APPLICATION OF METAL MATRIX COMPOSITES (MMCs) IN A SATELLITE BOOM TO REDUCE WEIGHT AND VIBRATIONS AS A MULTIDISCIPLINARY OPTIMIZATION

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Abstract

Critical space missions, demand lightweight space structures with high pointing accuracy and dimensional stability in the presence of dynamic and thermal disturbances [1,2]. Therefore both organic-matrix and metal-matrix composites (MMCs) have been developed for space applications [1,2].

Simultaneous reduction of weight and band averaged vibration transmission in a satellite boom structure is the major task of the present study. This study approached the design problem by material selection among a list of MMCs and changing the cross sections of truss members. Optimization problem was solved using GA as a constrained one by new penalty functions.

1 Introduction

From the onset of the space era, both organic matrix and metal matrix composites (MMCs) with high specific stiffness and near-zero coefficient of thermal expansion (CTE) have been developed for space applications [1,2]. The magnitude of deformation in structure due to vibrations and dynamic loads is directly dependent on natural frequency of the structure and also the natural frequency is proportional to the modulus of elasticity [3]. The mission of a large flexible space structure is to support an electronic device such as a gamma sensor or an antenna in a certain direction. Performance of these structures is highly sensitive to vibrations [4,5].

Composite Large Space Structures (LSS) including booms, planar surfaces, antennas, platforms and space stations have been proposed for use in NASA's Space Station "Freedom" and the DOD's Global Protection Against Limited Strikes programs. Because of their low mass and high strength and stiffness, composite repetitive lattice structures are ideal for these space applications. LSS will be required to sustain severe environmental effects, radiation, thermal cycling, atomic oxygen bombardment, collision with micrometeoroids and space debris, hostile actions of transient operational loads, slewing, manned activities, control system, and the mobile service center- while maintaining strict mission parameters. Platform pointing is one example of these requirements and necessitates tolerances of less than one thousandth of a degree. Over time, material and structural degradation will occur due to environmental effects causing a change in the structure's stiffness and dynamic response. Likely, this structural damage will require immediate repair to restore the LSS to full mission capability [6, 7].

During operations, the LSS will experience a multitude of internal and external loads while maintaining mission requirements. For manned platforms such as the space station, internal loads include: crew motion, fluid transfer, rotating machinery, payload slewing, mobile service system (equipment and payload transfer device), re-boost and control system torques. Externally applied loads are due to station operations and the orbital space environment. Under external operations, the station will have the shuttle or orbital maneuvering vehicle docking with the station. The orbiting structure will also experience aerodynamic drag, solar pressure drag, gravity gradient, solar thermal winds and electrostatic/electromagnetic body forces. Because of microgravity in space, most operational loads are insignificant to the strength of the structure while the main operational requirement of the structure is restricting the LSS dynamic response to meet mission requirements. This is a function of the stiffness of the configuration and materials. Space structures and materials must be strong enough to support the prior loads and limit the structure's dynamic response to meet the mission requirements [6, 7].

The extreme environment in space presents both a challenge and opportunity for material scientists. In the near-earth orbit, typical spacecraft encounter naturally occurring phenomena such as vacuum, thermal radiation, atomic oxygen ionizing, radiation and plasma, along with factors such as micrometeoroids and human-made debris. For example, the International Space Station, during its 30-year life, will undergo about 175,000 thermal cycles from +125°C to –125°C as it moves in and out of the Earth's shadow. Re-entry vehicles for Earth and Mars missions may encounter temperatures that exceed 1,500°C. Critical spacecraft missions, therefore, demand lightweight space structures with high pointing accuracy and dimensional stability in the presence of dynamic and thermal disturbances. Composite materials, with their high specific stiffness and low coefficient of thermal expansion (CTE), provide the necessary characteristics to produce lightweight and dimensionally stable structures. Therefore, both organic-matrix and metal-matrix composites (MMCs) have been developed for space applications [1].

Despite the successful production of MMCs such as continuous-fiber reinforced boron/aluminum (B/Al), graphite/ aluminum (Gr/Al), and graphite/ magnesium (Gr/Mg),[8-12] the technology insertion was limited by the concerns related to ease of manufacturing and inspection, scale-up, and cost. Organic-matrix composites continued to successfully address the system-level concerns related to micro-cracking during thermal cycling and radiation exposure and electromagnetic interference (EMI) shielding; MMCs are inherently resistant to those factors.

Concurrently, discontinuously reinforced MMCs such as silicon-carbide particulate (p) reinforced aluminum (SiC_p/Al) and G_p/Al composites were developed cost effectively both for aerospace applications (e.g., electronic packaging) and commercial applications. Three processing methods have been primarily used to develop MMCs: high-pressure diffusion bonding, casting, and powder-metallurgy techniques. More specifically, the diffusion-bonding and casting methods have been used for continuous-fiber reinforced MMCs. Discontinuously reinforced MMCs have been produced by powder metallurgy and pressure-assist casting processes. MMCs such as B/Al, Gr/Al, Gr/Mg, and Gr/ Cu have been manufactured by diffusion bonding for prototype spacecraft components such as tubes, plates, and panels [8-12].

While the desire for high-precision, dimensionally stable spacecraft structures has driven the development of MMCs applications thus far have been limited by difficult fabrication processes. The first successful application of continuous-fiber reinforced MMC has been the application of B/Al tubular struts used as the frame and rib truss members in the mid-fuselage section and as the landing gear drag link of the Space Shuttle Orbiter [1]. Several hundred B/Al tube assemblies with titanium collars and end fittings were produced for each shuttle orbiter. In this application, the B/Al tubes provided 45% weight savings over the baseline aluminum design [1].

The major application of Gr/Al composite is a high-gain antenna boom for the Hubble Space Telescope made with diffusion-bonded sheet of P100 graphite fibers in 6061 Al. This boom (3.6 m long) offers the desired stiffness and low CTE to maintain the position of the antenna during space maneuvers. In addition, it provides the wave-guide function, with the MMC's excellent electrical conductivity enabling electrical-signal transmission between the spacecraft and the antenna dish. Also contributing to its success in this function, is the MMC's high dimensional stability so that the material maintains internal dimensional tolerance of ±0.15 mm along the entire length [8-12]. While the part currently in service is continuously reinforced with graphite fibers replacement structures produced with less expensive discontinuously reinforced aluminum (DRA). Like the Gr/Al structural boom, a few MMCs have been designed to serve multiple purposes, such as structural, electrical, and thermal-control functions. For example, prototype Gr/Al composites were developed as structural radiators to perform structural, thermal and EMI-shielding functions[10]. Also, Gr/Cu MMCs with high thermal conductivity were developed for high-temperature structural radiators [11]. A DRA panel is used as a heat sink between two printed circuit boards to provide both thermal management and protection against flexure and vibration which could lead to premature failure of the components in the circuit board. In technology development programs sponsored by the U.S. Defense Advanced Research Projects Agency and the U.S. Air Force, graphite/magnesium tubes for truss-structure applications have been successfully produced (jointly by Lockheed Martin Space Systems of Colorado and Fiber Materials of Maine) by the filament-winding vacuum-assisted casting process[1].

Of the DRA composites, reinforcements of both particulate SiC_p/Al and whisker (w) SiC_w/Al were extensively characterized and evaluated during the 1980s. Potential applications included joints and attachment fittings for truss structures, longerons, electronic packages, thermal planes, mechanism housings and bushings [8-12].
Because of their combination of high thermal conductivity, tailorable CTE (to match the CTE of electronic materials such as gallium arsenide or alumina) and low density, DRA composites are especially advantageous for electronic packaging and thermal-management applications [8,9]. Several SiC_p/Al and Gr_p/Al electronic packages have been space-qualified and are now flown on communication satellites and Global Positioning System satellites. These components are not only significantly lighter than those produced from previous metal alloys, but they provide significant cost savings through net-shape manufacturing [9]. DRA is also used for thermal management of spacecraft power semiconductor modules in geosynchronous earth-orbit communication satellites displacing Cu/W alloys with a much higher density and lower thermal conductivity, while generating a weight savings of more than 80%. These modules are also used in a number of land-based systems, which accounts for an annual production near 1 million piece-parts. With these demonstrated benefits, application of DRA MMCs for electronic packages will continue to flourish for space applications [8-12].

2 Present and future Status of application of composite materials in space structures

When continuous-fiber reinforced MMCs were no longer needed for the critical strategic defense system/missions, the development of those MMCs for space applications came to an abrupt halt. Major improvements were still necessary and manufacturing and assembly problems remained to be solved. In essence, continuous-fiber reinforced MMCs were not able to attain their full potential as an engineered material for spacecraft applications. During the same period, Gr/Ep, with its superior specific stiffness and strength in the uniaxially-aligned fiber orientation, became an established choice for tube structures in spacecraft trusses. Issues of environmental stability in the space environment have been satisfactorily resolved [1,9,12].
However, particle-reinforced metals provide very good specific strength and stiffness, isotropic properties, ease of manufacturing to near net shape, excellent thermal and electrical properties, and affordability, making discontinuous MMCs suitable for a wide range of space applications. The high structural efficiency and isotropic properties of discontinuously reinforced metals provide a good match with the required multi-axial loading for truss nodes, where high loads are encountered. DRA is a candidate for lightly-loaded trusses, while discontinuously reinforced Ti (DRTi) is more favorable for highly-loaded

trusses. DRTi, now commercially available in both the United States and Japan, offers excellent values of absolute strength and stiffness as well as specific strength and stiffness[1].

A wide range of additional applications exist for discontinuously reinforced metals. Opportunities for thermal management and electronic packaging include radiator panels and battery sleeves, power semiconductor packages, microwave modules, black box enclosures and printed circuit board heat sinks. For example, the DSCS-III, a military communication satellite, uses more than 23 kg of Kovar for microwave packaging. Replacing this metal with Al/SiC_p, which is used for thermal management in land-based systems, would save more than 13 kg of weight and provide a cost savings over Kovar components. Potential satellite subsystem applications include brackets and braces currently made from metals with lower specific strength and stiffness, semi-monologue plates and cylinders, fittings for organic-matrix composite tubes, hinges, gimbals, inertial wheel housings and electro-optical subsystems[1]. MMCs are routinely included as candidate materials for primary and secondary structural applications. However, simply having the best engineered material with extraordinary strength, stiffness and environmental resistance is no guarantee of insertion. The availability and affordability of continuously reinforced MMC remains a significant barrier to insertion. Designers who often make the decision of material selection must become more familiar with the properties, commercial availability and life-cycle affordability of existing discontinuously reinforced metals. Material performance must be integrated with innovative design and affordable manufacturing methods to produce systems and subsystems that provide tangible benefits. However, in the absence of system-pull and adequate resources, it is difficult to surmount the technical and cost barriers[8-15].

Lightweight, stiff, and strong Gr/Al and DRA MMCs will continue to be included in material trade studies for spacecraft components, as MMCs offer significant payoffs in terms of performance (e.g., high precision, survivable) for specific systems. For successful use in space applications, continuous MMCs must become more affordable, readily, available, reliable/reproducible, and repairable, exhibiting equivalent or better properties than competing graphite/ epoxy or metallic parts. Discontinuous metals, with their broad range of functional properties including high structural efficiency and isotropic properties offer the greatest potential for a wide range of space-system applications. A good understanding provided by years of research and a strong industry based on applications in the automotive, recreation, aeronautical and land-based communications markets, have established the foundation for cost-effective insertion of discontinuously reinforced metals in the space industry.

3 Genetic algorithms (GAs)

Genetic algorithm (GA) is known as a powerful tool for unconstrained optimization problems [16-20]. In this work, cross sections and material properties would be assumed as design variables. The approach is to change resize the truss members till the optimizer achieves a structure with high performance. These types of design variables make a large nonconvex design space. Also optimization problems of the sort posed here are characterized by having many variables, highly non-linear relationships between the variables and the objective function and also an objective function that has many peaks and troughs [21, 22]. In short they are difficult to deal with the search for methods that can cope with such problems have led to the subject of evolutionary computation [21]. Therefore the old optimization methods would not be recommended for these types of problems and evolutionary algorithms based on statistical principles are more useful.

4 Multidisciplinary Optimization Problem

A two-dimensional lightweight cantilever structure is studied in current paper, of which the whole structure is redesigned so that the new geometrical parameters and a new material will be selected in a multidisciplinary optimization problem to reduce vibration transmission over a 100HZ bandwidth and the structural weight.

Here optimization is achieved by the use of the GA approach. The approach was material selection among a list of MMCs and changing the cross sections of truss members. Optimization problem was solved using GA as a constrained one by new penalty functions. So, the optimization process in a stochastic search is applied to find the MMCs with best characteristics and new dimensions. The G.A. used here is fairly typical of those discussed in the well-known book by Goldberg [17] but encompasses a number of new ideas that are particularly suited to engineering design problems.

5 Initial Structure

A simple model of the main structure is two dimensional and the members are connected in a regular pattern (Fig. 1). The defined mission for the structure is to support antenna, camera and sensitive sensors in a satellite or space station. Because of the considerable length and weak joints between members, it belongs to the large flexible space structures category (LFSSs) and the vibration response and deflection both are the performance parameters in its mission. Random vibration has a special property which excites the structure in all natural modes, not in a certain frequency and several resonances occur simultaneously. Also, due to high modal densities of LFSSs the vibrations might be catastrophic and cause destabilizing effects. The periodicity of the structure causes the mode to be extended through structure and the magnitude of deformation would be increased. The space truss in Fig. 1 is constrained at the end which the joints $(0,0)$ and $(1,0)$ are taken to be pinned to ground; all other joints are free to move in $X-Y$ plane.

The beams are all either 1m or 1.414m long. All members are made of Aluminum 2024. Other physical and mechanical properties are listed below:

$EA = 69.67MN,\ EI = 2.86MNm^2$

Mass per unit length: $\bar{m} = 2.74kg/m^2$

It is excited by a point transverse force halfway between $(0,0)$ and $(1,0)$ and the damping of the structure is fixed so that the normal modes of the uncoupled beam elements all have a constant bandwidth of $20s^{-1}$.

A finite element model (FEM) for this structure is developed using Euler-Bernoulli beam theory and a consistent mass matrix formulation. For example, damping model for Aluminum was considered in the form of a proportional model expressed by Eq.1. In which selecting the values α= 0.0 and β=20.0 reflect a lightly mass proportional, damped structure.

$$[C]=\alpha[K]+\beta[M] \qquad (1)$$

6 Formulation of Optimization Problem

One of the objectives of design problem considered here and in other studies [21], is vibration response (or Vibration Transmission) at the end beam of structure. This function is defined by Eq. 2.

$$J=\int_{150HZ}^{250HZ}\sum_{j=10}^{11}\sqrt{v_{xj}^{2}+v_{yj}^{2}}\,df \qquad (2)$$

The frequency response of initial structure is observed in Fig. 2. Many peaks and troughs are seen in the range of 150-250Hz, which remark the high modal density of the structure in this range.

The mission of structure, implies that the vibrational response be reduced in the broadband-frequency region(100Hz band).

Designer should determine the relative importance of two objectives with proper C_1 and C_2 coefficients.

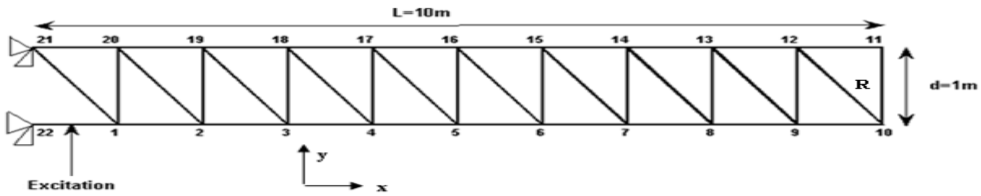
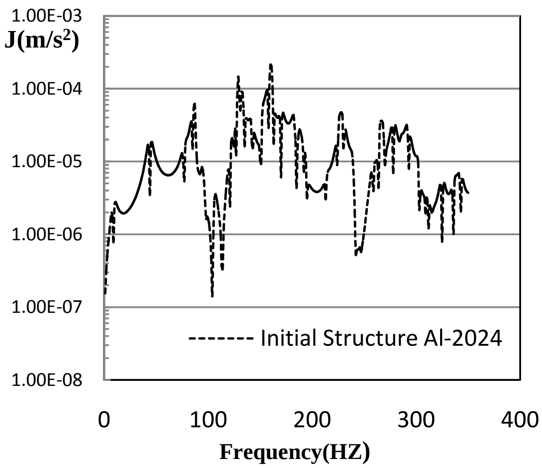


Fig. 1 Configuration of Initial Design as a LFSS with Periodic Pattern.



A summary of governing equations and constraints are collected in Eq. 3.

$$\begin{cases} Max \rightarrow \varphi(\overline{x}) = 3 - \left(C_1\ \overline{W} + C_2\ \overline{J}\right) \\ Subject\ to: \begin{cases} \mathrm{W} \le \mathrm{W_i} \\ J \le J_i \\ \mathrm{R_{i_{min}}} \le \mathrm{R_i} \le \mathrm{R_{i_{max}}} \\ \mathrm{R_{O_{min}}} \le \mathrm{R_O} \le \mathrm{R_{O_{max}}} \end{cases} \end{cases} \tag{3}$$

$$\overline{W} = \frac{W}{W_{\max}} = \frac{W}{231.2} \quad \text{و} \quad \overline{J} = \frac{J}{J_{\max}} = \frac{J}{0.006}$$

$$C_1 + C_2 = 1$$

Where, $\varphi(\overline{x})$ is the objective function in a maximization formula to be used in Genetic Algorithm. $\overline{W}$ and $\overline{J}$ are non-dimensional forms of weight and vibration transmission, respectively. As it was stated in problem description, the cross section of truss members would be changed during optimization. Hence, the Aluminum rod elements are replaced with tubes elements with new dimensions $\mathrm{R_i}$ and $\mathrm{R_o}$, i.e. $\mathrm{R_i}$ and $\mathrm{R_o}$ are interior and exterior radii respectively.

The optimum solution must be better than the initial structure from the points of weight and vibration characteristics, so by using penalty functions, these constraints have been considered in governing equations of optimization. An optimality function represented by $F(\overline{x})$, is defined by Eq.4.

$$\begin{cases} F(\overline{x}) = \varphi(\overline{x}) - \alpha . P(\overline{x}) \\ P(\overline{x}) = k_1\ (\overline{W} - 1) + k_2\ (\overline{J} - 1) \end{cases} \tag{4}$$

Where

α : Penalty Factor

$P(\overline{x})$: Penalty Function

Also a relation to express vibration transmission in "decibel" unit is in Eq. (5).

$$VTR(dB) = 20 \log \frac{\overline{J}_{Initial\ \mathrm{Structure}}}{\overline{J}_{Optimized\ \mathrm{Structure}}} \tag{5}$$

7 GAs Parameters and Design Variables

In optimization process, design variables are cross sections and the material properties which are considered in governing equations in Eqs.3.

The main parameters used to control the stochastic method of optimization may be summarized as follows:

$\mathrm{N_{gen}}$: the number of generations allowed to stop the process; $\mathrm{N_{i_{pop}}}$:the initial population size or number of trials used to start the process; $\mathrm{N}_{m_{pop}}$ the number of middle population after applying the Genetic operators on initial population.

P[mutation]: The proportion of the new generations'genetic material that is randomly changed.

P[crossover]: The proportion of the surviving population that are allowed to breed.

P[elitist]: The proportion of the current population that has high order optimality and would be entered to next generation.

The values assigned to these parameters are as below and during several optimization processes, would not be changed.

Table 1. GA Variables in this Study.

GA operators		*GA parameters*	
P[MUTATION1]	100%	N_{gen}	*Variable*
P[MUTATION2]	100%	$N_{i_{pop}}$	*20*
P[Crossover1]	60%	$N_{m_{pop}}$	*84*
P[Crossover2]	60%		
P[Elitist]	2%		

The portion of vibration transmission in multidisciplinary objective function is assigned by designer equal to 70% (C_2 = 0.7) and for structural weight this portion is 30% (C_1 = 0.3).
This multidisciplinary optimization has some constraints which have been considered as penalty functions and their effects on optimization process were investigated in reference [23]. It was revealed that linear dynamic penalty factor (LDPF) has an accelerating effect on convergence to optimal solutions and reduces the cost of calculations. In contrast the death penalty factor (DPF) decreases the convergence rate. Thus in this study, GAs is applied with LDPF to seek optimum solutions.

8 Results of Optimization

As it was mentioned earlier, the optimization used here is based on resizing the truss members cross section and material selection for the structure. The high structural efficiency and isotropic properties of discontinuously reinforced metals provide a good match with the required multi-axial loading for truss nodes, where high loads are encountered. Specially, DRA is a candidate for lightly-loaded trusses.
With respect to benefits and workability of Metal Matrix Composites (MMCs) in space structural design especially DRA which was discussed in introduction, a set of these materials are considered in Table 2 as a database for material selection in optimization process. In addition, some conventional metal alloys in space structures are considered in this database.
The magnitude of deformation in structure due to vibrations and dynamic loads is directly dependent on natural frequency of the structure and originally the natural frequency is proportional to the modulus of elasticity. Hence, the modulus of elasticity of a MMC has a essential role in behavior of the structure susceptible to vibrational environment. The other important parameters in material selection considering the application of the structure in space mission are the density and coefficient of thermal expansion (CTE). Some of data for these materials are inserted in table2.
It was assumed that during the stochastic search, geometric parameters R_O and R_i of structural elements deviate from the values in initial structure. The search was continued to ensure the convergence of optimization process to optimum solutions.
In each case of optimization, the radii of tubes are constrained during optimization.

When the constraints on geometrical parameters were considered as:

$1.5\text{ cm} \le R_O \le 2.5\ cm \qquad 0.7\text{ cm} \le R_i \le 1.3\text{ cm}$

The optimization process was continued to 100 generations to ensure the convergence to optimum geometric values and the best material satisfying the weight and vibration filtering criteria. The convergence process versus evolutionary generation number is plotted in Fig. 2. The selected material after 100 generations is Al-6061 T6-10%Gr which its properties are shown in Table 2. Also the optimum values of tube cross sections obtained as $R_i = 0.71$ cm and $R_O = 1.5$ cm respectively.
Fig.3 shows the vibrational behavior of the optimum design made of composite material Al-6061 T6-10%Gr in comparison with initial structure made of Aluminum in the bandwidth of 150-250HZ. It was demonstrated that the filtering capability of new design has been improved for the whole 100 HZ frequency range. Using Eq. 2 yields an average of vibrational energy for the whole 100HZ bandwidth which signifies that the vibration filtering capability of new design is increased equal to 7.2 dB.

Table 2. List of materials as a database in material selection in optimization process.

Material		***Yield Stress (MPa)***	***Ultimate Strain %***	***Young's Modulus (GPa)***	***Thermal Conductivity*** $(cal\ cm^{-1}\ s^{-1}\ K^{-1})$	***CTE*** $(10^{6} K^{-1})$	***Density*** (kg/m^{3})
Name	***Composition***	200	6.0	75.2	0.360	21.4	2800
A356-T6	**AlSi7g**	303	1.2	86.9	-----	20.7	2835
F3S.10S-T6	**AlSi9Mg10SiC**	338	0.4	98.6	0.442	17.5	2871
F3S.20S.T6	**AlSi9Mg20SiC**	359	0.3	87.6	0.360	20.2	2700
F3K.10S-T6	**AlSi10CuMgNi10SiC**	200	6.0	75.2	-----	21.4	2800
A390		241	3.5	71.0	0.36	21.4	-----
F3D.10S-T5	**AlSi10CuMnNi10SiC**	331	1.2	93.8	-----	20.7	2787
F3D.20S-T5	**AlSi10CuMnNi20SiC**	400	0.0	113.8	0.442	17.5	2610
F3D.20S-T5	**AlSi10CuMnMg10SiC**	317	0.5	91.0	-----	20.2	2710
F3N.20S-T5	**AlSi10CuMnMg20SiC**	338	0.3	108.2	0.346	17.8	2820
6061 –T6	**+10%Al_2O_3**	335	7	83	0.384	20.9	2795
6061 –T6	**+15%Al_2O_3**	340	5	88	0.336	19.8	2839
6061 –T6	**+20%Al_2O_3**	365	3	95	-----		2860
6061 -T6	**+20%SiC**	397	4.1	103.4	----	15.3	2870
6061 -T6	**+30%SiC**	407	3.0	120.7	----	13.8	2840
7090-T6		586	10.0	73.8	----	----	2750
7090-T6	**+30%SiC**	676	1.2	124.1	----	----	124.1
6092-T6	**AlMg1CuSi17.5SiC**	448	8.0	103.0	----	----	2714
6092-T6	**AlMg1Cu1Si25SiC**	530	4.0	117	----	----	2752
6061-T6	**15%Al_2O_3**	317	5	87.6	----	----	2839
2618-T6	**+13%SiC**	333	----	89.0	----	19.0	2846
2618-T6	**+12%SiC**	486	----	100.1	----	----	2790
Az91	**+20%AL_2O_3**	----	----	55	----	----	2017
AZ80	**+10%SiC**	----	----	54	----	----	1882
AZ80	**+20%SiC**	----	----	64	----	----	1973
AZ80	**+30%SiC**	----	----	76	----	----	2071
Ti	**+10%SiC**	----	----	126	----	----	4514
Ti	**+20%SiC**	----	----	137	----	----	4317
6061-T6	**+10%C(Graphite)**	----	----	85	----	----	2714
6061-T6	**+15%C(Graphite)**	----	----	90	----	----	2752
6061-T6	**+25%C(Graphite)**	----	----	101	----	----	2800
6061 alloy	**+10%(Gr,Al_4C_3)**		4.3	69	----	----	2450
6061 alloy	**+20%(Gr,Al_4C_3)**	285	1.5	77	----	----	2979
6061-T6	**+10%TiB_2**	317	8.0	91	----	----	2579
6061-T6	**+20%TiB_2**	----	----	110	----	----	2405
6061-T6	**+30%TiB_2**	----	----	131	----	----	2500

Also the new design constructed of tubes made of Al-6061 T6-10%Gr is considerably lightweight than the initial structure made of aluminum rods. The weight reduction of the optimum design is 42%.

When the constraints on geometrical parameters were considered as:

$R_O = 1.0$ cm=const $\quad 0.25 \text{ cm} \le R_i \le 0.8$ cm

The optimization process was continued to 48 generations to ensure the convergence to optimum geometric values and the best material satisfying the weight and vibration filtering criteria.

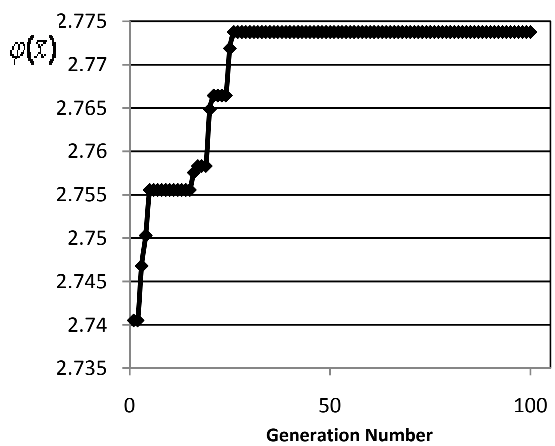


Fig.2. Convergence Diagram of Multidisciplinary Objective Function ($\varphi(\bar{x})$) Versus Generation Number for Constraints of $1.5\ cm \le R_o \le 2.5\ cm$ and $0.7\ cm \le R_i \le 1.3\ cm$

The convergence process versus evolutionary generation number is plotted in Fig. 4. The selected material after 100 generations is Al-6061 T6-30%SiC_P which its properties are shown in Table 2. Also the optimum values of tube -cross sections obtained as $R_i = 0.33cm$ and $R_O = 1.0cm$ respectively.

Fig. 5 shows the vibrational behavior of the optimum design made of composite material Al-6061 T6-30%SiC_P in comparison with initial structure made of Aluminum in the bandwidth of 150-250HZ. It was demonstrated that the filtering capability of new design has been improved for a 100 HZ frequency range.

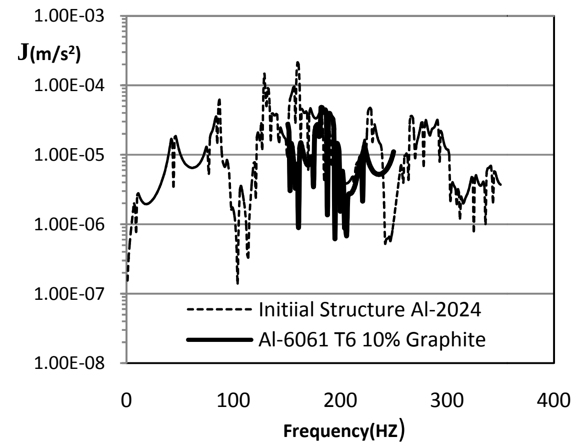


Fig.3. Optimized Design for C_1=0.3, C_2=0.7 with Constraints of $1.5\ cm \le R_o \le 2.5\ cm$ and $0.7\ cm \le R_i \le 1.3\ cm$ in 8400 Evaluations Over 100 Generations (Weight Reduction is 42% and filtering capability is increased as 7.2 dB).

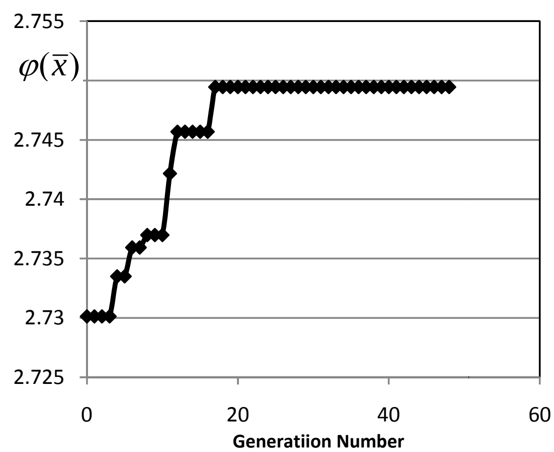


Fig.4. Convergence Diagram of Multidisciplinary Objective Function ($\varphi(\bar{x})$) Versus Generation Number for Constraints of $R_o = 1.0\ cm = const$ and $0.25\ cm \le R_i \le 0.8\ cm$

Using Eq. 2 yields an average of vibrational energy for the whole 100HZ bandwidth which signifies that the vibration filtering capability of new design is increased equal to 3.62 dB. Also the new design constructed of tubes made of 6061 T6-30%SiC_P is considerably lightweight than the initial structure made of aluminum rods. The weight reduction of the optimum design is 70%.

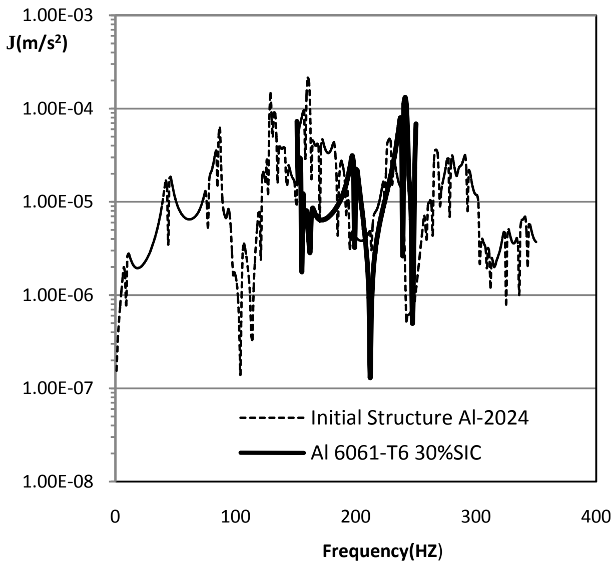


Fig.5. Optimized Design for C_1=0.3, C_2=0.7 with Constraints of $R_o = 1.0\ cm = const$ and $0.25\ \text{cm} \le R_i \le 0.8\ \text{cm}$ in 4032 Evaluations Over 48 Generations (Weight Reduction is 70% and filtering capability is increased as 3.62 dB).

9 Conclusions

In current study, optimization of a space truss to reduce the weight and vibration transmission in a 100HZ bandwidth was performed by resizing the cross sections of truss members and selecting the new material among a database of MMCs. As it was explained in introduction, GA as a stochastic search method is a recommended method for this type of problems which the design space is highly non-convex and the objective functions are quite nonlinear. Also, another important aspect of this problem was material database preparation among MMCs which due to sensitivities of these types of composites, it was recognized more reliable to select the database materials among those with former applications in space structures with similar missions. Hence, at the beginning, a literature survey for applications of composite materials in space practical missions was presented. According to the literature, the high structural efficiency and isotropic properties of discontinuously reinforced metals provide a good match with the required multi-axial loading for truss nodes, where high loads are encountered. Specially, DRA is a candidate for lightly-loaded trusses.

Two optimization problems with two different constraints on geometrical variables were considered. Each process was continued by GAs program to ensure the convergence to optimum geometric values and the best material satisfying the weight and vibration filtering criteria.

It concludes that:

In the first optimization, the selected material was Al-6061 T6-10%Gr . Also the optimum values of tube cross sections obtained as $R_i = 0.71$ cm, $R_O = 1.5$ cm respectively. It was demonstrated that the filtering capability of new design has been improved for the whole 100 HZ frequency range. The averaged vibration filtering capability of new design is increased equal to $7.2\,dB$. Also the new design constructed of tubes made of Al-6061 T6-10%Gr is considerably lighter than the initial structure made of aluminum rods. The weight reduction of the optimum design is 42%.

In the second optimization, the selected material was Al-6061 T6-30%SiC_P and the optimum values of tube cross sections were obtained as $R_i = 0.33$ cm, $R_O = 1.0$ cm respectively. It was demonstrated that the filtering capability of new design has been improved for the whole 100 HZ frequency range. The averaged vibration filtering capability of new design is increased equal to $3.62\,dB$. Also the new design constructed of tubes made of Al-6061 T6-30%SiC_P is considerably lighter than the initial structure made of aluminum rods.

So, as it was revealed after two optimization processes, the best composite materials among the database with discontinuous reinforcements were selected as Al-6061 T6-30%SiC_P and

Al-6061 T6-10%Gr . The modulus of elasticity of these two DRAs has an essential role in behavior of the space structure susceptible to vibrational environment. This characteristic refers to the magnitude of deformation in structure caused by vibrations and dynamic loads which is directly dependent on natural frequency of the structure and originally the natural frequency is proportional to the modulus of elasticity

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