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A Review: Aeronautical Components and Systems Should have their Weight Reduced throughout the Design Process

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Abstract— *Lightweight requires cutting-edge materials and imaginative engineering to achieve the same or better technical performance with less material. This approach has been widely used in automobiles, fashion, and packaging, and the aviation sector may benefit from it. Traditional lightweight methods have used high-performance materials like composites, structural optimization using computationally-aided engineering, and cutting-edge manufacturing processes including additive manufacturing, foam metals, and hot forming. This article will examine the most prevalent lightweight technologies and their possible usage in aviation, such as power plants and airframe components. Solar-powered aircraft wings require improvement and are open to lightweight technology. High aspect ratios cause non-linear distortion, aileron reversal, flutter, and rigid-elastic coupling. Lightweight aircraft, UAVs, and rocket subsystems are all being considered. Cutting-edge optimization methods may optimize structural elements and geometrical parameters for optimum structural stiffness, least mass, and energy storage. Additive manufacturing may create composite or multi-material components that can serve several purposes.*

Keywords*— *High-Frequency Structure, Lightweight Design, Aerospace Industry

I. INTRODUCTION

Lightweight design, especially in airplanes, is connected to green aviation. Aviation's role in climate change and environmental deterioration has spurred emission reduction efforts. The World Civil Aviation Organization has set a goal to reduce emissions from aviation by half by the year 2050. Solar energy and improved energy efficiency seem to be two paths for accomplishing this objective. It may be possible to conserve fuel and cut down on pollution if an airplane's size is decreased. The Boeing 787 improved its fuel economy by 10–12% after shedding 20% of its original weight. A design that is less in weight produces fewer greenhouse gas emissions while also improving acceleration, structural rigidity, and cost. A solar-powered unmanned aerial vehicle (UAV) with its low weight-optimized to its full potential might result in the creation of environmentally friendly aircraft. Solar-powered unmanned aerial vehicles (UAVs) have lower energy densities and less rigid wings. There are several requirements that must be satisfied by ultralight aircraft, including a low specific weight (less than 115 kg) and then a restricted fuel capacity (19 L). A lightweight structure improves performance and flight time. Rocket design requires lightweight. (Miracle, 2019)

II. OBJECTIVE

The research aimed to fulfill the following objectives:

- To study the Materials selection for the aerospace industry
- A Conventional numerical and computer-aided structural optimization
- The Advanced metal forming

III. METHODOLOGY

The lightweight design assumes fewer, lighter materials may deliver the same or better technical outputs. Modern materials on quantitatively optimized structures made utilizing acceptable manufacturing techniques are used to achieve a lightweight design in aviation components and systems. Modern lightweight materials reduce weight and increase efficiency. Composite materials compete with aluminum alloys in many innovative aviation applications, although metals, especially aluminum alloys, still dominate aerospace utilization. Structural optimization, which strategically places features to reduce material consumption and improve structural performance including strength, stiffness, and vibration damping, may help lighten a structure. Optimizing structures usually involves dimensions, forms, and topologies. Lattice structures provide multiscale optimization. Manufacturing limits material and structural optimization. Additive manufacturing, foam metal, and improved metal forming have increased multi-scale structural optimization adaptability.

IV. MATERIALS SELECTION FOR THE AEROSPACE INDUSTRY

Choosing the correct aircraft materials is critical throughout component and system development. From design through disposal, It has an effect on several aspects of an aircraft, including its structural efficiency, flying performance, capacity, energy consumption, safety and dependability, lifetime cost, recyclability, and disability. Materials used in the construction of aerospace structures are required to have specific properties, including high levels of strength, stiffness, exhaustion endurance, as well as damage tolerance; low densities; high levels of thermal stability; high levels of resistance to corrosion and oxidation; and commercial characteristics such as cost, service, and production. Aerospace architectural engineering has to find ways to boost structural efficiency in order to keep pace with the need for lighter aircraft constructions. Enhancements are made in areas such as energy efficiency, agility, payload, flight duration, and total life cycle cost, including greenhouse gas emissions. Thus, aircraft structural design must increase structural efficiency to meet basic service requirements. Studies have found that lowering a building's density improves structural efficiency the greatest. Use lightweight materials. (Williams et al., 2019)

Commercial aircraft use aluminum alloys, titanium alloys, high-strength steels, and composites for structural components. These parts comprise 90% of an airplane's bulk. From the 1920s through the late 19th century, aircraft airframes were nearly entirely composed of metal, with aluminum alloy being the most preferred owing to its strength and stiffness. Passenger safety and flying performance drove airplane design. Before 2000, most civil aircraft airframes were built of light aluminum alloys, which are still used today. High-performance composites developed in the 1960s and 1970s are used to make more aeronautical constructions.

- ***Aerospace-grade metals***

Examples of the distribution of different aluminum alloys used in the construction of numerous typical Boeing aircraft show that aluminum alloys are still widely used in aerospace, despite the increasing popularity of higher-performance composites like carbon fiber. Due to their cheap price, high dependability, outstanding manufacturability, strong ductility, and corrosion resistance, advanced aluminum alloys are favored for many lightweight aircraft structural applications including, but not limited to, the skin of the fuselage, the upper and the lower wing skins, and the wing stringers. Despite the rise in popularity of sophisticated composites in this aerospace industry, high-strength aluminum alloys that have been made possible by improvements in techniques of heat treatment are still viable alternatives. Aluminum alloys may offer a varied set of properties if they are chemically changed and thermally treated to fulfill the needs of a broad number of applications. This may be accomplished via the use of thermal processing. Al-Cu (2xxx sequence), Al-Zn (7xxx sequence), and Al-Li are three of the most frequent types of aluminum alloys used in aeronautical applications. (Liu et al., 2021)

- ***Titanium-rich metals***

Titanium alloys have excellent specific strength (Beta C titanium alloy has a specific strength of ca. 260 kNm/kg, which is around 3 times something like Co-Mo steel 4130 and 1.27 times that of high-strength aluminum alloy 7075-T6), stiffness, fracture toughness, fatigue resistance, as well as corrosion resistance. Titanium alloys are superior to steel and aluminum alloys in a number of ways, making them a great choice for aircraft frames as well as power plants. Titanium alloys have a broad range of potential applications, but they are seldom employed due to their high price and low manufacturability (often about seven times more than conventional Al alloys). Titanium alloys are very versatile thanks to their high strength as well as resistance to corrosion. Today, titanium alloys are primarily used in the aircraft industry for airframes as well as engine components (which account for 7% as well as 36% of the industry in terms of overall weight, respectively).

- ***Heavy-duty metal construction***

Steel's low cost compared to other commercial aerospace materials, ease of production, broad availability, steel's tremendous strength, and rigidity make it a popular structural material. While high-strength steels have been well suited for aircraft construction, they are not commonly employed due to their restrictions. Their high density and sensitivity to corrosion as well as embrittlement are only two of these issues. Steels make up between 5 and 15 percent of a commercial jet's load capacity, and that number has been going down for quite some time. High-strength steels have drawbacks, yet they are nonetheless used in applications that need extreme strength and stiffness, such as life-saving devices. Gearing, bearings [5a], as well as undercarriage components are some of the most prevalent uses of high-strength steel in the aerospace industry.

- ***Aircraft composites***

Fiber-reinforced polymers (FRPs) and fiber metal laminates (FMLs) are two examples of high-performance composites being evaluated for use in aircraft alongside aluminum alloys and other ground-breaking lightweight aerospace materials. Aerospace composites outperform most metals in terms of specific strength and specific stiffness at moderate temperatures (about 150 to 200 °C). The mechanical properties of several commercially available carbon-reinforced polymers are compared. One of the numerous advantages of composites is that they may have their lay-ups modified to provide optimal strength and rigidity in the required directions, along with developing resistance to fatigue, corrosion, and moisture. A key barrier to the widespread use of composites is their greater price in comparison to metals. According to research (Kim & Chang, 2020)

Aside from aluminum alloys, carbon fiber-reinforced polymer (CFRP) is probably the most common structural material for aircraft. The wings, empennage, and fuselage, in addition to the control surfaces, are all constructed mostly from carbon fiber reinforced (CFRP) (e.g. rudder, elevator, and ailerons). Semi-structural parts like fairings and often make use of glass-fiber-reinforced polymer (GFRP). Aramid fiber polymers are often employed in situations calling for material with great impact resistance. Better mechanical qualities than monolithic metals make composites like glass fiber reinforced aluminum (GLARE) and fiber metal laminates (FML) popular in the aircraft industry (particularly in the Airbus A380). Typical GLARE sites include the outside skin of both the fuselage and also the tail portion, often known as the empennage.

- ***Aspects of materials used in aviation***

When designing an aircraft system, it's important to weigh a variety of factors, such as price, safety, and compliance with regulations, before settling on a final material. Loading, temperature, humidity, corrosion, and noise are all factors to think about while designing a system or component. Example stressors that wings face throughout service include fatigue, bending, strain, torsion, vibration, and vibration. For wings, the main constraints are characteristics such as elasticity, tensile strength, compressive strength, buckling strength, as well as vibration modes are all important for wing structures. Combustion chambers are very high-pressure environments that need materials with exceptional heat stability and oxidation resistance. Materials with several constituent parts that work together to form a whole, composites like carbon fiber reinforced polymers (CFRPs) as well as glass fiber reinforced epoxy resins (GLARE), offer much superior specific strength and stiffness than metals, making them a suitable candidate for lightweight design in many aircraft components and systems. However, numerous aviation applications still make use of metals due to their low price, vast availability, and ease of manufacture. (Summe, 2019)

V. CONVENTIONAL NUMERICAL AND COMPUTER-AIDED STRUCTURAL OPTIMIZATION

Optimizing the structure of a product or component is often done to improve its functionality in some way, whether it is by increasing its strength, stiffness, and vibration performance; decreasing its weight, peak stress, and displacement; or cutting its cost. Analytical optimization, the traditional method of optimization, often depends on the intuition and knowledge of the engineers based on trial findings and, as a consequence, a design may take considerable study and time to obtain the desired results.

Recent advances in computer-aided engineering and finite element analysis provide new ways to optimize structures. Every iteration of the design process involves the creation of a roughly optimized model using numerical structural optimization. When it comes time to develop the next approximate model, the design solution from the previous approximation optimization is utilized to revise the finite element model and conduct a comprehensive system analysis. Repeated iterations of the design process are used until an optimal solution is found. (Williams et al., 2019)

Conventional numerical structural optimization

Traditional numerical structural optimization techniques are often broken down into three distinct groups: size/shape optimization, shape/topology optimization, and topology optimization.

Adjusting for optimal proportions: The best dimensions of a structure may be found by several techniques, but the most basic of them is sizing optimization. Depending on the specifics of the design, the thickness, breadth, and length of the goals are all viable options. The section characteristics of a particular component are adjusted to achieve a desired stress, displacement, or other criterion value.

The term "shape optimization" refers to the process of maximizing a structure's usefulness by adjusting its external borders and internal hole shapes. By shifting the placement of grids, it may be utilized to create any desired form for the building's exterior. Connectivity within the structure is not altered in any way throughout this optimization procedure. (Kim & Chang, 2020)

To find the optimal distribution as well as arrangement of components in a given design space, engineers employ a technique called topology optimization, which is a kind of structural optimization. Topology optimization enables a wide variety of topological changes, such as modifying the shape of the structure and the density of its holes. The concept behind topology optimization is to transform the optimization issue into a material demand problem with the use of a characteristics function that takes on the values 1 and 0 in the material and void domains, respectively.

SIMP (solid isotropic material with penalization), BESO (bidirectional evolutionary structural optimization), GAs (genetic algorithms), as well as LSTs (local search techniques) are only few of the structural optimization methods available (level set methods).

Studies on Real-World Optimization Problems: Aerospace engineering, automotive, lighter weight bicycle design, engineering, etc. have all benefited greatly from the use of numerical structural optimization. Natural lightweight structures served as inspiration for the topology optimization technique used in the creation of the Alfred-Wegener-design Foundation's lightweight bionic bicycle, which reduced the weight of the bike by 60%, and the collaborate of Zhu et al., who made available Airbus with a model of even a topology-optimized engine bracket that could be cast from an optimized main wing box rib. (Liu et al., 2021)

The Advanced metal forming

Metal forming plays a critical role in the production of metal sheet components. Intricate geometries may make it difficult to develop lightweight metals like aluminum alloys and titanium alloys at ambient temperature and now after the structure has been optimized. Technologies for metal shaping have been created to render metals more malleable, allowing for the creation of complex optimized structures. (2019)

The solution high temperature, forming, and then in quenching (HFQ) technique is a modern approach to metal forming that improves the material's formability and the component's mechanical characteristics. The precipitates are dissolved into the material matrix by heating the sheet to its solution heat therapy (SHT) temperature and holding it there for an extended period of time. Here, we use a method called the HFQ® procedure. SHT is so effective because it produces a homogeneous microstructure, which greatly enhances ductility. Quenching and shaping occur simultaneously when the material is passed through a series of cold dies. After rapid cooling, a supersaturated solid solution (SSSS) forms, and its consistent microstructure is preserved. Once the material has been artificially aged, it is heated above its aging temperature and reaps the benefits of the precipitates' strengthening capabilities. In conclusion, the HFQ® technique has the potential to considerably enhance the material's formability, allowing for the formation of intricate components with much less spring back as well as distortion. It has been successfully used in high-strength steel and aluminum alloys. Using HFQ® technology, for instance, AA7075 was stamped into a complex vehicle beam all in one go. Alternate processing methods provide significant challenges when attempting to produce complex AA7075 components. (2019) A True Miracle

When traditional forming procedures are unable to provide the desired result, superplastic formation (SPF) is employed to construct the necessary components or processes. Granules must be very small and spherical, with a grain diameter of around 5 m, for superplastic deformation to occur. In addition, diffusion can only occur at temperatures higher than half the melting point. Its extreme ductility in this condition is shown by the fact that the sample length may be extended by more than 200%. Deformation may aid static dispersion processes, which dominate grain development under these circumstances. A material's sensitivity to strain rate and, by extension, its elongation at failure, are both reduced due to grain formation. In two-phase systems, such as titanium alloys (e.g. Ti6Al4V), the presence of a phase with a low diffusivity, such as the alpha phase, serves to suppress development of the beta phase, which has a greater diffusion coefficient and hence prevents excessive grain expansion. Thermoforming, blow formation, vacuum forming, and other methods are among the several that may be used to create SPF. The primary benefit of SPF is that it permits the manufacture of complex-shaped elements with little spring back and residual stresses. The primary downsides of this technology, however, are its poor processing speed and high energy requirements. (Krishnadas Nair, 2019)

VI. CONCLUSION

Lightweighting boosts efficiency and performance. Aircraft components and system design use this concept. Advanced lightweight materials and numerical structural optimization enable lightweight design with sophisticated production processes. Over a century, metals, especially aluminum alloys, have been aircraft materials. Metals are strong, rigid, damage-tolerant, fracture-resistant, and manufactural, making them good structural materials. Metal processing and raw materials make it inexpensive. New heat treatment and metal processing methods may optimize aeronautical components and systems employing lightweight Al-Li and TiAl alloys. Aeronautical composites challenge metals. Metals are heavier than composites, yet composites are stronger and stiffer. CFRPs, the most common aerospace composites, have up to three times the stiffness and more than five times the strength of aluminum alloys. Nanocomposites excel. Composites are costlier and less manufactural than metals, restricting their application. Structural optimization optimizes material distribution to minimize weight and improve aerospace component and system strength, stiffness, and vibration. Structural optimization includes size, form, and topology. Computers optimize software. Multi-scale lattice structure optimization may optimize weight and performance. Numerous variables complicate numerical optimization. Numerical optimization requires efficient algorithms. Manufacturability limits material and structural optimization. Additive manufacturing, foam metal processing, and advanced metal forming provide both processes additional versatility by allowing them to make materials with poor manufacturability and intricate structural geometries. Additive manufacturing and foam metal methods still struggle with production time, cost, standardization, and process.

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