Application note

Reliability-based Design Optimization of an Airbus Fuselage Crossbeam

Executive Summary

Critical safety requirements stipulate that buckling eigenvalues of a fuselage crossbeam need to remain above a safety threshold – irrespective of crossbeam manufacturing tolerances. Engineers used Optimus to minimize the weight of a perforated Airbus fuselage crossbeam while fulfilling tolerancing requirements. Optimus helped them capture and automate the MSC Nastran based simulation process, to enable an efficient approach to explore the design space, and hunt for an optimal, reliable design.

In a first step, a deterministic design optimization of the crossbeam was performed. Then the reliability of this optimum was assessed in a second step – which confirmed that the required 3σ reliability level could not be achieved. The large variations on crossbeam dimension parameters and shell thickness parameters actually required a reliability-based design optimization (introducing the reliability index into the optimization process) – to ensure that buckling mode safety is guaranteed regardless of manufacturing variations. With Optimus, the engineers identified an optimum that delivered the requested buckling reliability with only a minor weight penalty.

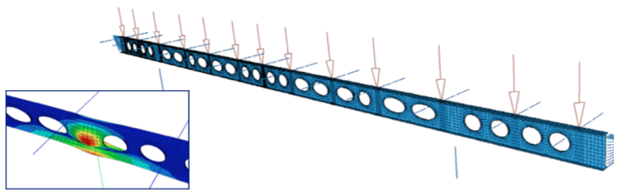

Fig. 1: Engineers optimized a perforated fuselage crossbeam to minimize weight while fulfilling buckling safety requirements.

1. Simulation Facts

Simulation models & software

MSC Nastran SOL 105 is used to perform a linear buckling analysis on a finite-element shell model of the fuselage crossbeam. This shell model is created with Patran. In some use scenarios described in this application note, Patran will also be used as a mesh morphing tool to pre-process crossbeam dimension variations during reliability assessment or reliability-based design optimization.

2. Solution Approach

Simulation process automation

Optimus captures the entire simulation workflow using a graphic drag-and-drop process editor, covering both Patran pre-processing and MSC Nastran linear buckling mode analysis. The interfaces with Patran and MSC Nastran enable Optimus to parameterize the analysis model and automate the execution of the entire simulation workflow. During the parametric simulation campaign, Optimus automatically updates the design parameters and parses output results for a specific combination of design parameters.

Design parameter selection

Two types of design parameters are considered:

- 54 shell thickness parameters, related to:
  - beam web
  - upper & lower beam flanges
  - edges of web holes
- 6 crossbeam dimension parameters:
  - web height (WH)
  - hole edge width (HEW)
  - left & right upper flange width (UFL, UFR)
  - left & right lower flange width (LFL, LFR)

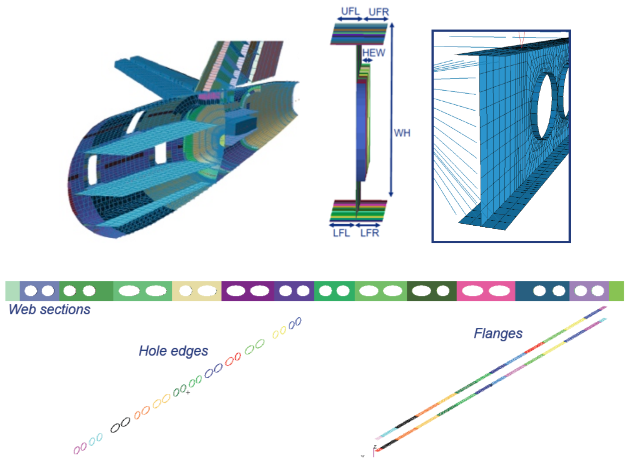

Fig. 2: Illustration of shell thickness and crossbeam dimension parameters on crossbeam analysis model

Design objective specification

The objective is to minimize crossbeam mass, and at the same time ensure that critical buckling safety requirements are met when taking into account crossbeam manufacturing variations.

Solution strategies

<u>Deterministic design optimization</u>

Design parameters relate to shell thickness parameters, while nominal crossbeam dimensions are considered to be fixed. The

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optimization process therefore does not require any mesh morphing operations; the corresponding simulation workflow will only include the MSC Nastran finite element solver (Fig. 3).

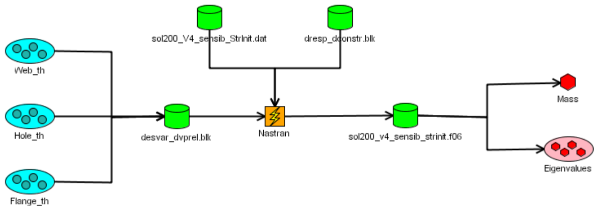

Fig. 3: Crossbeam simulation workflow

The optimization process will target to minimize crossbeam mass, constraining the first buckling eigenvalue to remain above 1.2. Optimus varied thickness of crossbeam flanges, web sections and hole edges as part of the optimization process, which used the NLPQL local gradient-based optimization algorithm. The design optimum resulting from this high-dimensional optimization challenge, reduced crossbeam weight 9.6%.

A reliability assessment of this optimum, involving Monte Carlo simulation that takes into account variations on both shell thickness & crossbeam dimension parameters, showed that the first buckling eigenvalue is very sensitive to slight crossbeam manufacturing variations – and that the required 3σ reliability level could not be achieved for this optimum (Fig. 4). Therefore it was required to switch to a reliability-based design optimization strategy.

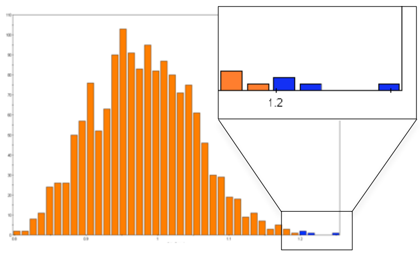

Fig. 4: Probability distribution of first buckling eigenvalue based on reliability assessment using Monte Carlo simulation (only blue values comply with buckling value constraint)

Reliability-based design optimization

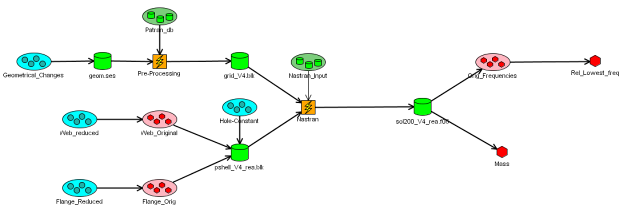

Fig. 5: Crossbeam simulation workflow

The optimization process will not just target minimum crossbeam mass, but will also focus on providing 3σ level reliability for the first buckling eigenvalue to remain above 1.2. The engineers took the design optimum obtained from the deterministic optimization as the baseline configuration. They used Optimus to coordinate the process of implementing variations on both shell thickness and crossbeam dimension parameters within preset boundaries, re-meshing the crossbeam model with Patran and driving MSC Nastran SOL105 (simulation workflow depicted in Fig. 5).

Using one of its efficient local optimization algorithms, Optimus automatically drove the simulation workflow and identified a reliable optimum. The optimization process, involving thousands of virtual experiments, was completed in less than 2 days. The subsequent reliability assessment showed that the optimum even slightly outperformed the requested 3σ.

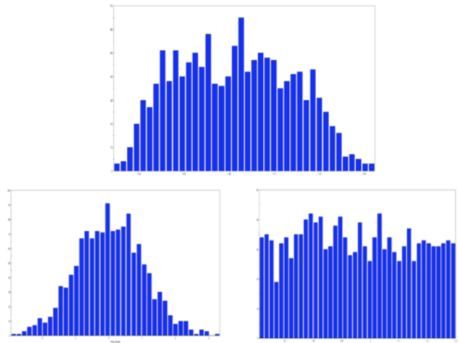

Fig. 5: The top chart illustrates the probability distribution of the first buckling eigenvalue, confirming reliability to exceed 99.9% (>3σ). The bottom charts relate to web height and web thickness of the crossbeam.

3. Results

The deterministic crossbeam design optimization delivered a 9.6% mass reduction compared to the nominal design. Although nominally constraining the first buckling eigenvalue to remain above 1.2, a reliability assessment showed this optimum to be unsatisfactory. However, Optimus' reliability-based design optimization delivered an optimum that was confirmed to be 99.9% reliable with respect to the first buckling eigenvalue, with a weight penalty of only 2%.

4. Benefits

- Optimus easily captures and successfully orchestrates simulation workflows, eliminating the need for manual intervention by the engineer involved in simulation-based design.
- Optimus easily integrates Patran & MSC Nastran into the simulation workflow, offering direct access to the design parameters.
- Optimus' Reliability-Based Design Optimization (RBDO) capabilities not only provide improved design performance, but also a higher degree of confidence in the design – in this particular case confirming 99,9% reliability with respect to the constraint on the first buckling mode eigenvalue.

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