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Bizjet engine cowling weight optimization

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Abstract

Commercial aviation has evolved as the fastest, safest and most expansive mode of transportation, crucial for meeting the demands of a growing economy and population. However, alongside this rapid growth, the aviation industry is a significant contributor to global warming and environmental pollution. To address this issue, several steps have been taken over the past few decades to mitigate the environmental impact by reducing noise and decreasing fuel consumption per flight.

A key strategy every aircraft manufacturer employs is reducing the weight of its aircraft. This decreases fuel consumption and CO2 emissions and results in subsequent cost savings for the airliner, amounting to millions of dollars over each aircraft's lifetime. Weight reduction of aircraft components can be achieved by various methods, such as adopting alternate materials and optimizing the designs.

This paper outlines the best practices in design and analysis aimed at optimizing the weight of aircraft engine cowling structures, contributing to the goal of substantial aviation.

Introduction

An aircraft structure is essential for providing strength and rigidity while meeting all its design requirements. However, excess structural weight increases the cost of manufacturing for the airframer and reduces the efficiency/range of the aircraft for its operator (airliner). Achieving an optimal structural weight is imperative as it translates to an increase in the aircraft's payload capacity, often making the difference between a profitable airliner and a failure.

This paper presents in detail the best design and analyses approaches used in weight optimization of aircraft engine cowling structure. Typically, engine cowling structure features a round or elliptical profile for smooth wind flow, minimizing aerodynamic drag.

A few characteristics of the aircraft engine cowling design are:

- Lightweight structure subjected to severe environment
- Very expensive in terms of product development and production
- Meets several design requirements, such as:
    - Performance
    - Structural
    - Airworthiness

Objective

This paper aims to identify the diverse opportunities for weight reduction within existing aircraft engine cowling structures, validate the optimized design through virtual simulation and achieve significant weight savings.

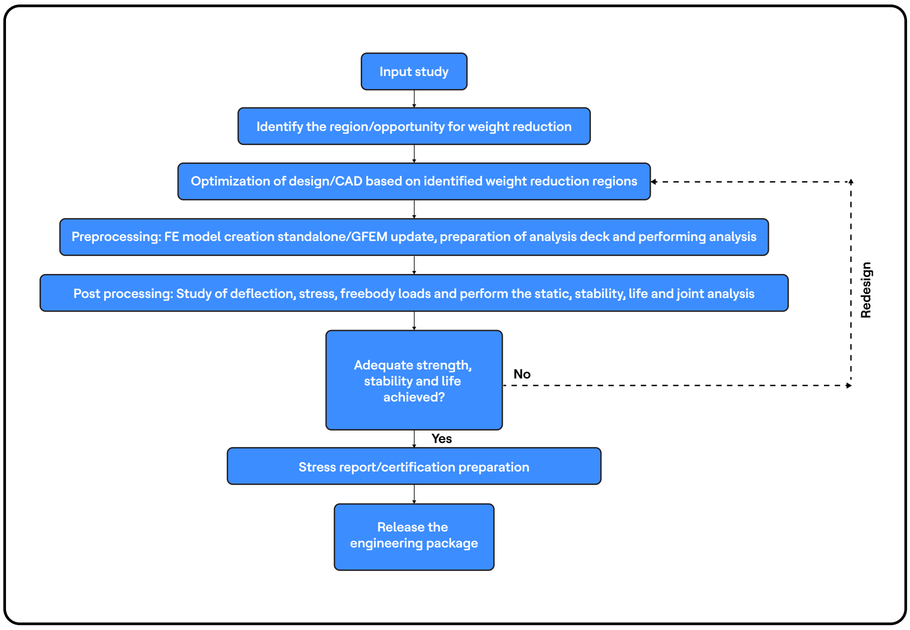
Challenges

For performing the weight optimization of an aircraft structure, multiple challenges must be faced, including:

- Drive toward maximum weight reduction with no or minimal cost impact
- Changes cannot deviate the current defined load path
- Changes must conform to the current part envelope/boundaries
- No change in existing material to avoid logistic and supply chain issues
- Effect of the optimization on the surrounding structure
- Manufacturing and assembly feasibility of the proposed design

Solution

Aircraft structural weight optimization is performed by identifying the weight reduction opportunities in several components of the aircraft engine cowling structure. The following flow diagram depicts the weight optimization cycle.



- Review the components by analyzing the existing design, strength and durability criteria
- Identify and list the potential components that provide weight reduction opportunities based on review
- Perform various applicable design modifications for the identified components, including:
    - Thickness reduction
    - Edge distance reduction
    - Scalloping
    - Web cutouts
    - Casting conversion
    - Fastener count reduction
- Validate the optimized design by virtual simulation with appropriate boundary conditions and loads using various CAE software like MSC Nastran.

Design best practices

Best practices considered for design modifications are given below.

- **Thickness reduction**

The manufacturer decides the thickness and tolerances based on the procurement and machining capability. Table 1 shows the minimum thickness considered for aluminum and titanium materials as well as the machining tolerance for this activity.

Table 1: Material thickness and tolerances

Material	Manufacturing process	Minimum thickness (in)	Machining tolerance (in)
Aluminum	Machined	0.05	+/-0.01
Titanium	Machined	Flat Face - 0.060 Curvature - 0.080	+/-0.01
Aluminum	Casting	0.04	+/-0.03

The following guidelines must be followed while reducing the thickness of the components.

- As per AC No: 20-135, for the components that fall under fire zones, the following minimum thickness materials must be considered acceptable for use in firewalls or shrouds for non-structural/non-load-carrying applications, without being subjected to additional fire tests.
- Stainless steel sheet, 0.015 inches thick
- Mild steel sheet protected against corrosion, 0.018 inches thick
- Titanium sheet, 0.016 inches thick
- Monel metal sheet, 0.018 inches thick
- Steel or copper-base alloy firewall fittings/fasteners

Note: Distortion of the thin sheet materials and the subsequent gapping at lap joints or between rivets is difficult to predict. Therefore, testing the simulated installation is necessary to prove the integrity of the design. However, the rivet pitches of two inches or less on non-load- carrying titanium firewalls of 0.020 inches or steel firewalls of 0.018 inches are acceptable without further testing.

- Step requirement: Thickness reduction must not exceed one-third of the original thickness. If the thickness reduction needs to be greater than one-third of the original thickness, several steps with a maximum of one-third of the original thickness should be considered.
- Minimum bend radius for all sheet metal parts must be equal to the thickness of the respective part.
- For thickness reduction, the mating face of the component is kept unchanged, and reduction in thickness must be performed on the free face of the component to avoid assembly issues.
- If the reduced thickness is less than the fastener's grip length, a boss should be provided to maintain it.
- Edge distance reduction

The minimum edge distance criteria subject to reparability at joint regions are shown in Table 2.

Table 2: Edge distance criteria

Edge distance at free edge	Edge distance at fillet edge
Minimum edge distance of 1.5D + tolerance	Sheet metal parts - 1D to 1.5D Machined parts - 1D

Where D is the diameter of the fastener

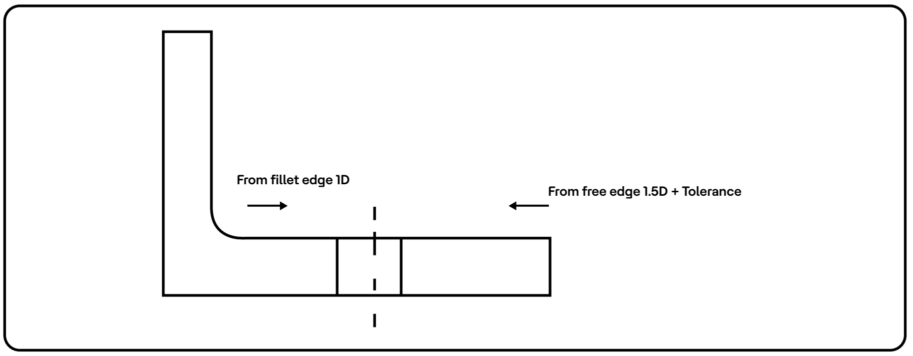


Figure 1: Edge distance reduction

- **Scalloping**

  Scalloping is done between fasteners, as shown in Figure 2.

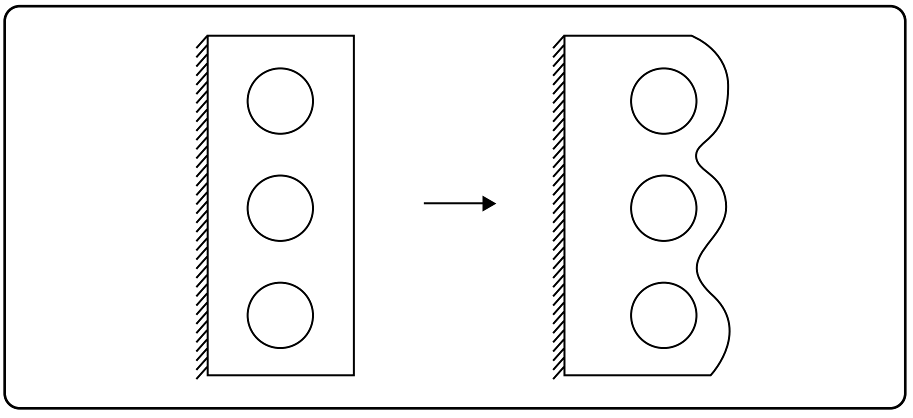


Figure 2: Scalloping

- **Web cutouts**

  Web cutouts are created or enlarged by maintaining the minimum edge distance of 1.5D+ tolerance, as shown in Figure 3.

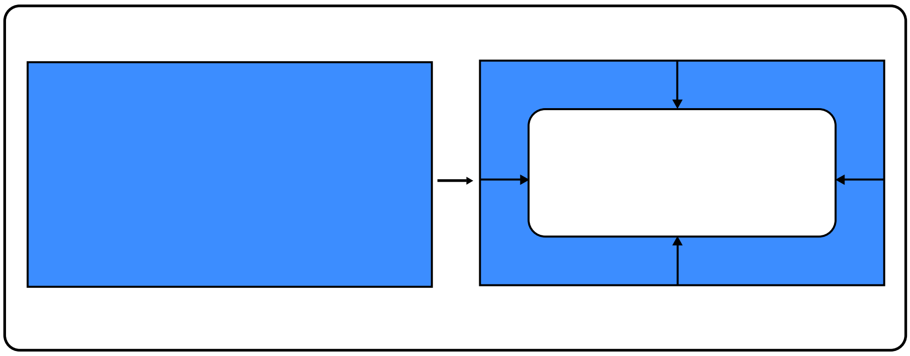


Figure 3: Web cutouts

  - A minimum fillet radius of 0.06 inches should be considered for all edge fillets.

Analysis best practices

Stress analysis best practices include:

- **The thickness to be considered for analysis of machined parts is shown below:**

  - For nominal thickness < 0.08 inch

    Analysis thickness = Nominal thickness - machining tolerance + 10% nominal thickness.

    e.g., for nominal thickness = 0.06 inch for machined aluminum

    Analysis thickness = 0.06 – 0.01 + 10% * 0.06 = 0.056 inch

  - For a nominal thickness ≥ 0.08 inches, analysis thickness considered same as nominal thickness.

    e.g., for nominal thickness of 0.09 inches of titanium, analysis thickness considered is 0.09 inches.

    Note: For minimum thickness and machining tolerances, refer to Table 1.

- **Fastener stiffness calculation**

  CBUSH stiffness for fasteners is calculated using the Huth method instead of very high stiffness (the default), which makes joints stiffer.

- **Appropriate boundary condition**

  Simulations are performed with isostatic boundary conditions. Redundant boundary conditions are removed to simulate the realistic behavior.

- **Advanced nonlinear Finite Element (FE) methods (SOL 400):**

  With the help of the advanced nonlinear FE method, the prediction of stresses is more realistic in the plastic region, especially when analyzing ultimate loads such as fan blade-off conditions where local plasticity is acceptable without detrimental failure.

- **For SOL 105 stability analysis, best practices, such as those listed below, can be considered. These analyze the lean structure by removing conservatism.**

  - Remove the z-offset from the shell and beam elements.
    Linear buckling analysis has the offset restriction because the offset vectors remain parallel to their original orientation when computing the differential stiffness. Specifying offset vectors produces incorrect results.

  - High CGAP rotational stiffness was included; otherwise, negligible CGAP rotational stiffness gives very high displacements, which are unrealistic and generate incorrect eigenvalues.

  - The MSC default value for PARAM MAXRATIO causes diagonal ratio issues. Hence, the 1.0e7 PARAM MAXRATIO value is used to resolve this issue.

  - Parameter K6ROT 100 provides sufficient rotational stiffness in the z-direction of shell elements to suppress the grid point singularities.

  - Generally, SOL 105 is carried out at the Generalized Finite Element Model (GFEM) level; this creates separate nodes set for components being analyzed in the assembly and is defined using card "ASET1" in the Nastran deck to save significant processing time and avoid large output file sizes for eigenvalue extraction.

  - Stability factors considered for eigenvalue analysis.

    No buckling of structures up to 1.0 x limit load for all metallic components and composite internal surfaces.

  - No buckling of structures up to 1.2 x limit load for composite aerodynamic surfaces.

- **The fitting factor of 1.15 as per 14 CFR Part § 25.625 is applied on each part of:**

  - The fitting

  - The means of attachment

  - The bearing on the joined members

Note: A joint is considered exempt from the above requirement if it is a continuous joint or if substantiation of the joint is supported by test data.

- **A minimum casting factor of 1.25 is considered as per 14 CFR part § 25.621 for casting conversion.**

  The casting factors are considered to account for inconsistencies during the casting process. Castings are subject to variability in mechanical properties during the casting process, resulting in imperfections, such as voids, within the cast part.

- **Classical hand calculations (section checks, flange bending, etc.) are performed at all the hot spot regions for limit and ultimate analysis since FE analysis includes the stress concentration effects, which are localized and not appropriate for limit and ultimate analysis.**

- **For carrying out section analysis for a redundant structure having a complex load path, cut sections at the critical location are considered while building Finite Element Model (FEM) itself, which later helps in extracting the free body loads quickly and accurately.**

- **To simulate the effect of prying, GAP elements are created. The stiffness of the CGAP elements is determined by iterating the FE model for varying CGAP stiffness magnitudes from 1.0e6 to 10. The stiffness value at which the stress behavior remains unaffected with a change in stiffness is considered for the structural analysis.**

- **If the thermal FE model is unavailable, the thermal loads in the structure are calculated using the Gatewood method. The calculated thermal loads are appended to mechanical loads for performing the structural analysis.**

Conclusions

- The weight optimization is performed with multiple constraints following design and analysis best practices.

- Weight saving of 12 pounds is achieved, which is about 20% of overall weight.

- Cost-saving to airframer:
    - Cost-saving for each pound = $ 1,500/lb
    - Total weight reduction for 2 cowling = 12* 2 = 24 lbs. per aircraft
    - Total savings per aircraft = 24 lbs. * $ 1,500 = $ 36,000 per aircraft
    - 50 such aircraft are produced in a year hence total savings per year = $36,000 *50 = $ 1.8 million
    - The more aircraft, the greater the savings

- This proven design and best practice weight reduction analysis can be implemented on other aircraft structure components, saving millions of dollars. All the optimized components are employed with design for manufacturing and assembly methods, eventually reducing the cost while maintaining its quality.

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List of abbreviations

DFMA	Design for manufacturing and assembly
FE	Finite Element
FEM	Finite Element Model
GFEM	Generalized Finite Element Model
NASTRAN	NASA Structure Analysis
MSC	MacNeal-Schwendler Corporation

Author information

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Richard has been associated with HCLTech since 2013. He has more than 13 years of experience in aircraft primary structures, secondary structures and nacelle components using classical analysis methods and finite element analysis tools. He pursued his master's in aeronautical engineering. His areas of interest include Aircraft structures, optimization and CAE simulations. He has worked on several commercial programs such as Boeing 787 -8/-9-10, A350-900/-1000.

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Vishal has been associated with HCLTech since 2016 and has more than 17 years of experience in the aerospace industry. He is an expert in aerostructure analysis, CAE simulations and MRB of nacelle components. He has worked on commercial and Bizet programs such as Airbus A320neo, A350 Boeing 787 and Mitsubishi Regional Jet.

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Sunil has been associated with HCLTecH since 2015. He has over 19 years of industry experience in aircraft structures. He pursued his master's in product design and manufacturing. His areas of interest include aircraft design, composite structures, thermoplastics, additive manufacturing, optimization and CAE simulations. He leads a team of proficient, dynamic stress engineers for various aero-structures programs. He has worked on several commercial and Biz jet programs such as Boeing 787, Airbus A220, A320, A350, Embraer E2-175, E2-190, Mitsubishi Space Jet, Bombardier, Gulfstream and Dassault, to name a few.