VTVL concept optimisation of the landing gear

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DOI: 10.13111/2066-8201.2017.9.1.8

Received: 27 January 2017/ Accepted: 23 February 2017/ Published: March 2017

International Conference of Aerospace Sciences "AEROSPATIAL 2016"
26 - 27 October 2016, Bucharest, Romania, (held at INCAS, B-dul Iuliu Maniu 220, sector 6)
Section 4 – Materials and Structures

Abstract: *Vertical takeoff, vertical landing (VTVL) is a subject of international interest at the moment thanks to the successful recovery of the Blue Origin vehicle. Aggressive weight targets with a short development time in the aerospace and space industry clearly need an integration of advanced computer aided structural optimization methods. Topological optimization is used from the concept phase of a design process development in order to obtain a fundamental design approach. The aim of the article is to determine the principal directions for distribution of the material for a VTVL landing gear within the specified volume in order to obtain the initial design approach. To achieve the maximum performance within the studied component, the result is then refined from a manufacturability point of view. The use of such methods notably reduces the development iterations between the design and stress departments. Thus, the overall time is reduced which translates into a lower overall cost and shorter time development from the concept to the final product.*

Key Words*: VTVL, landing gear, structural optimisation, topological optimisation, low mass.*

1. INTRODUCTION

A number of performance-related innovations are needed for future space transportations systems such as fully reusable launch vehicles [1]. An important subject of study is the development of reusable rockets capable of vertical takeoff and vertical landing (VTVL) to perform different types of missions. Generally in order to achieve the necessary experience, the development starts with concept vehicles at a smaller scale.
From the beginning, low mass was a real target for aerospace and space vehicles. It is desirable that the available material to be distributed as efficiently as possible in order to fulfill its intended purpose. The concept of structural of optimization was born from this necessity. That means finding the best solution considering a group of already established criterions.

The major challenge faced by researchers in structural optimisation is to develop methods that are suitable for use with such software packages. Another major challenge is the high computational cost associated with the analysis of many complex real-life problems.

In many cases the engineer who has the task of designing a structure cannot afford to analyze it more than a handful of times [2]. Optimization generally finds design variables to maximize/minimize an objective function, while design constraints are simultaneously satisfied. In structural optimisation, the optimization problem is defined for the design of a structure. Nowadays, structural optimization is widely accepted due to the development of the finite element method (FEM) [3]. The goal of modern design is to optimize the total system rather than the individual components [4].

Using topology optimization, the entire structure can suffer modifications. This type of analysis can be used starting with the concept phase, thus reducing the number of exchanges between the design and stress departments. This leads to a downsize in time and costs.

2. MOTIVATION

The purpose of this paper is to demonstrate the impact that the topological optimization may have on the research and development of new structures.

It will be shown the usefulness of optimization software in determining the optimum design of a landing gear for a VTVL autonomous reusable vehicle powered by a turbojet engine. The structure in Fig 1 is considered as a starting point. The black area represents the design space of the landing gear while the blue area is a summary representation of the vehicle in question. The goal of this analysis is to determine the optimum material directions in the established area required for an efficient load distribution.

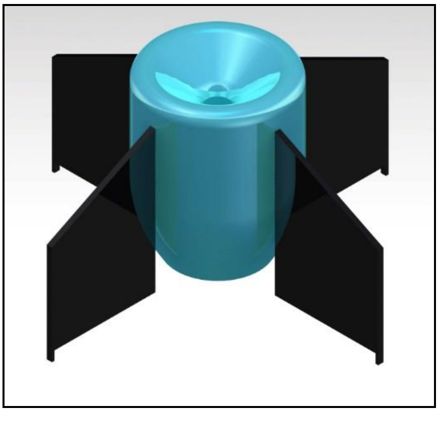


Fig. 1 Initial design

3. STUDIED OPTIMIZATION SOFTWARE

Topological optimization is used to generate a conceptual design with a focus on the global behavior of the structure, which can be followed by a local optimization for each component.

Depending on the type of the optimization that may be performed, a software program must be chosen. There are pros and cons between choosing a solver designed mainly for optimization problems and those that solve such problems using an auxiliary module. The dedicated software (e.g. INSPIRE [5]) is more user friendly but in order to verify the structure against more complex analysis it may be needed to use some other software packages. On the other hand there are some well-known software packages dedicated to structural analysis (e.g. NASTRAN [6], ANSYS), where the developers noticed the importance of structural optimisation and included a module for this type of analysis. In this paper a topological optimization analysis will be performed with one tool from each category presented above: INSPIRE from solidThinking, ALTAIR and NASTRAN 2012 from MSC. To facilitate this process, the solver MSC Nastran has developed a comprehensive set of solutions shortening the long process of optimization. Using “sol 200”, effective and feasible solutions can be obtained, which may be further analyzed. The optimisation module includes all of the most popular solutions of optimization like size, shape or topology optimization. Inspire allows designers to create and investigate the effectiveness of structures created easily and quickly. Hence, the optimum distribution of the material is determined in much less time.

4. INPUT DATA

From studying the existing literature [7], it was found that in order to reduce the instability of the vehicle during the landing phase, the power is strongly reduced at a distance above the ground of about 1-1.5 meters. This result in a load of four times the weight of the vehicle distributed over the landing gear.

The landing gear considered in this paper has four feet and the weight of the vehicle is considered to be approximately 60 kg. Thus, each foot will be subjected to a load of 600 N.

Fig. 2 presents the design space considered for each foot. The structure is attached to the vehicle via points 1 and 2 and the load is introduced via point 3.

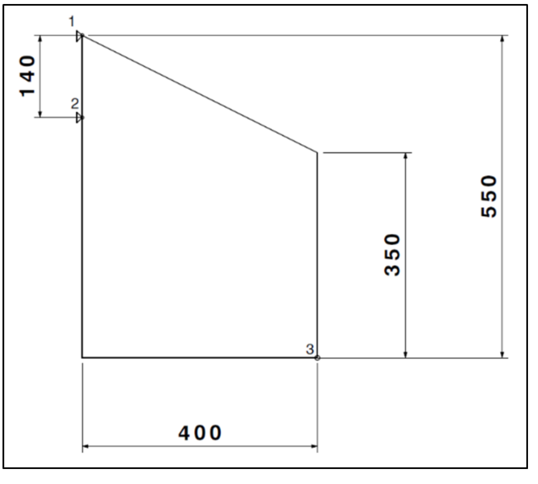


Fig. 2 Design space overall dimensions

The material considered is one commonly used in the aviation and space industry but also in the space one due to its good mechanical properties shown in Table 1.

Table 1. Mechanical properties of the material

F_{tu} [MPa]	F_{ty} [MPa]	E [MPa]	ρ [Kg/m^3]	μ	Material
468	393	71000	800	0.33	7075 T7351 MMPDS-5D

F_{tu} – ultimate tensile allowable strength, MPa
F_{ty} – yield tensile allowable strength, MPa
E – Young Modulus, MPa
ρ – density of the material, Kg/m^3
μ – Poisson coefficient

5. RESULTS

Topology optimization allows selecting the best elements in a given design space that maximize the use of material.

Research on numerical topology optimization started two decades ago and since then progress has been steadily converting it into a very mature discipline.

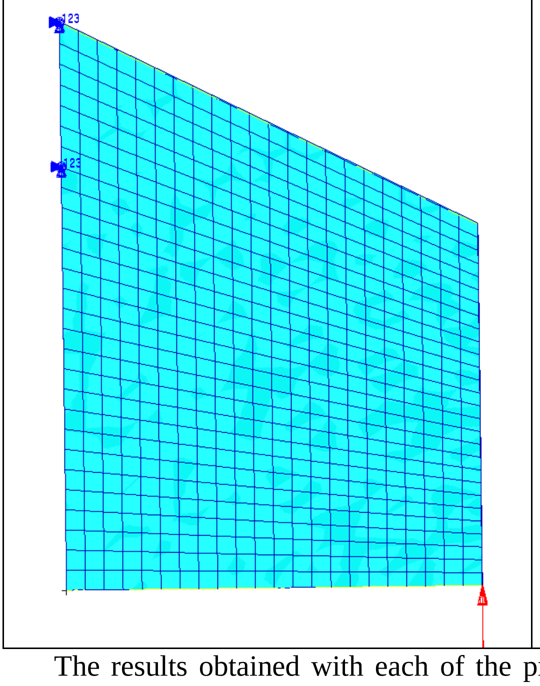
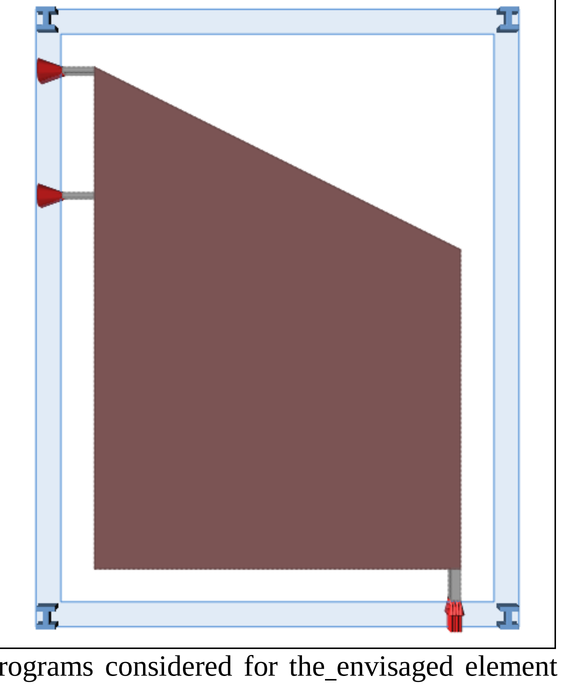
In this type of optimisation, the idea is to design the material properties so that at the end of the optimization run their values are either 0.0 or their nominal values. The elements with 0.0 material properties are discarded from the design, while elements with their nominal values are kept [8].

The analysis conducted with both optimization software programs aims to determine the effective material distribution, i.e. the landing gear geometry.

Because the goal of this study is to determine the general layout of the material, an extrusion condition was imposed perpendicular to the plane defined by the three points shown in Fig. 2.

The geometry was modelled using 3D elements and two types of element size were considered: 20 mm and 10 mm. Table 2 presents the input data for the optimization analysis.

Table 2. Input data

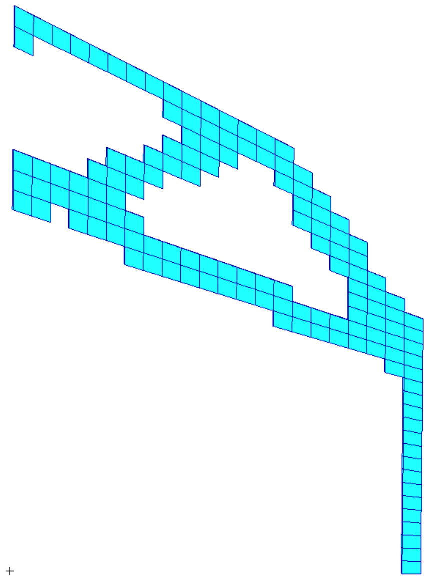
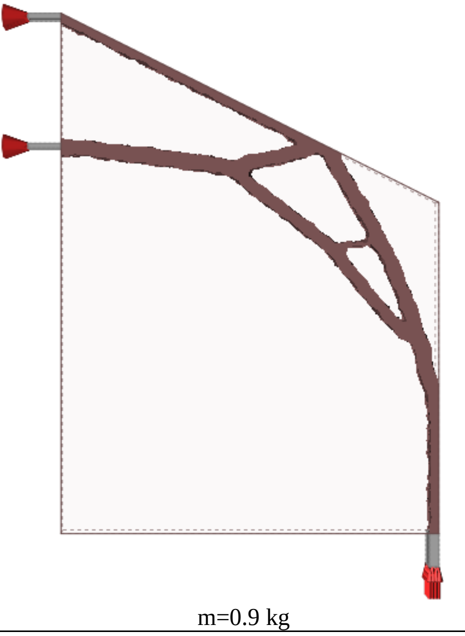
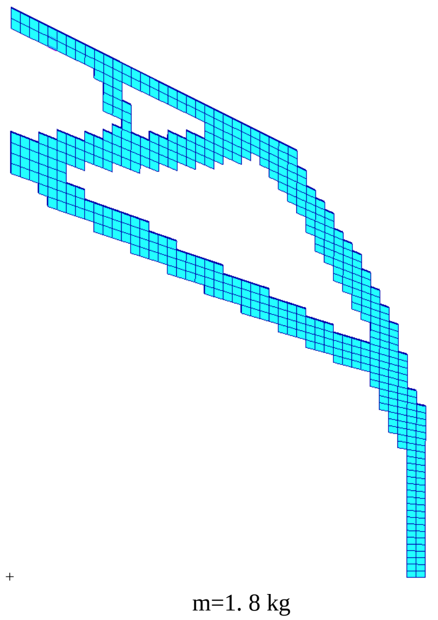
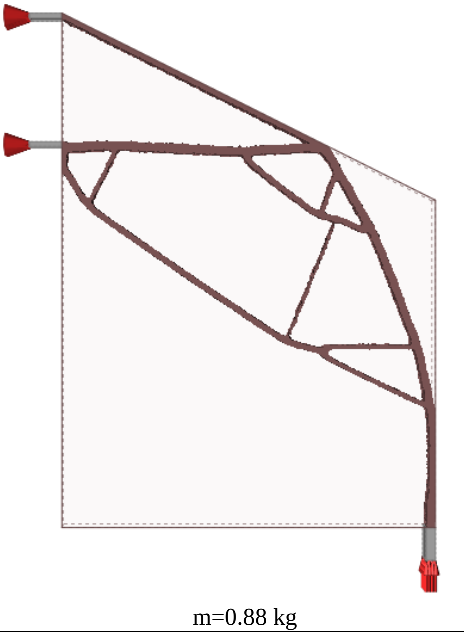
Input data NASTRAN	Input data INSPIRE
	

The results obtained with each of the programs considered for the_envisaged element sizes are shown in Table 3.

It is noted that the tendency of the material distribution is about the same. The dedicated software specialized in optimisation analysis (INSPIRE) has a more clearly defined solution with more constructive elements, although the same element size was used.

Another difference appears at the final mass of the optimized structure, the one obtained with PATRAN / NASTRAN being higher.

Table 3. Output data

NASTRAN sol 200	INSPIRE
Element size of 20 mm	
 m= 2.125 kg	 m=0.9 kg
Element size of 10 mm	
 m=1. 8 kg	 m=0.88 kg

6. CONCLUSIONS

The geometry obtained with INSPIRE has a lower mass and more constructive elements than the one resulted from the analysis performed with NASTRAN. In both cases the same main directions of the material distribution can be noticed. With this in view a concept design for the landing gear of the vehicle previously considered is proposed in Fig.3.

This concept design can be used in two main ways. Firstly, by replacing the distribution of the material with classical, modular structures (closed profiles, joints, bolts, etc.) and, secondly, the cross section of the resulted structure can be used to determine the size of the profiles. Using a closed profile offers an additional benefit by significantly increasing the stiffness of the structure.

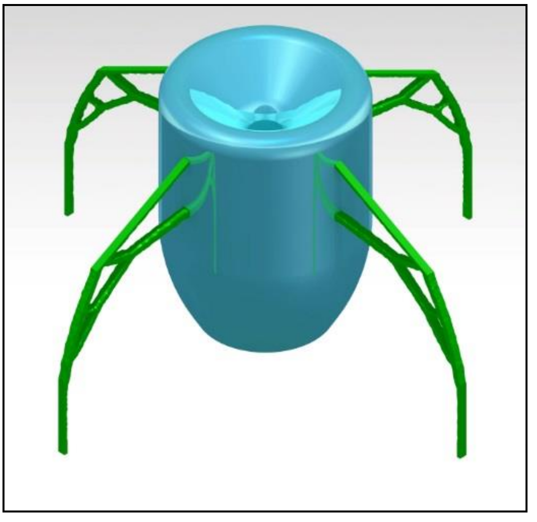


Fig. 3 Concept design

Besides the structural elements, a landing gear may have additional dampers for shock absorption. Fig. 4 shows a basic example of the dampers disposal on the concept structure resulted from the optimization analysis.

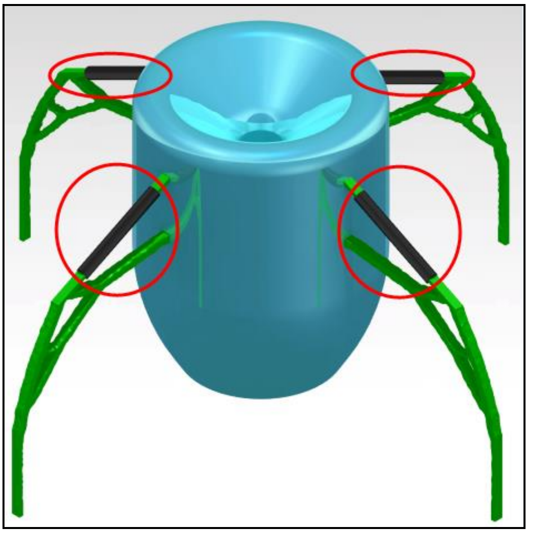


Fig. 4 Dampers disposal on the concept structure

The landing gear evolution from the design space considered at the beginning of this paper to a concept design with dampers is presented in Fig. 5.

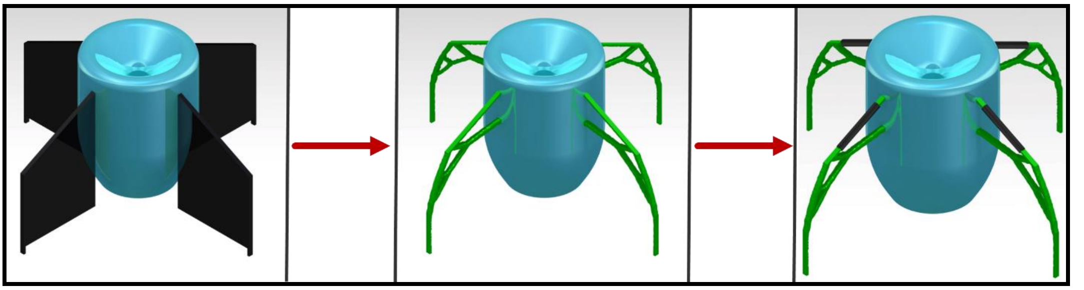


Fig. 5 Landing gear concept design steps

It is clear that topological optimization is a necessary step for obtaining a future development of advanced structures in order to reduce the iterations between the design and stress departments, thus greatly reducing the time and costs.

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