Novel Aspect of Composite Sandwich Fairing Structure Optimization of a Two Stages Launch Vehicle using MDO Independent Subspace Approach

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Abstract: In this paper, a novel composite sandwich structure analysis of Launch Vehicle (LV) fairing is considered and proposed by a new Multidisciplinary Design Optimization (MDO) for a two-stage launch vehicle. Accordingly, "Multidisciplinary Design Optimization based on Independent Subspaces" (MDOIS) is employed using the "Fixed Point Iteration" (FPI) method to achieve the best convergence at system level (SL) to segregate the disciplines. Therefore, two proposed subspaces overcome difficulties of common mentioned MDO of LVs. By considering variables as propulsion, trajectory and also composite sandwich fairing structure design regarding to the variables of designing and the performing optimization process, the fairing mass has been reduced more and considerably with respect to the common two stages LVs.

Keywords: Composite sandwich structure, Fairing, Launch vehicle, MDO, MDOIS, System analysis

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1 INTRODUCTION

From systems engineering point of view, any vehicles can be considered as a "System of Interest" (SOI) which include definable subsystems [1]. In a systemic design, every subsystems are defined in the system architecture to satisfy specific requirements and has a respective functions [2]. According to the mentioned concepts, to satisfy the constraints of all subsystems in designing process of vehicles which is taken into account as complicated systems, it seems necessary to consider systemic (multidisciplinary) design approaches [3]. It is feasible to use "simulation based design" approach in designing of the complicated systems[4].

For this purpose a batch of integrated modules are responsible for design analyzing in operational domain not only to determine requirements of both vehicle and mission, but also to examine the optimality level of designing. By defining a specific criterion for a nominated designing solution, system's constraint can be taken into account. For an example, LVs structural constraints are the system requirements similarly; mission's requirement such as velocity and height can be considered as trajectory constraints. The comprehensive module, which includes analytical modules of designing disciplines and guarantees the interdisciplinary consistency is named Multidisciplinary Design Analysis (MDA).

As a matter of fact, to design a multidisciplinary system it seems needful to enjoy multidisciplinary analytical tools in order to analyze the effects of different design disciplines on the each other, subsequently, MDO methodologies are necessary to achieve the best design solutions. MDO is a design optimization which considers interactions of some engineering disciplines simultaneously to prepare better and more efficient solutions during design process of complex systems [5]. The MDO organization, which includes the role of both design disciplines coupling and their relations with optimizers are called MDO architecture. Up to now, different types of architectures with various applications have been proposed by the researchers and recently they have been well categorized and described by Martins and Lambe [6].

Due to many scientific and technologic competitions, in spite of the spending cost and time for such competition, a lot of researches have been done on MDO of LVs. Nicholas et al [7] had proposed a methodology to design an Expendable LV (ELV) about post ARIANE5 European launchers family. Lee et al[8], optimized the fairing nose geometry of a space vehicle by refined Response Surface Method. Moreover, Braun et al. [9] focused on the application of Collaborative Optimization (CO) architecture to the multidisciplinary design of a single-stage-to-orbit LV. Next review is belonged to the Brigss et al. [10] who have examined the initial modeling of a medium LV capable of placing a payload into the geostationary transfer orbit. Bayley [11] performed design optimization of a multi-stage-to-orbit LV using genetic algorithm (GA) to minimize the weight and cost of the vehicle concurrently. Then, Rafique et al. [12] had proposed a novel method for MDO of an air-launched-space LV by using a hybrid of GA and Sequential Quadratic Programming (SQP).

Rafique et al. aimed to deliver a satellite of 200kg to Low Earth Orbit (LEO) with minimum possible gross launch weight. Furthermore, Jodei et al. [13] developed the system sensitivity analysis method for MDO of a two-stage solid-propellant LV. Hosseini and Toloie in reference [14] developed MDO of a multi-stage-to-LEO by minimizing the gross weight and cost of LV. At the same year, Ebrahimi et al. [15] applied Particle Swarm Optimization (PSO) algorithm to MDO of a solid-propellant LV. Their proposed method not only maintained quality of the solution, but also could considerably reduce the cost of calculations.

However, Aldheeb et al. [16] employed differential evaluation method to optimize the trajectory design of a micro LV. At the same year, Balesdent et al. [17] proposed a MDO method based on transversal decomposition of design process which was more appropriate with multi-stage LV architecture. In addition, Balesdent [18], acquired advantages and the drawbacks of MDO methods about LV design problem. Next, Castellini et al. [19] presented both engineering models and optimization algorithms for MDO. Moreover, Darabi et al. [20] examined capability of CO method and evolutionary algorithms to solve multidisciplinary problems with the intention to reduce weight of a liquid-propellant LV.

There are no valuable and praiseworthy researches in the field of LV optimization by MDO w.r.t structure analysis specifically, sandwich structures for LVs. Sandwich structure optimization can perform as a single-discipline beside other disciplines to increase the effectiveness of MDO. However, researches in the field of sandwich structures was belonged to the other fields. For an example, Salimi et al. [21] proposed an optimized design of marine composite sandwich structures subjected to the underwater explosion.

In their research, structure analysis and optimization process were performed by Finite Element Method (FEM) and GA respectively. In this way, Yuan et al. [22] modeled the aircraft fuselage as a composite sandwich cylinder shell. Then, they optimized the structure by using FEM with intention to minimize the total weight. The design constraints were the structural stability and composite failures criteria. Afterwards, Yuan et al. [23]

optimized the sandwich composite cylinders which are applicable to airplane fuselages. They developed both the comprehensive GA optimization method and acoustic transfer vector method to minimize the internal pressure of airframes.

It has been shown that optimization method is able to improve efficiency of the calculations and set an excellent compromise between weight, mechanical performance as well as acoustic characteristics of the sandwich airframe. At the same year, Ullah et al. [24] proposed an approach to conceptual design and evaluation of LV by multi attribute decision making analysis that is utilizable in the early phase of the aerospace system design and decision making.

Ma et al. [25] examined the design and optimization of both the shape and the material gradient of the sharp hot structure to meet the hypersonic Flight Conditions (FCs). To this end, GA and ABAQUS software were used to optimize the shape of the structure and simulate both the temperature and the stress distribution with different material gradients for the structure respectively. Furthermore, in 2015 Ebrahimi and Vahdat Azad [26] performed the sensitivity analysis and the multi-objective optimization of honeycomb sandwich cylindrical columns under axial crushing loads.

They optimized different models of the structure by PSO algorithm to reach maximum specific energy absorption capacity and minimum peak crushing force. Finally in this literature review, Baroutaji et al. [27] studied thin wall sandwich tubes with aluminum foam core that laterally crushed under quasi-static loading conditions.

In this paper, at first step, LV's design analysis including sandwich structure analysis of LV fairing has been considered. To reach the optimization process convergence, due to the two-way coupling existing between structure and trajectory of vehicle, the optimization distribution approach has been adopted in the design domain by using MDO Independent Subspace (MDOIS) approach.

Moreover, in the proposed architecture, convergence trend at system level (SL) has been performed by "Fixed Point Iteration" (FPI) method as an iterative process. Next, to segregate the subjects, two subspaces have been proposed as novelties for this LV problem. The first subspace is a MDO which includes propulsion, aerodynamics, weight, trajectory disciplines and the second subspace includes fairing structure optimization as a single- discipline optimization. The details of these design subspaces will be described. Finally, results and achievements of this research demonstrate new and novel views for next research in the field of MDO especially, MDOIS for LVs for the future studies.

2 MDO CONCEPT

2.1. History

The main idea of aerospace system overall optimization has been proposed by Ashley in 1982 [28]. He has stated, that there are more than 8000 papers about optimal control, optimization, aerodynamic optimization as well as structural optimization, but there is no even one paper about design optimization of an aerospace vehicle.

Sobieski has written an important paper in 1991 about MDO as a new design approach which has the potential to be able to accomplish the purposes stated in the above paragraph [29]. This paper, which is sited in most MDO papers, could be known as the formal beginning of MDO usage.

According to Sobieski's definition, MDO is a design optimization which considers interactions of some engineering disciplines simultaneously to prepare better and more efficient solutions during design process of complex systems. MDO method with design automation brings high-speed computers to help humans' intelligence and genius. By doing so, the optimized results, according to costumers' requirements, is reached in a shorter time interval in comparison with common methods. This could be known as one of the most important advantages of MDO.

After introducing MDO to research councils and highlighting its advantages and capabilities, many researchers were interested to hear more about this method. At the same year, the technical committee of MDO was formed in "American Institute of Aeronautics and Astronautics" (AIAA). In 1992, "International Society of Structural and Multidisciplinary Optimization" (ISSMO) was held. This trend was such that more than 2000 papers were written until 1996 [30].

2. 2. MDO Architectures

One of the most important considerations during MDO execution, to reach an optimized design, is how disciplinary analytical models are organized in optimization structure. This organization, which includes the way of both design disciplines coupling and their relations with optimizers, is called MDO Architecture. The MDO Architecture could be defined in different categorizations such as single-level structures (e.g. IDF and MDF) versus multi-level ones (e.g. CO).

Martins and Lambe (2013) [31] have categorized these methods according to a novel view. The architecture categorization with a brief definition of each one have been shown in Fig. 1. Of course, the categorization does not necessarily cover all probable states to implement MDO and researchers are still examining new methods and proposing novel structure according to their specific problems.

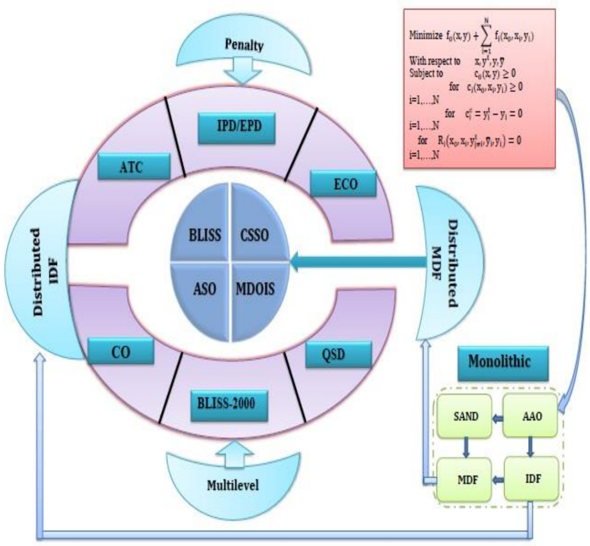

Fig. 1 Categorization of several MDO Architecture [31].

3.1. Problem Definitions

Space systems design problem is complicated with intense coupling between design disciplines such as space sections, launcher as well as ground sections. One of the space systems characteristics is that a small change in the system (or in a subsystem) could have drastic effect on other systems (or subsystems) and also can affect other technical characteristics. Therefore, the most important aspect of space systems design is that which mission and design elements affect mainly on LV to satisfy design requirements.

To convert a space system design problem to a constrained optimization one, cost function, design variables and their upper and lower bounds should be determined. Similarly, in the following step, both equality and inequality constrains, which define limited domain, should be determined. Cost function, quantify the amount of design optimality and acts as a criterion which shows the direction of search. Constraints determine the feasible design. Finally, the constrained optimization problem in mathematical form (for conceptual design of a space system), is defined as an algorithm that evaluates appropriate solution alternatives according to evaluation criteria, and results the best one.

In this research, the problem is MDO of a two-stage liquid-propellant LV with the concentration on the fairing structure optimization. The mission of the LV is to carry a fifty-kilogram satellite to the two-hundred-kilometer circular orbit (the orbital speed of 7784 meter per second). On this basis, the steps which should be performed are as follows: According to the problem which is conceptual design of a LV, five disciplines including propulsion, structure, weight, aerodynamics and trajectory are more influential in comparison with other disciplines such as aerodynamic heating and guidance algorithms, navigation, control, etc. Hence, in this research, the five stated disciplines will be used in the MDO architecture.

3.2. Propulsion Analysis

In this carrier, a liquid-propellant propulsion system has been used. In references, there are various algorithms for propulsion calculations with different fidelity. In this work, specific impulse (*Isp*) is given and thrust is a function of burning rate which is obtained by [21]:

$$Thrust = Isp \times \dot{m}$$

Where $\dot{m}$ is the burning rate or the input propellant mass into the engine (as the design variable), and Isp is specific impulse of engine (as design parameter). It should be mentioned that in this problem, to reduce the number of design variables and to facilitate the optimization convergence, the 2nd stage thrust has been considered constant, and only the burning rate of 1st stage (and consequently related thrust) is considered as the propulsion variable.

3.3. Weight Analysis

Total mass of LV includes propellant, structure of stages (engine, reservoirs and other compartments), payload and fairing. According to the fact that change in the burning rate or the burning time of stages, changes the propellant mass and also the fairing mass is changing in optimization process, this module is responsible to overall mass variations of LV.

3.4. Trajectory Analysis

To analyze the pitch angle of LV, the “three degree of freedom” (3DoF) analysis was performed by Trajectory Program [13]. In this module, 3DoF equations, are numerically integrating over time by initial condition. The LV has been taken into account as a point mass, and the Earth has been considered rotational and also elliptical. To model the atmosphere, the 1976 standard atmosphere (without wind) has been used. By using this module, eventual trajectory constraints (including altitude, velocity, and path angle), and also maximum dynamic pressure is calculated. In this paper, the eventual constraints are considered as design constraints of first subspace, and maximum dynamic pressure has been considered as input of second design subspace.

3.5. Aerodynamic Analysis

In the conceptual design phase of a LV, aerodynamic analysis needs high-speed calculation methods to be able to enjoy them in flight trajectory simulation. Certainly, numerical methods based on solution of Navier-Stokes equations are not useful for this application. One of the fast ways, with a mediocre precision, which is appropriate to use in conceptual design of LVs, is MD99 [32] which is comprehensively utilized in aerospace industry. In order for MD99 to use in MDO structure, after vehicle sizing and overall dimensions' determination, the software is running, and its outputs as function of flight conditions (FC), which include angle of attack, Mach number and altitude, are saving. Afterward, during trajectory simulation, at different FC, new data are interpolated according to the available data table (software outputs).

3.6. Structure Analysis

The fairing structure includes a flexible core and a composite sandwich shell which is formed from two conical and cylindrical sections. The geometrical parameters of conical (and cylindrical) sandwich shell of fairing have been shown in figure 2. Since common theories are not able to predict local effects and precise deformations in the core direction, the high order analytical model proposed in [33], which is able to consider effects of core flexibility, is used.

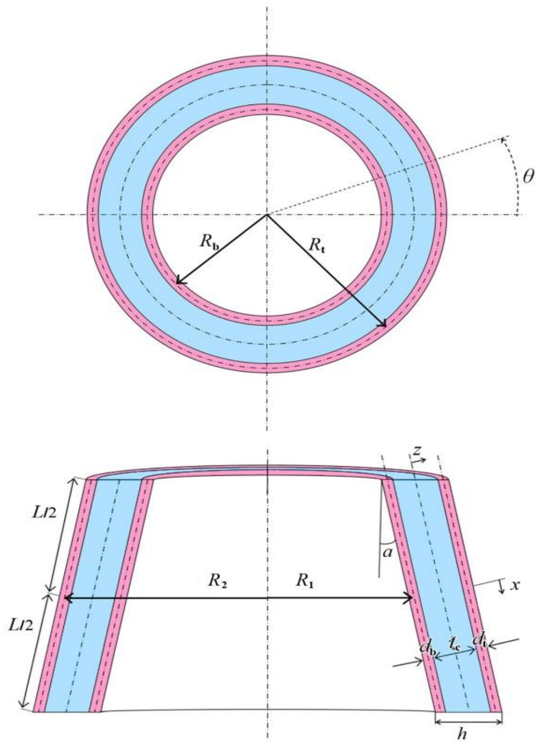

Fig. 2 Geometrical parameters of conical composite sandwich shell of fairing [33].

In this approach, to obtain critical buckling loads of the intended structure, the equations of motion as well as boundary conditions are obtained by using energy method and Hamilton principle. Then, governing equations are presented according to displacement components which include longitudinal, circumferential and radial displacements of mid-plane of surfaces, and their rotational components as well as shear stresses of core. Finally, twelve equations and twelve unknown parameters are resulted. To obtain the solution of conical composite sandwich shell, due to complexity of the problem, the response is considered as powered series. Then, by applying the boundary conditions on both ends of the cone, the coefficients matrix of the series is resulted. Afterwards, by equating the determinant of the coefficients matrix with zero, the critical buckling loads (p_{cr} and q_{cr}) and relevant mode shapes are reached, where p and q are axial compressive load and distributed external pressure perpendicular to the surface respectively. (The details of equations deriving and how to calculate buckling loads have been explained in [33]). Accordingly, structure analysis module will be a black box which receives structure loading (p and q) and also geometrical variables of structure as inputs, and presents critical buckling loads of the structure (q_{cr} and p_{cr}) as the module outputs.

3.7. Design Structure Matrix

To exhibit the relation existing between above analytical modules, Design Structure Matrix (DSM) has been shown in figure 3.

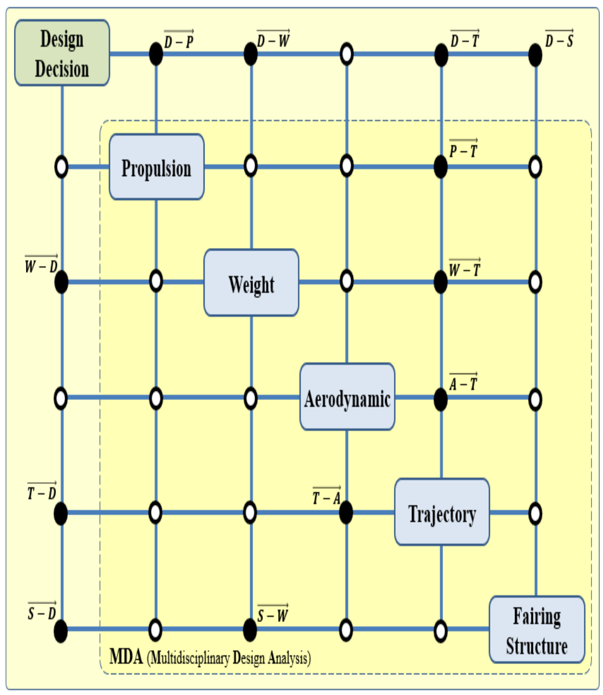

Fig. 3 Design Structure Matrix.

The interdisciplinary variables which have been shown in figure 3 have been defined in the Table 1.

Table 1 Explaining of proposed interdisciplinary variables vectors in this research

Vector	Explaining
$\overrightarrow{D-P}$	Burning rate of the 1st stage
$\overrightarrow{D-W}$	Burning rate and burning time duration of the 1st stage
$\overrightarrow{D-T}$	Trajectory characteristics (pitch program variables)
$\overrightarrow{D-S}$	Geometrical characteristics of sandwich structure
$\overrightarrow{P-T}$	Thrust of the 1st stage
$\overrightarrow{W-T}$	Gross Mass
$\overrightarrow{A-T}$	Aerodynamic forces coefficients
$\overrightarrow{T-A}$	FC
$\overrightarrow{S-W}$	Fairing mass
$\overrightarrow{S-D}$	Critical loads
$\overrightarrow{T-D}$	Final path angle, Final altitude, Final velocity, p_{max}, q_{max}
$\overrightarrow{W-D}$	Gross Mass

4 FORMULATION OF LV'S MDO

As was determined in the previous section, two analytical blocks in design space had intense bidirectional coupling. Hence, to reach convergence, the iterative methods are needed. However, fortunately optimization distribution in space could be used and each design constraint be satisfied by one of optimizers, because outputs of analytical modules towards optimizers are from these two blocks. The schematic of optimization distribution and FPI logic usage to reach convergence, has been shown in Figure 4.

The details of this optimization distribution will be explained in the following sections.

4.1. Subspace1: System Design

The design subspace is, itself, a MDO of MDF class due to the fact that design-subspace includes four disciplines of propulsion, weight, aerodynamics and trajectory. As has been explained, bidirectional coupling between aerodynamics and trajectory does not forces MDA to use iterative methods and proceeds by reciprocating approach during simulation time. The characteristics of the design subspace will be explained as follows.

- **Optimization Algorithm**: According to the fact that systemic design space of LV is intensely non-linear and has many local optimums, it is better for this subspace to use optimization algorithms which perform global searches. Here, GA is used.
- **Design Variables**: Burning rate and burning time of 1st stage motor as well as pitch program variables.
- **Constraints**: Final velocity, altitude and path angle should be equal to 7784 m/s, 200 km, and 0 respectively.
- **Objective Function**: Weight of lunch.
- **Design subspace outputs**: Maximum imposed aerodynamic pressures on fairing structure during simulation.

As has been explained before, according to the fact that fairing mass is calculated from fairing structure design subspace, the fairing mass is considered as a parameter (constant) in this step.

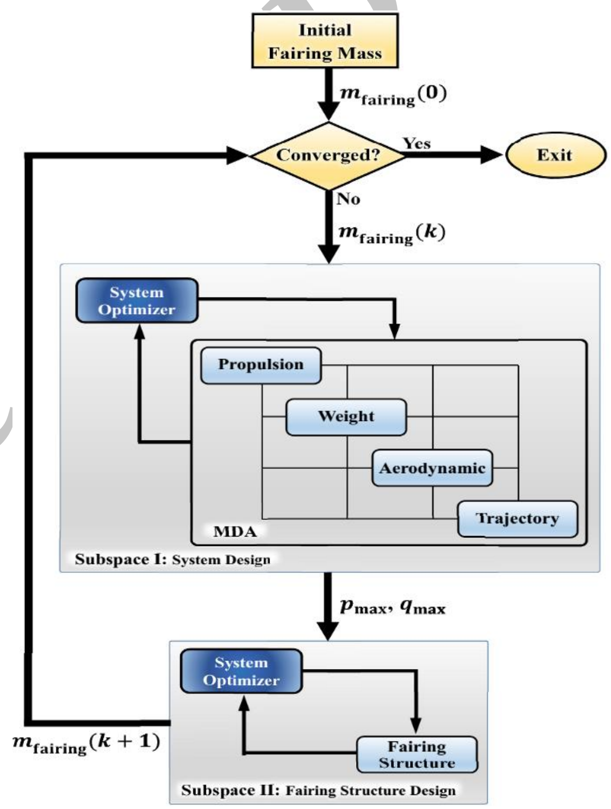

Fig. 4 Proposed formulation for MDO of LV.

4.2. Subspace2: Fairing Structure Design

According to the fact that this design subspace has one design discipline, the consideration is only a simple optimization (single-discipline). The optimization characteristics will be explained as follows.

- **Optimization Algorithm**: In this subspace, the Simplex algorithm, whose process begins with an initial point, has been used, because the space of fairing structure design is simpler and has fewer local minimums than the design subspace1.
- **Design Variables**: design variables of fairing structure are: thickness of the inner face sheets (d_b), the number of the inner face sheets (n_b), thickness of the core

(t_c), thickness of the outer face sheets (d_t), the number of the outer face sheets (n_t). In this paper a particular set of laminated cones, namely, regularly anti-symmetric cross-plied cones, are considered.

- **Design constraint**:

$$\frac{p}{p_{cr}} + \frac{q}{q_{cr}} \leq 1$$

- **Objective function**: minimizing the fairing mass
- **Design subspace output**: fairing mass

Here, aerodynamic loads p and q are design parameters (constant) which enter to this subspace from systemic design subspace.

Table 2 The results of MDO via reciprocation of data between design subspaces

Iteration	Design Subspace	Fairing Mass (kg)		$p_{critical}$ (N)	$q_{critical}$ (pa)	Gross Mass (kg)
0	Initialize	100				
1-1	System	100	→	45542.157	102130	25984.599
1-2	Structure	59.263	←	45542.157	102130	25984.599
2-1	System	59.263	→	44597.249	102130	25247.543
2-2	Structure	57.8531	←	44597.249	102130	25247.543
3-1	System	57.8531	→	44571.384	102130	25223.464
3-2	Structure	57.81406	←	44571.384	102130	25223.464
4-1	System	57.81406	→	44570.674	102130	25222.799
4-2	Structure	57.81298	←	44570.674	102130	25222.799
5-1	System	57.81298	→	44570.655	102130	25222.780
5-2	Structure	57.812955	←	44570.655	102130	25222.780
6-1	System	57.812955	→	44570.654	102130	25222.780
6-2	Structure	57.812954	←	44570.654	102130	25222.780
7-1	System	57.812954	→	44570.654	102130	25222.780
7-2	Structure	57.812954	←	44570.654	102130	25222.780

4.3. Optimization Results

To obtain the result, initial fairing mass is considered 100 kg and FPI process began with systemic optimization. During the optimization, p_{max} and q_{max} have been equal to 45542.157 N and 102130 pa respectively. By choosing FPI approach, this time is structural optimization turn. At the first step of structural optimization, fortunately the weight of fairing was reduced about 40 kg. The results of this iterative process, and also the trend of fairing mass decrease in any iterative of FPI trend have been shown in table 2 and figure 5 respectively.

In Table 2, each row is related to optimization process in each design subspaces. Arrows direction shows optimization process in such a way that the parameters of each subspace (the output of previous optimization subspace) are considered as constant, and after optimization process, the subspace output is calculated (as the parameter for next subspace).

As can be seen, by running optimization process, fairing mass has been reduced from 100 kg to 57.8 kg which shows about forty-two-percent decrease. In addition, fairing mass decrease has affected gross mass of LV and has reduced it from 26 tons to 25.2 tons (about three-percent decrease), because systemic design of LV has been performed in addition to structural optimization. The reason of 780 kg decrease in weight of LV is the fairing consideration as the payload of stages. As a matter of fact, about 780 kg decrease in weight of LV is the result of about forty-two kg decrease in fairing weight. This systemic effect represents the importance of multidisciplinary examining of complex designs.

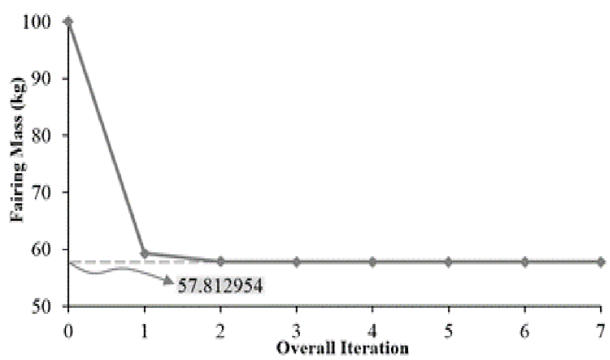

Fig. 5 Fairing mass decrease graph.

5 CONCLUSION

In this paper, for the first time, fairing design of a LV by sandwich structures as a component of the LV MDO architecture was proposed. As was seen, from theoretical view, the idea causes a considerable decrease in weight of fairing structure. Of course in operational state, manufacturing requirements should be considered, but these requirements were not considered due to the objective of this paper which is to accommodate fairing structure optimization in MDO of LV architecture. Although sandwich structures usage in fairing of LV caused forty kg decrease in fairing weight, this slight amount caused about 780 kg decrease in weight of LV due to the importance of upper stages mass distribution. The results of this paper emphasize again on systemic design and enjoying MDO in multidisciplinary vehicles. As was seen, effects of a subsystem optimization should be considered on the whole system.

Another important achievements of this paper is to use MDO in the new architecture. In this new architecture, despite its high similarities to MDOIS method, the systemic convergence is achieved by using FPI method. The novel method was named "MDO based on Dependent Subspaces" (MDODS) by the paper writers due to semantic similarity of this method to MDOIS and also explicit dependency of subspaces to each other. This method is recommended for problems that entire design space can be divided into several subspaces in a manner that subspaces have explicit but simple dependency to each other.

REFRENCES

[1] Walden, D., Roedler, G., Forsberg, K., Hamelin, R. and Shortell, T., INCOSE Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities, John Wiley & Sons, 2015.

[2] Liu, D., Systems Engineering: Design Principles and Models, CRC Press, 2015.

[3] Sadraey, M. H., Aircraft Design: A Systems Engineering Approach, John Wiley & Sons, 2012.

[4] Huang, Y., Seck, M. and Fumarola, M., A Simulation Based Design Framework for Large Scale Infrastructure Systems Design, MAS: Proceedings of The 11th International Conference on Modelling & Applied Simulation, Vienna, Austria, 2012, pp. 19-21.

[5] AIAA, White Paper on Current State of the Art. AIAA Technical Committee on Multidisiplinary Design Optimization (MDO), 1991.

[6] Martins, J. R., A. B. Lambe, Multidisciplinary Design Optimization: A Survey of Architectures, AIAA Journal, Vol. 51, No. 9, 2013, pp. 2049-2075.

[7] Duranté, N., Dufour, A., Pain, V., Baudrillard, G. and Schoenauer, M., Multidisciplinary Analysis and Optimisation Approach for the Design of Expendable Launchers, 10th AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference Albany, New-York, USA, 2004.

[8] Lee, J. W., Jeon, K. S., Byun, Y. H. and Kim, S. J., Optimal Space Launcher Design Using a Refined Response Surface Method Fuzzy Systems and Knowledge Discovery, 2005, pp. 1081-91.

[9] Braun, R., Kroo, I. and Moore, A., Use of the Collaborative Optimization Architecture for Launch Vehicle Design, Proceedings of the 6th AIAA/NASA/ISSMO Symposium on Multidisciplinary Analysis and Optimization, 1996.

[10] Briggs, G., Ray, T. and Milthorpe, J., Optimal Design of an Australian Medium Launch Vehicle, Innovations in Systems and Software Engineering, Vol. 3, No. 2, 2007, pp. 105-116.

[11] Bayley, D. J., Design Optimization of a Space Launch Vehicle Using a Genetic Algorithm, Auburn, Auburn University, 2008.

[12] Rafique, A. F., Linshu, H., Zeeshan, Q. and Kamran, A., Multidisciplinary Design of Air-Launched Space Launch Vehicle using Simulated Annealing, Advances in Artificial Intelligence, 2009, Vol. 5803, pp. 719-26.

[13] Jodei, J., Ebrahimi, M. and Roshanian, J., Multidisciplinary Design Optimization of a Small Solid Propellant Launch Vehicle using System Sensitivity Analysis, Structural and Multidisciplinary Optimization, Vol. 38, No. 1, 2009, pp. 93-100.

[14] Hosseini, M., Toloie, A., Nosratollahi, M. and Adami, A., Multidisciplinary Design Optimization of an Expendable Launch Vehicle, Recent Advances in Space Technologies (RAST), 2011.

[15] Ebrahimi, M., Farmani, M. R. and Roshanian, J., Multidisciplinary Design of a Small Satellite Launch Vehicle using Particle Swarm Optimization, Structural and Multidisciplinary Optimization, Vol. 44, No. 6, 2011, pp. 773-84.

[16] Aldheeb, M. A., Kafafy, R., Idres, M., Omar, H. M. and Abido, M. A., Design Optimization of Micro Air Launch Vehicle using Differential Evolution, Journal of Aerospace Technology and Management, Vol. 4, No. 2, 2012, pp. 185-96.

[17] Balesdent, M., Bérend, N. and Dépincé, P., Stagewise Multidisciplinary Design Optimization Formulation for Optimal Design of Expendable Launch Vehicles, Journal of Spacecraft and Rockets, Vol. 49, No. 4, 2012, pp. 720-30.

[18] Balesdent, M., Bérend, N., Dépincé, P. and Chriette, A., A Survey of Multidisciplinary Design Optimization Methods in Launch Vehicle Design, Structural and Multidisciplinary Optimization, Vol. 45, No. 5, 2012, pp. 619-42.

[19] Castellini, F., Lavagna, M., Riccardi, A. and Büskens, C., Multidisciplinary Design Optimization Models and

Algorithms for Space Launch Vehicles, 13th AIAA/ISSMO Multidisciplinary Analysis Optimization Conference Fort-Worth, TX USA. 2010.

[20] Darabi, H., Roshanian, J. and Zare, H., Design of Liquid-Propellant Engine using Collaborative Optimization and Evolutionary Algorithms, Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering, Vol. 229, No. 2, 2014, 0954410014529423.

[21] Salimi, H., Saranjam, B., Fard, A. H. and Ahmadzadeh, M., Use of Genetic Algorithms for Optimal Design of Sandwich Panels Subjected to Underwater Shock Loading, Strojniški vestnik-Journal of Mechanical Engineering, Vol. 58, No. 3, 2012, pp. 156-164.

[22] Yuan, C., Bergsma, O., Koussios, S., Zu, L. and Beukers, A., Optimization of Sandwich Composites Fuselages under Flight Loads, Applied Composite Materials, Vol. 19, No. 1, 2012, pp. 47-64.

[23] Yuan, C. O., Roozen, N. B., Bergsma, O. and Beukers, A., Multi-Discipline Optimization of Sandwich Cylinders Under a Point Force Excitation, Aerospace Science and Technology, Vol. 30, No. 1, 2013, pp. 183-191.

[24] Ullah, R., Zhou, D. Q., Zhou, P., Hussain, M. and Sohail, M. A., An Approach for Space Launch Vehicle Conceptual Design and Multi-Attribute Evaluation, Aerospace Science and Technology, Vol. 25, No. 1, 2013, pp. 65-74.

[25] Ma, Y., Yao, X. and Su, Y., Shape Optimization and Material Gradient Design of the Sharp Hot Structure, Acta Astronautica, Vol. 103, 2014, pp. 106-112.

[26] Ebrahimi, S., Vahdatazad, N., Multiobjective Optimization and Sensitivity Analysis of Honeycomb Sandwich Cylindrical Columns Under Axial Crushing Loads, Thin-Walled Structures, Vol. 88, 2015, pp. 90-104.

[27] Baroutaji, A., Gilchrist, M., Smyth, D. and Olabi, A. G., Analysis and Optimization of Sandwich Tubes Energy Absorbers Under Lateral Loading, International Journal of Impact Engineering, Vol. 82, 2015, pp. 74-88.

[28] Ashley, H., On Making Things the Best-Aeronautical Uses of Optimization, Journal of Aircraft, Vol. 19, No. 1, 1982, pp. 5-28.

[29] AIAA. White Paper on Current State of the Art, AIAA Technical Committee on Multidisiplinary Design Optimization (MDO), 1991.

[30] Chen, X., Yan, L., Luo, W., Xu, L., Zhao, Y. and Wang, Z., Research on Theory and Application of Multidisciplinary Design Optimization of Flight Vehicles, Proceedings of the 47th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, 2006.

[31] Martins, J. R., Lambe, A. B., Multidisciplinary Design Optimization: A Survey of Architectures, The American Institute of Aeronautics and Astronautics Journal, Vol. 51, No. 9, 2013, pp. 2049-2075.

[32] William, B., Missile Datcom, Status and Future Plans, 15th Applied Aerodynamics Conference, American Institute of Aeronautics and Astronautics, 1997.

[33] Mozaffari, A., Morovat, F. and Zare, H., Analytical Solution for Buckling of Composite Sandwich Truncated Conical Shells under Combined External Pressure and Axial Compression Load, International Journal of Advanced Design and Manufacturing Technology (ADMT), Vol. 8, No. 4, 2015.