagonals strengthened the wing. The spars, plus the spar caps at each end, were shaped to give the wing aerodynamic features. This shape is often called the airfoil.

Design

- As technology has grown, so have the manufacturing techniques. Hence, in the early twentieth century, metal rods and pieces began to replace the wooden components. Metal skins, rolled very thin were weather-resistant as opposed to the fabric skins. The ribs and spars of the plane were made by riveting many pieces together. When aluminum alloys became available at the end of the 1920's, ribs and spars were often stamped (cut) out of whole aluminum sheets.
- At first, when the aircraft flew, the wood or metal frame took all of the stress. The fabric or thin metal skin could not withstand any of the load. Later, thicker metal skin was put on airplane frames. This thicker skin was able to share the stress. The metal frame could then be made of lighter metal. Hence, the aircraft's final weight was lighter!
- Nowadays, aircraft industry is moving towards developing aircraft with even materials that are even lighter such as composite materials. In fact, the design work continues in the field of aircraft structures for a better balance of weight and strength.

Loads Acting on an Aircraft