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Optimization of Aircraft Engine Bracket Design through Material Selection and Structural Analysis

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A B S T R A C T :

This study aims to enhance the structural fatigue life of an aircraft engine bracket by optimizing its design, dimensions, and material composition. The primary objectives include reducing stress concentrations and displacements while minimizing material usage, thereby lowering production costs and resource expenditure. A comprehensive finite element analysis (FEA) was conducted using MSC Patran and Nastran, complemented by fatigue life calculations. The results demonstrate significant improvements in performance through parametric redesign and material substitution, validating the proposed methodology for aerospace applications.

Keywords: fatigue,air craft,engine,MSC Patran and Nastran

1. INTRODUCTION

Overview of Aircraft

Aircraft Overview

Aerodynamic principles underpin an aircraft's operation, which is reinforced by buoyancy and dynamic forces acting on its surfaces. Aerodynamic loads, fuel weight, crew, and cargo must all be supported by the airframe, which includes the fuselage, wings, empennage, and landing gear. Thrust, drag, lift, and gravity are important forces. During flight, control surfaces (rudder, elevators, and ailerons) regulate roll, pitch, and yaw.

Principle of Aircraft Operation

The fundamental ideas behind the aircraft's operation are Newton's laws of motion and Bernoulli's theorem, which address air motion and the forces acting on a body moving in relation to that air. A device that generates thrust to move an item forward is called a propulsion system. Thrust is often produced on airplanes by utilizing Newton's law of action and reaction. The engine accelerates a gas, or working fluid, and the engine experiences a force as a result of the response to this acceleration.

1.2 The Principles of Aerodynamics

Newton's principles of motion and Bernoulli's theorem are essential to aircraft operation. Newton's third law, which states that accelerating a working fluid (such as air) creates reactive force, is how propulsion systems create thrust. Rockets deliver fuel and oxidizer, but air-breathing engines use ambient oxygen.

Aircraft Parts

The airframe of an aircraft consists of the following major units:

1. Fuselage
2. Wings
3. Stabilizers
4. Flight controls surfaces
5. Landing gear
6. Empennage

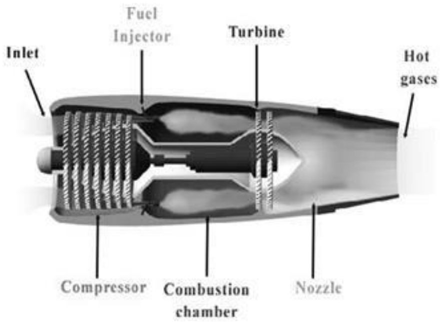
The fuselage is the main structure that houses the crew, systems, and cargo. Designs include monocoque/semi-monocoque shells (for load distribution via stressed skin) and welded trusses (for stiffness).

2. Wings: Produce lift and support heavy loads. made with metal skin, ribs, and spars.
3. Landing Gear: Cushions during taxiing or landing. Systems with struts, shock absorbers, and wheels are among the fixed and retractable varieties.
4. Empennage: The part of the tail that controls pitch and yaw (rudder, elevator, vertical and horizontal stabilizers).

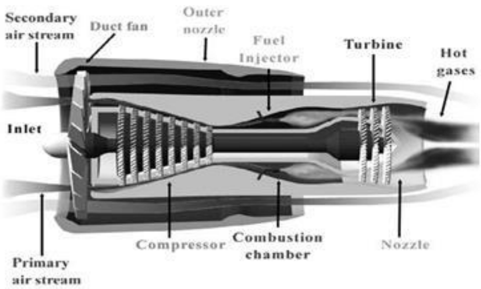
2. Aircraft Engines and Additive Manufacturing

2.1 Types of Engines

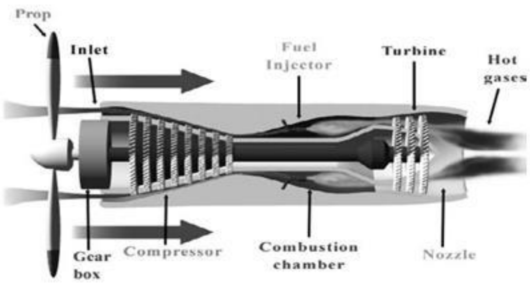
Internal combustion uses a piston-driven crankshaft, or Otto cycle, to transform fuel into mechanical energy.
Engines that use turbines: Core thrust, or turbojets



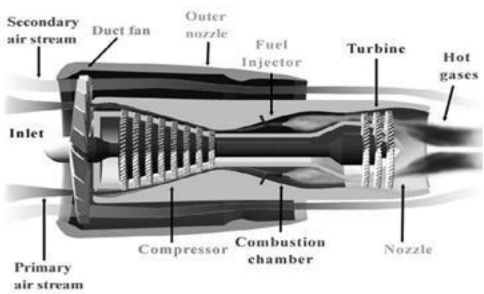
turbofans (bypass air for efficiency)



turboprops (propeller-driven)



and afterburning turbojets (supersonic applications)



2.2 AM, or Additive Manufacturing

AM uses digital models to manufacture components layer by layer, allowing for complicated geometries with little waste. Fuel nozzles, brackets, and turbine blades are examples of aircraft applications. Principal advantages:
Efficiency of Materials: ≈2 is the buy-to-fly ratio (compared to 15–20 for CNC).
Materials: stainless steel, Co-Cr-Mo, Ni/Al alloys, and Ti-6Al-4V.
Controlling the quality of powder for essential components is a challenge.

3. Design and Optimization of Brackets

In engines, wings, and landing gear, brackets hold hydraulic and electrical cables in place. Structural integrity is at risk of failure. Design specifications:

3.2 Resources

Alloys made of steel, titanium, and aluminum.

3.3 CAD-Based Optimization Tool: Parametric redesign using CATIA V5.

Procedure:

1. A non-parametric STEP file was imported.

2. Reverse-engineered with Generative Shape Design and Part Design.

3. For dimensional control, positioning drawings and axis systems were used.

4. Produce a FEA-optimized 3D model.

4. Analysis of Finite Element (FEA)

4.1 Approach

Software: Nastran (solver), MSC Patran (pre-processing).

Element Types: 2D (plates), 3D (solids), and 1D (beams).

Material Models: homogeneous, isotropic, linear elastic.

Materials Examined: 2024-T3 Aluminum

Ti-6Al-4V

Stainless Steel 5-5PH

1. Vertical: downhill 35,586 N.

2. Lateral force is horizontal.

3. Combined loading at 42° from vertical.

4.3 Mesh

280,218 tetrahedral components made up the original model.

147,000 tetrahedral components (45% decrease) make up the optimized model*.

5. Analysis of Fatigue

5.1 Conceptual Structure

There are three types of fractures: tensile, shear, and tearing.

Stress amplitude (S_{eq}) controls fatigue life (N_f).

The HCF is more than 10\sup>5</sup>. elastic deformation; cycles.

Low-Cycle Fatigue (LCF): strain-life models and plastic deformation.

S-N curves: Connect cycles of stress to failure.

5.2 Aluminum 2024-T3 Calculations

The original vertical model was N_f = 4.83 × 10^{. 11}

Horizontal: 2.13 × 10^{= N_f 15}

42° N_f = 3.53 × 10<sup> is the load. 13.

Vertical: N_f = 2.77 × 10^{is the optimized model. 5}

Horizontal: 3.19 × 10^{= N_f 6}

42° N_f = 7.40 × 10^{is the load. 6}

6.1 Displacement and Stress

Optimized Design: Maximum stress was decreased by 25–30% for all materials.

Material Performance: The best strength-to-weight ratio was provided by aluminum.

Titanium has the least displacement because to its high rigidity.

6.2 Fatigue Life

In their original forms, all materials showed enhanced lifetimes, with aluminum topping 10⁵ cycles (HCF regime).

Design Specifications for Brackets

Throughout the aircraft's lifespan, the brackets must be made to avoid damaging the system, structure, or insulating brackets. They must weigh as little as feasible, which will lower the aircraft's total weight and result in indirect cost savings. Brackets are made to function as intended within the aircraft's operating temperature. The brackets' special characteristic is that they can be quickly and easily installed by a single technician, saving a ton of time during both assembly and disassembly.

Low Cycle Fatigue (LCF):

The component can withstand intense application loads and has a life of fewer than 100,000 cycles. The material behavior in the net section will be mostly plastic if the highest stress level in a cycle is higher than the yield strength. There won't be many cycles until failure. Typically, the fatigue behavior is described using a strain-life curve rather than the S-N curve. that the degree of plasticity in the net section, or the stress level, defines the true difference between HCF and LCF rather than a certain number of cycles.

Infinite Life:

The stress level, sometimes referred to as the endurance limit or fatigue limit, below which a material never fails. The terms "never fails" and "infinite life" are relative. For steel, the test is stopped after 2*106 cycles (if failure is not found before then) and is considered to have an endless lifespan. The slop of the S-N curve changes at this point and aligns with the x-axis.

Non-ferrous alloys do not have a definite endurance limit, in contrast to steel, as the S-N curve never becomes parallel to the x-axis. Numerous variables, including surface conditions, corrosion, temperature, residual stresses, geometry (stress concentration factor Kt), mean stress (stress ratio), and others, affect the fatigue limit level.

DIFFERENT FATIGUE LIFE PHASES

A slip band inside a grain is where the crack first appears. Cycled shear stress causes cyclic slip, which results in the production of slip steps. When oxygen is present, the newly exposed surface of the material in the slip steps oxidizes, preventing slide reversal. on this instance, the slip reversal takes place on a nearby slip plane, causing extrusions and intrusions to appear on the material's surface.

Beginning of a Crack (Ni)

This is how many cycles are needed to start a crack. During this time, fatigue is a material surface phenomena since it usually arises from dislocation pile-ups and flaws such surface roughness, voids, scratches, etc.

Crack Growth (Np)

which is often regulated by stress level, is the number of cycles needed to expand the crack steadily to a critical size. The most researched component of fatigue is the prediction of fracture propagation since most common materials have faults. As a bulk attribute, fracture development resistance is dependent on the material when the crack enters it. The phenomena is no longer surface-level. An significant component in predicting the increase of weariness is the level of stress.

Quick fracture

When the crack length reaches a critical number, the critical crack grows extremely quickly. The fatigue life expression does not include a rapid fracture phrase since rapid fracture happens soon.

The main component for quick fracture prediction or fracture-resistant design is the material's fracture toughness KIC.

7. Conclusion

An essential structural component for the engine's correct operation is the engine mount bracket. The mounting bracket has undergone a number of evaluations to verify its stability and strength under various engine and supporting structure loadings. The 2024-T3 aluminum alloy, titanium 6AL-4V, and 15-5PH (H1025) stainless steel were among the materials used in the study. The goal is to investigate the bracket's strength and fatigue life as the material and shape vary. According to the research and analysis, the bracket's life is more than 105 cycles in three load scenarios (horizontal, vertical, and angle of 420 from vertical) using three different materials.

By comparing of mechanical properties, cost and applications,Aluminium is better than all other two materials.In future studies I am planning to produce my final optimized model and conduct live experiments to understand the quality and stability of the bracket. As is well known, engine parts need to be composed of the majority of heat-resistant metals since they generate higher temperatures. I'm expanding this research for a potential future use in thermo-structural analysis.

RESOURCES

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