COMPARISON OF STRUCTURAL OPTIMIZATION TECHNIQUES FOR A NUCLEAR ELECTRIC SPACE VEHICLE

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Abstract

The purpose of this paper is to utilize the optimization method of genetic algorithms (GA) for truss design on a nuclear propulsion vehicle. Genetic Algorithms are a guided, random search that mirrors Darwin's theory of natural selection and survival of the fittest. To verify the GA's capabilities, other traditional optimization methods were used to compare the results obtained by the GA's, first on simple 2-D structures, and eventually on full-scale 3-D truss designs.

Introduction

There are many methods of optimization that are available for engineers. However all of these methods have their limitations. For example, numeric and gradient-based optimization start at an initial position and evaluate each surrounding point in the design space to determine the quickest direction to take towards the objective. These two methods work remarkably well for functions that are smooth and contain only one peak or valley. When many local maxima or minima exist, or if there are any plateaus within the design space, the search stops and thinking it is at the optimum point, however since each surrounding direction cannot improve the function, it only found a local optimum point.

This is where genetic algorithms (GA's) come into play. Developed by John Holland at the University of Michigan in the 1960's, genetic algorithms are a guided, but random search that mirrors Darwin's theory of natural selection and survival of the fittest with selective breeding. Due to its randomness and the utilization of "populations," GA's are able to cover the entire design space through numerous "generations." Each design variable's ("gene") value is converted to binary 1's and 0's, which make up a "chromosome." Fitness values are calculated using a fitness function (objective function). If the objective is to minimize the weight, lower fitness values are desirable. Chromosomes with these desirable values are given a higher percentage for crossover, a process in which genes in a chromosome are swapped with those from another chromosome,, thus giving the next generation improved solutions. Mutation is also introduced, where a 1 or 0 within the chromosome changes value in order to keep the population fresh and to prevent hard convergence. This process is repeated until a convergence is obtained, or the number of iterations reach the specified number of generations.

Simple Beam Optimization

The first procedure was to investigate optimization of a simple structure using the MATLAB Genetic Algorithm (GA) Toolbox. To do this it was compared to conventional gradient-based optimization found in MATLAB. The problem that was investigated was a simple pin-pin beam (Figure 1) with a fixed length of 10 ft. There was a 1000 lb load applied at one end.

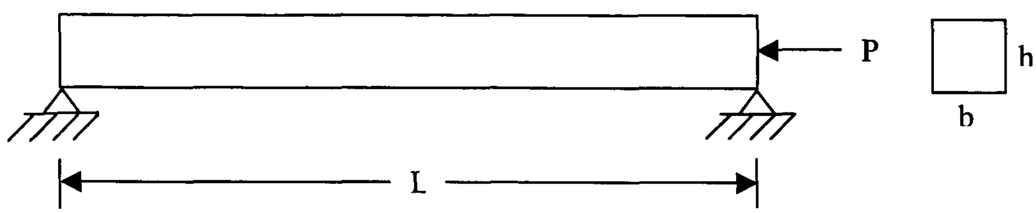

Figure 1: Simple Pin-Pin Beam

The objective was to minimize the weight while satisfying Euler buckling and material strength of 40000 psi. The material assumed for this problem as well as the following analysis was aluminum. The design variables were the cross sectional base (b) and height (h). For both the GA and gradient methods, a MATLAB m-file was created that would take into account the length and load, as well as the material properties. With each iteration of the GA process, the m-file would calculate the stress and the critical stress, and evaluate them against the constraints of not exceeding 40000 psi and that the stress would be less than the critical buckling stress. A fitness value was given for each b and h, and at the end of the process the b and h with the lowest values were selected as the final solution. After analysis, the results obtained for each method were comparable and the GA actually gave better results with an area of 1.2504 inches and a weight of 14.1757 pounds (Table 1).

	b (in.)	h (in.)	Stress (psi)	Weight (lb)
MATLAB Opt.	1.0000	1.2100	829.7500	14.2296
GA Toolbox	1.0001	1.2053	829.5860	14.1757

Table 1

10-Bar Truss Optimization

The focus was then moved to a benchmark problem that has been found in many optimization papers, a ten-member plane truss (Figure 2). It contains two bays, each of 360 inches in length as well as height. There are two loads of 100 kip located at nodes 2 and 4, respectively.

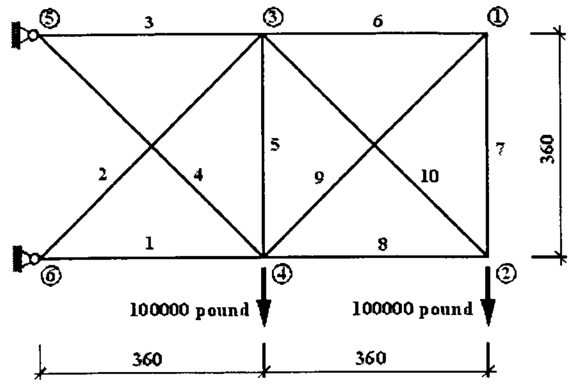

Figure 2: 10-Bar Truss

Due to the statically indeterminate nature of the problem, it was determined to use a finite element analysis of the truss for optimization. A modified version of a three-member truss found in the NASTRAN Optimization User's Guide was used to optimize the truss. The objective, again, was to minimize the weight. The variables in this case were the cross sectional areas of each member. The allowable stress in each member could not exceed 25000 psi in tension or compression, and a nodal displacement constraint of plus or minus 2 in. on nodes 1 through 4 while nodes 5 and 6 are fixed.

From the results (Table 2), it is clear that the NASTRAN optimization gave values of area and weight (5078 lb) that match those found in other papers using different methods. These results are encouraging and will be used later in the paper to compare with optimization of the same truss using the MATLAB GA Toolbox.

Bar number	Optimum cross section areas of bars, inch^2						
	Schmit, Miura	Schmit, Farchi	Venkayya	Haug, Arora	Software SOOOPT	NASTRAN	GA Toolbox
1	24.43	24.25	23.4	23.27	23.93	24.37	21.4359
2	21.06	20.69	21.08	21.2	20.96	20.818	24.3038
3	30.66	33.42	30.41	30.03	30.74	30.62	21.6214
4	8.58	8.39	8.69	7.47	8.53	8.4155	24.0098
5	0.1	0.1	0.1	0.1	0.1	0.1	0.3671
6	0.1	0.1	0.13	0.1	0.1	0.22981	0.1
7	0.1	0.1	0.1	0.56	0.1	0.16575	0.1
8	14.59	14.26	14.9	15.29	14.74	14.997	15.793
9	0.1	0.1	0.19	0.1	0.1	0.23011	0.1
10	21.06	20.69	21.08	21.2	20.96	20.44	24.1071
Weight, 10^3 pound	**5.074**	**5.092**	**5.088**	**5.061**	**5.074**	**5.078**	**5.8312**

Table 2

25-Bar Truss Optimization

The next step was to optimize a more complex 25-bar 3-D truss (Figure 3). Also found in the NASTRAN Optimization User's Guide, the objective, again, was to minimize the weight while satisfying certain constraints. The variables were the cross sectional areas of each member. However several of the members' areas were linked together to give a total of 8 design variables. The stresses allowed in each member could not exceed 40000 psi in tension or compression, and a nodal displacement constraint of plus or minus 0.35 inches on top points, nodes 3 and 4 was used.

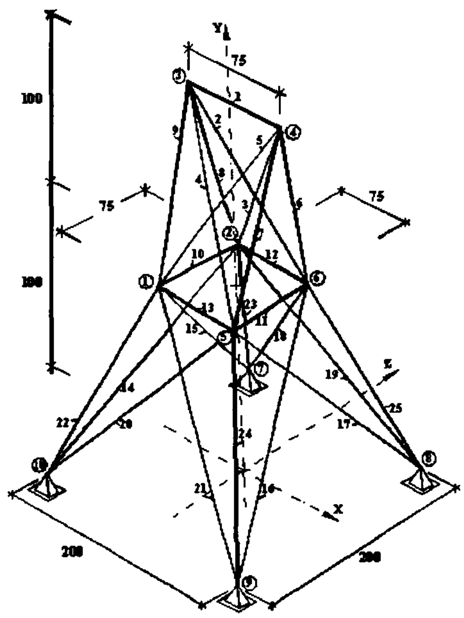

Figure 3: 25-Bar Truss

Similar results for the areas are found when comparing the results found in literature optimizing the same truss (Table 3a) with those obtained by the NASTRAN optimization (Table 3b). However, there is a slight discrepancy in weight between those found in the Software SOOOPT and the NASTRAN run. The reason for this difference is that the optimization in Table 3a combines elements 10, 11, 12, and 13 while the NASTRAN optimization linked elements 10 and 11, and, 12 and 13 separate.

Design Variable	Elements	Optimum cross section areas of bars, inch ^{2}	
		Haug, Arora	software SOOOPT
A_1	1	0.01	0.0146
A_2	2,3,4,5	2.0476	0.0379
A_3	6,7,8,9	2.9965	3.7032
A_4	10,11,12,13	0.01	1.3428
A_5	14,15,16,17	0.6853	0.7897
A_6	18,19,20,21	1.6217	0.2794
A_7	22,23,24,25	2.6712	3.9071
Structural weight, pound		**545.04**	**486.55**

Table 3a

Design Variable	Elements	Cross sectional area, inch ^{2}
		NASTRAN
A1	1	0.87171
A2	2,3,4,5	2.0406
A3	6,7,8,9	2.8821
A4	10,11	0.13318
A5	12,13	0.08597
A6	14,15,16,17	0.69774
A7	18,19,20,21	1.671
A8	22,23,24,25	2.6767
Structural weight, pound		**548.03**

Table 3b

10-Bar Truss Optimization Using Genetic Algorithms

Once the process was verified, it was decided to compare the optimization of the ten-member truss using NASTRAN to an optimization of the same truss using the GA Toolbox of MATLAB. The GA program used for the simple beam optimization was modified to perform a loop in which each member of the truss would be optimized individually. Since the forces could not be solved with conventional methods, the forces within each member obtained from the NASTRAN optimization were used in the MATLAB GA run. The results were comparable, however one area, member 4, had a significant difference than that found in the NASTRAN run, as well as the rest of the literature.

Conclusion

From the results obtained, it can be concluded that GA's are a feasible approach for optimization, however further work must be completed. The plan is to use the NASTRAN optimization, and eventually GA's, on a 80-meter truss that will be the baseline design of the vehicle. Due to the randomness, it is hopeful the GA's will give solutions and designs that could not be obtained using conventional optimization methods.

References

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