SUCCESS STORY

Developed an Advanced 3D Shape Optimization Method and Related Software to Automatically Generate Lightweight Core Structures for the Aviation Industry

Reduced Mass By 53% to 76% on Three Realistic Aerospace Components

Composite skin being manufactured over a topology optimized structure that can withstand large compacting forces (left: CAD model of optimized design; middle: fiber placement process over the design; right: resulting fly-away core structure).

PROBLEM

The design of 3D core structures is a major consideration in the production of highly engineered, lightweight components such as those common in aerospace applications. Core structures serve two critical functions: they provide a solid base for depositing other structural materials, and they serve as a skeletal structure that contributes to the load bearing capacity of the final part. The complexity of both the manufacturing and in-use forces experienced by the core structures prevents the use of existing computational approaches for shape and topology optimization. Hence, existing approaches to designing core structures either cannot take advantage of the design opportunities enabled by additive manufacturing, or they produce over-engineered solutions using ordinary lattice structures.

OBJECTIVE

The objective of this project was to reduce design times for structurally optimal 3D core structures. The design time aimed to be an order of magnitude reduction from days to hours. A further objective was the simultaneous reduction in fabrication (print) time and material usage through co-optimization of the design and 3D printing process. A substantial increase in geometric freedom for the target shapes offers the potential for major reductions in life-cycle energy costs for operational vehicles containing the proposed core structures due to reduced weight.

AMERICA MAKES TECHNOLOGY DEVELOPMENT ROADMAP

This project aligns to:

DESIGN

ASTM PROCESS CATEGORY
Material Extrusion

EQUIPMENT
Stratasys' Objet Connex 350 & FDM, Arcam S12, EOS M290, CubePro, Siemens' NXOpen API & NX Platforms

MATERIAL:
PA6. P12, Similar Stronger Alternatives

TECHNICAL APPROACH

The technical approach was to develop a computational system and educational materials for the optimal design and additive manufacturing of 3D core structures central to the aerospace industry with fused deposition modeling (FDM) technologies. This included investigating advanced solutions using finite element methods, nonlinear high dimensional optimization, and design for additive manufacturing (DFAM). The technology was applied to functional components provided by Automated Dynamics (AD), Aurora Flight Sciences, and United Technologies Research Center (UTRC). This novel design technology aimed to alleviate some of the fundamental limitations associated with current CAD/CAM/CAE/PLM tools and practices. Once the technology validation was complete, it was incorporated into Siemens NXOpen API platform for wide scale dissemination.

ACCOMPLISHMENTS

A fully developed software module for 3D optimal shape design for problems involving large force uncertainties was delivered including integration of this software into Siemens' CAD platform. Successful 3D printing of the three real test cases was designed using the developed software on Stratasys' 3D printers. A battery of successful 1:1 scale physical tests clearly demonstrated the success of the project. Video and images of all the physical validation studies were captured. Training materials were developed that include a description of alternative methods that can be used for a different parametrization of the model. An article describing the computational algorithms and methods behind the innovation is available at bit.ly/VDEL4058.

PROJECT PARTICIPANTS

Project Principal:
Carnegie Mellon University

Public Participants:
U.S. Department of Defense
National Science Foundation
U.S. Department of Energy

Other Project Participants:
Automated Dynamics
Aurora Flight Sciences
Lockheed Martin
Stratasys, Inc.
Siemens Industry, Inc.
United Technologies Corporation

PROJECT END DATE

May 2018

DELIVERABLES

- Description of design problems, requirements, and performance metrics
- Detailed algorithms on topology optimization under moving loads
- Rules for interpreting topology optimization results in the form of parametric models
- Quantified results for material anisotropy characterization using physical testing
- Algorithm transition and integration into Siemens' CAD platform, dissemination, user testing (COTS)
- Library of digitally compiled workforce education material
- Results from formative feedback from Lockheed Martin, Aurora, and Stratasys
- Tutorial on how to use the final technology within Siemens' CAD platform and as a stand-alone executable
- Videos of fiber placement process for the design problems
- Results of inspection and failure analysis encountered during the fiber placement process
- Part orientation, printer settings, equipment specifications, and material details for parts printed using Stratasys' machines
- Algorithms for high quality volumetric meshing for topology optimization
- Dynamic testing and system identification on test samples
- List of practices for fiber placement methods
- Grand challenge design problem: requirements, rules, and objectives

FUNDING

$2M total project budget

($1.1M public funding/$900K private funding)

4058 Optimal Design and AM of Complex Internal Core Structures for High Performance Aerial Vehicle Production

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