GALLOGLY COLLEGE OF ENGINEERING
SCHOOL OF AEROSPACE AND MECHANICAL ENGINEERING
The UNIVERSITY *of* OKLAHOMA

Topology Optimization of Aileron Hinge Bracket

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Introduction

- The Van's Aircraft RV-14 aileron hinge bracket connects the aileron to the wing and allows rotational motion. The original bracket consists of multiple components joined by rivets.
- Rivet and bolt holes create geometric discontinuities, which act as stress concentrators and can reduce long-term structural health.
- The bracket was redesigned as a single integrated component to eliminate unnecessary riveted joints.
- CAD modeling in SolidWorks and FEA in ANSYS were used to evaluate stresses under representative loading.
- Topology optimization identified removable material, targeting a 30% mass reduction while maintaining structural strength and improving aircraft efficiency.

Objectives

- Apply variable loading to bracket
- Run topology optimization on the bracket

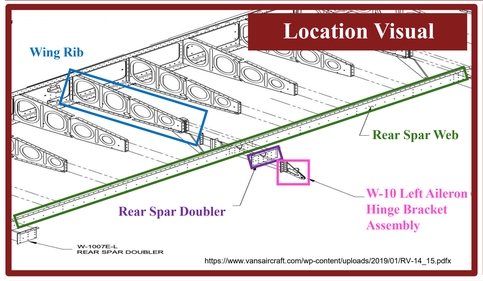
Constraints

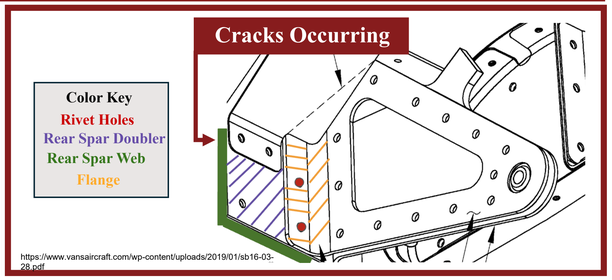
- Maintain structural integrity under loading conditions
- ≥ 30% weight reduction
- FAA/ASTM/ANSI standards
- Availability of aircraft information
- Availability of modeling software licenses

Standards

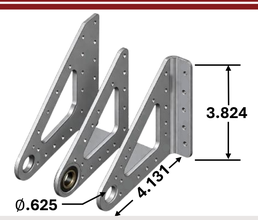
- Federal Aviation Administration — 14 CFR §25.657 (FoS ≥ 6.67 bearing strength)
- Federal Aviation Administration — 14 CFR §25.572 Fatigue
- Federal Aviation Regulations — Quality assurance & certification requirements
- ANSI/BHMA A156.1-2021 — Hinge dimensions, durability, and safety testing

Background



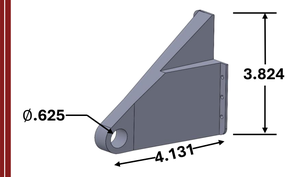


Design 1 → Design 2 → Design 3



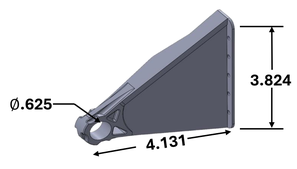
Multiple Components

- ✓ Several separate parts
- ✓ Riveted assembly required
- ✓ Includes multiple rivet holes



Single Solid Component

- ✓ Designed in SOLIDWORKS
- ✓ One integrated part
- ✓ Eliminates rivet holes



Optimization Component

- ✓ Generates unique solutions
- ✓ Retains bracket key features
- ✓ Redistributes stress effectively

Topology Optimization

Fusion 360 Generative Design

1. Generative design explores possible geometries
2. Produces geometry though generative design
3. Produces multiple candidate designs
4. Optimized for individual load scenarios

ANSYS Topology Optimization

1. Topology optimization finds optimal structure
2. Removes surplus material from a design space
3. Produces one optimized design
4. Supports multi-load optimization

Optimization Formulation

FEA → Compliance Calculation → Sensitivity Analysis → Density Update

$KU = F$

- Solves structural equilibrium
- K = stiffness matrix
- U = nodal displacements
- F = applied forces

$c(\rho) = U^T K U$

- Solver seeks stiffest structure
- Quantifies stiffness by minimizing compliance
- Lower compliance induces stiffer structure

$-P(\rho^e)^{p-1} d^{eT} K_f^e d^e$

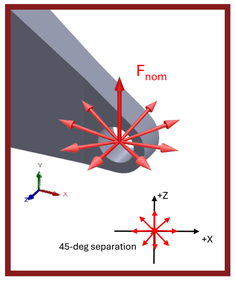
- Calculates sensitivity of compliance: $\frac{\partial L(\rho,\lambda)}{\partial \rho^e}$
- Solved value evaluates element densities

$0 < \rho_e \leq \varkappa \leq 1$

- Solver reduces density in regions of low stress
- $\rho_e = 1$ represents solid material
- $\rho_e = 0$ represents a void

Variable Loading

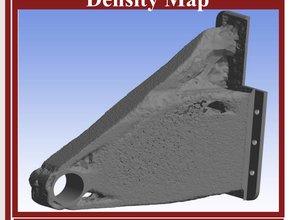
- Represents perturbations in magnitude and direction on standard loading using various load cases
- 5-deg and 10-deg cone of deflection
- 0.7 F_{nom} to 1.3 F_{nom}
- 22 total load cases
- More realistic model of loading seen in operating conditions
- For this study, F_{nom} = 46.8 lb_f



Results

- ANSYS outputs .stl file of optimized design
- New optimized part withstands all variable loads
- SolidWorks used to create a refined part model
- Retained the stress pathways found through topology optimization
- Geometry simplified
- Validate the solution using FEA analysis of the refined part
- Apply the determined worst load case
- The target factor of safety is 1.25 to meet aerospace standards for structural hinges
- The new factor of safety is 1.41
- ANSYS solved the optimization in around seven hours

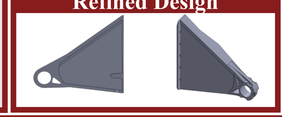
Density Map



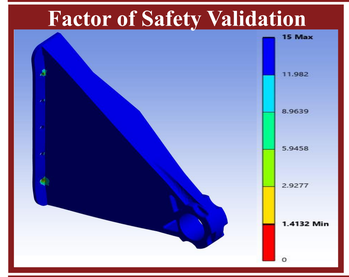
ANSYS Output



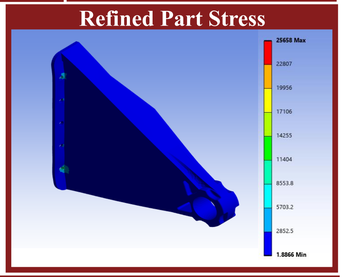
Refined Design



Factor of Safety Validation



Refined Part Stress



Conclusions

- Topology optimization generated novel designs which allowed for the simplification of a built-up design to one made with a single component
- Method successfully removes unnecessary rivet holes and the associated stress concentrations

Future Steps

Manufacturing

CNC Milling



- Low cost compared to additive manufacturing
- Single-part fabrication from an aluminum billet
- High machining precision for critical features

Static and Cyclic Load Testing

Static Loading:

- Evaluates bracket performance under maximum applied load
- Ensures stresses remain below material yield strength

Cyclic Loading:

- Evaluates performance under repeated loading cycles
- Assess fatigue life and crack initiation