**Introduction**

The design and development of structural components used in airplanes is a multi-stage iterative process. Often, the key issues are knowledge of the design as well as the property requirements, identification and selection of materials that are likely to meet the requirements, optimization of processing and composition methods to achieve consistent quality of the desired products, and the service durability and economic sustainability of the finished components (Wanhill). An aircraft is comprised of several parts and components. Some of the major components in an aircraft include fuselage, wings, empennage, aircraft frames, landing gear, and power plant. Beyond these basic parts, an aircraft also has sub-parts that play a key role in ensuring that the airplane can fly. These are several other systems that play a significant role in ensuring that the plane is not only operating safely but also the passengers are comfortable. The major materials that have been used in aircraft structures include wood, steel, titanium alloys, aluminum alloys, and fiber reinforced composite. In this paper, the material of focus is aluminum.

**Properties of Materials for Aircraft Structure**

The selection of materials used for structural components is one of the most important factors that determine the successful development of an aircraft. The materials selected for structural applications are exposed to various environmental conditions such as loads, temperatures, and humidity. Additionally, the materials are exposed to different mechanical solicitations which include torsion, tension, bending, compression, creep, and cyclical forces. Presently, there are several materials to choose for the design of aircraft structures. However, choosing the best material among the many alternatives is not an easy task due to the number of variables involved.

The choice of material is influenced by the cost involved. Overall, the ultimate idea is to ensure that the materials chosen can meet the critical conditions that will face the airplane in the years of service. Poor selection of materials may result in challenges in the operation of an aircraft. Selection of a heavy material means that the aircraft will not fly or that it will be able to fly but carry only less additional weight. Selection of weak materials means the airplane cannot withstand the forces applied to the structures. This will cause the failure of the parts and endangers the passengers. These are just some of the few factors that need a careful balance when selecting materials that are to be used to produce various structures in an aircraft.

The physical properties that are critical for the materials used in aerospace applications are the coefficient of thermal expansion, specific gravity (density), and the elastic modulus. Often, density and elastic modulus are the primary physical properties. The density and elastic modulus of material are usually prime considerations for the structural efficiency of an airplane (Wanhill). Extensive analysis as shown that weight savings associated with low density outweigh all other improvements in the properties as shown in Figure 1.

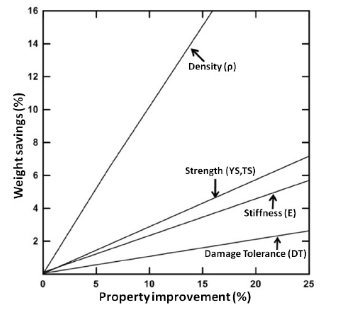


Figure 1Impacts of potential property on potential weight savings (Wanhill).

In an aircraft, the most important properties for the design of structural parts are weight and strength with good stability in environmental conditions. The idea is to select a lightweight but strong material that is capable of operating in corrosive environments. For the reasons mentioned earlier, the properties of materials that are considered for structural applications in aircraft design are ultimate stress, yield stress, temperature limits, stiffness (modulus of elasticity), fatigue resistance, corrosion resistance, fabrication, and ductility. Other properties include fragility at low temperatures, maintainability, crack growth resistance, and reliability. The minimum weighs possible is the single most important factor in the design of an aircraft. Any material that meets the minimum requirements in other properties is selected so long as it is the lightest.

**Problems Facing the Airplane Structure Materials**

To understand the problems facing the aircraft materials, it is important to understand the various parts of an aircraft and the constraints that need to overcome in those areas. The material that needs to be selected for every structure has to overcome the constraints imposed on the structure. One of the most important constraints in an aircraft structure is the loading. Various structures in the plane are subjected to different types of loading. The structural integrity of every structure in an airplane is therefore measured by its ability to withstand the loading subjected to it. If a structure does not support the loading imposed on it, the structure will fail, and it can lead to severe consequences such as loss of assets and lives. As mentioned previously, some of the major components/structures in an aircraft are fuselage, wings, landing gears, engine parts, engine blades (fan, turbine, and compressor), combustion chambers, and cryogenic pressure vessels. All these structures are subjected to different kinds of loadings. Therefore, one of the key design constraints in these parts is loading.

Airplane fuselage is subjected to different types of loading. Some of the major types of loading subjected to the fuselage include fatigue, bending, tension, compression, and bending (Wanhill). The fuselage is supposed to be capable of working under these loadings without failure. The corresponding design constraints for the various loadings are buckling (compression), strength (tension), deflection (bending), and damage tolerance (fatigue). Loadings and the corresponding design constraints for an aircraft wing include bending (buckling), tension (strength), twist (deflection), and vibration (vibration), fatigue (damage tolerance). For the landing gears, the types of loadings, as well as constraints, are similar to those experienced in the fuselage: compression (buckling), tension (strength), bending (deflection), and fatigue (damage tolerance). Engine discs are subjected to two types of loading: rotation and thermo-mechanical fatigue. The constraint for rotation is strength and ductility, while that for thermo-mechanical fatigue is low cycle fatigue. For the engine blades, some of the loadings that the material need to withstand and the corresponding constraints are bending (deflection), tension (strength), creep (vibration), thermal fatigue (temperature), and fatigue (microstructural stability). The combustion chambers have pressure and noise loadings with the corresponding constraints being thermal oxidation. Therefore, a material that has to be used in the combustion chamber has to withstand not only elevated temperatures but also the corrosive environment.

Aluminum is not used for structural applications in the aerospace industry in its pure form. While aluminum is usually considered for aircraft applications due to its superior properties as compared with other materials, it is usually in the form of an alloy. Pure aluminum is not ideal for structural applications due to its poor mechanical properties. Aluminum alloys have been popular materials for aircraft applications since the 1920s. Presently, there is a wide variety of aluminum alloys that are used for airframe structures. However, even within the alloys themselves, some exhibit superior properties than others. When one property of aluminum is improved, one or more properties are also sacrificed. This leads to different properties. For instance, 2024 aluminum alloy has lower ultimate stress as compared with 7075 in the aged condition. However, the 2024 alloy display superior fatigue properties. It is for this reason that 7075 is often selected for applications in the upper part of the aircraft structures, while 2024 is applied for the lower surface. This is because for the lower parts of the aircraft fatigue properties are very important as there are a lot of tensile loads subjected to it.

**Tests for Materials used in Aircraft Structures**

Materials used for the design of aircraft structures are not picked at random. Rather, they are selected carefully while considering a lot of factors. Basically, an aircraft will not fly if it is too heavy. Therefore, one of the most basic requirements for the material is to be of lightweight or low density. However, beyond the factor of density, there are also several other engineering requirements that the materials must meet for acceptance in the design of structures. Consequently, the materials that need to be chosen have to undergo a series of tests to determine the most appropriate one. To understand the tests that are performed in materials used in aerospace applications, it is necessary to examine the types of loadings that the structural components are subjected to. The structural components of an aircraft are usually subjected to four major kinds of loadings: tension, bending, torsion, and compression. Besides the tests associated with loading, there are also other critical tests. A material that meets mechanical properties may not be selected if, for example, it corrodes very fast. Corrosion is a major issue in structures as it has a major impact on the structural integrity of the systems, sub-parts, or major components of an aircraft. Another important test that need to be carried out is the thermal property. A material selected for structural applications need to tolerate temperatures. Again, temperature has an impact on the mechanical properties of a material. For instance, a material that usually has a high tensile strength at a certain temperature may become low if the material is exposed to elevated temperature.

Tension tests are also known as the tensile test. The principle behind the tensile test is Hooke’s law. That is, the elongation of material is associated with the applied force. Tension or tensile test is one of the most common tests performed in engineering materials. It is used to determine the strength of a material and how far it can stretch before it fails. It is a form of destructive test carried out in engineering materials. In this test, the sample of the material to be tested is subjected to tension. The load causing tension in the material is gradually increased until the material fails. The maximum load the material withstand before it fails used to calculate the tensile stress of the material. Materials with high tensile stress are selected for structural applications. Tension test is one of the most useful tests for materials used to design engineering structures as it can be used to determine material’s yield strength, ductility, strain hardening properties, ultimate tensile strength, Poisson’s ratio, and Young’s modulus.

Deflection tests are used to determine the degree of bending in a material subjected to some loads. Deflection tests are also known as flexural tests. They are conducted by placing a length of a material to be tested across a span. This is then followed by pushing down the material to bend it until it fails. Bending tests are used to determine various properties of engineering material. In the case of engineering structures, bending tests are used to determine the elastic modulus of bending, flexural strain, and flexural stress of a material (Khan-1). There are two types of bending very popular tests include 3-point and 4-point bending. In a 3-point bending test, the material to be tested is placed across a span supported on both ends and bringing down a point source the midpoint of the span and bending the test specimen until it fails. While bending the material, a record of the applied force (load) and the crosshead displacement are recorded. 4-point bending tests are carried out in a similar way to the 3-point bending. However, instead of the one-point source being placed to the midpoint of the span, two points slightly separated from the midpoint of the material are placed in contact with the specimen to be tested.

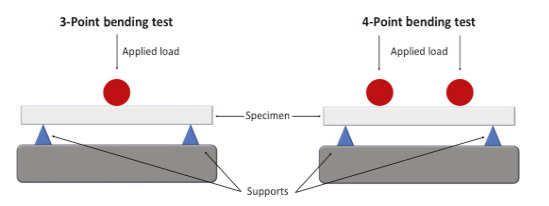


Figure 2. 3-Pont and 4-point bending test (Khan)

Torsion Tests. This type of testing is done by twisting a sample along an axis. It is one of the most useful tests for obtaining information of specimens such as maximum torque, torsional shear stress, breaking angle of material, and shear modulus (Khan-2). Usually, a longitudinal sample of the specimen to be tested is positioned in a torsion tester, and one of the ends is subjected to twisting loads around its long axis until it fails. During the process of twisting, the force and the angular displacement are recorded. Torsional tests are usually carried out for materials that may be subjected to torsional forces or loads.

Compression tests are usually performed to determine the behavior of engineering materials when subjected to compressive loads. The test specimen is loaded between two plates. Force is then applied to the specimen by moving the crossheads together. During the compression test, the applied load versus the deformation achieved is recorded. Compression tests have been used to determine various properties of a material such as a yield point, proportional limit, elastic limit, compression strength, and yield strength (Materials Evaluation and Engineering).

**Fatigue and Corrosion in Aircraft Structures**

In materials, science fatigue has been described as a situation where materials become weakened when they are subjected to cyclic loading. Often, fatigue occurs when there is structural damage that is not only progressive but also localized. Fatigue usually leads to the formation of cracks. There are several areas of an aircraft that are subjected to fatigue. As a result, such structures need to be constructed from materials with high fatigue strength. Corrosion is a chemical process that can lead to weakening and failure of engineering structures. It is therefore desired that materials that are used to design aircraft structures are carrion-resistant. Pure aluminum is corrosion resistant, and it is usually applied to the skin of its alloys to protect them from corrosion. There is a link between corrosion and fatigue failure in engineering components. Corrosion of part subjected to cyclic loads may lead to the initiation and propagation of cracks leading to fatigue failure.

**Types of Aluminum used in aircraft Structures**

Although there are several grades of aluminum and its alloys, not all of them are used in the design of aircraft structures. Often, the idea is to select a material that is lightweight or low density, corrosion-resistant, and strong. Pure aluminum is ideal when it comes to the issue of density and corrosion-resistance but fails in strength. Therefore, aluminum alloys are often selected for applications in the design of engineering structures for aircraft. in aircraft construction, the most popular aluminum alloys are 2024-T3, 6061-T6, 5052-H32, 3003-H14, and 7075 (Experimental Aircraft Info). The difference in grades is a result of the variation in the composition of alloying elements.

**References**

Wanhill, R. J. H. "Physical Property Significances for Aerospace Structural Materials." Aerospace Materials and Material Technologies. Springer, Singapore, 2017. 143-157.

Experimental Aircraft Info. ‘Aluminum Properties.’ Accessed 17 February 2020. https://www.experimentalaircraft.info/articles/aircraft-aluminum.php.

Khan, Yusuf. ‘Bending Tests.’ https://www.sciencedirect.com/topics/engineering/bending-tests. Accessed 17 February 2020.

Khan, Yusuf. ‘Torsion Testing.’ https://www.sciencedirect.com/topics/engineering/torsion-testing. Accessed 17 February 2020.

Materials Evaluation and Engineering. ‘Tension and Compression Testing.’ https://www.mee-inc.com/hamm/tension-and-compression-testing/. Accessed 17 February 2020.