International Conference of GIScience: Basis and Trans/ Interdisiciplanary Applications

دومین همایش بین المللی
علم اطلاعات جغرافیایی
بنیادها و کاربردهای بین رشته ای

ششمین بزرگداشت روز جهانی GIS
6th FUM_GISDay
2021/1400

Multidisciplinary design optimization of GIS UAV

Amirfarhang Nikkhoo[1], Ghazal Taghinia[2], Ali Esmaeli[3*]

1-MSc aerospace engineering student, Engineering Faculty, Ferdowsi University of Mashhad, Email: amirfarhang.nikkhoo@mail.um.ac.ir
2-MSc aerospace engineering student, Engineering Faculty, Ferdowsi University of Mashhad, Email: Ghazal.taghinia@mail.um.ac.ir
3[*]-Assistant professor, Mechanical engineering department, Engineering Faculty, Ferdowsi University of Mashhad, Iran, Email: aliesmaeili@ferdowsi.um.ac.ir

Abstract

GIS UAV design using Multidisciplinary Design Optimization (MDO) techniques is a complex task which involves different disciplines, mainly aerodynamic and structure. The multidisciplinary feasible (MDF) method is a new MDO approach and it involves solving a single optimization problem that calls a multidisciplinary analysis (MDA) when objective or constraint values are required**.** This paper optimized **E beex** fixed wing GIS UAV and maximization of Breguet range was chosen as objective function and two design variables, as spare thickness from structure part and twist angle from aerodynamic part, were mentioned. Finally, the results demonstrated that the flight range was sharply increased.

Keywords: GIS UAV, Optimization, MDO, Aerodynamic, Structure

1. INTRODUCTION

The planning of the flight and the management of the navigation of UAV is essential in order to identify the optimal route depending on the position and height of possible obstacles present in the operating zone . Thus it is essential to trace a path in terms of planimetry and altimetry. To this aim, the GIS environment is particularly useful to have a cartographic support that is accurate and precise for determining the route in planimetry, and to construct maps in which the altitude variation of the obstacles is represented and georeferenced[1].

Autonomous systems used by the military, including UAVs and UGVs, require frequent monitoring and intervention from human operators. Operators take into account any contextual information they can gather. In addition, missions are planned for these systems at varying levels of granularity. Some systems are given an end goal, some are given waypoints, and others require additional detail which might include teleoperation. Situations may arise during the execution of these plans that require dynamic replanning. An example of such an event for a UAV would be a failure requiring an emergency landing; an example of such an event for a UGV would be encountering a hazard. Contextual information such as the time of day and type of environment could inform navigation and emergency landing plans. Additionally, the use of GIS data together with sensor data gathered by autonomous systems could potentially improve the systems' reaction to anomalous situations that arise and improve navigation routes.

The objective of this effort is to explore the integration of GIS data with sensor data and time of day information to enable (1) UAVs to locate safe emergency landing locations without operator intervention, and (2) UGVs to incorporate contextual GIS information for navigation. Ultimately, the combination of GIS maps that include precomputed probabilities for preferred landing sites or navigation routes with current sensor data will help inform and improve the operation of UGVs and UAVs.

Preliminary evaluation of our system, which integrates GIS and sensor data, reveals potential impact through more efficient navigation and the ability to locate safe landing zones. This effort builds the foundation for employing GIS data streams in UAV landing and UGV navigation. The platform agnostic nature of our effort, which focuses on the fusion and processing of multiple layers of GIS data according to a specified mission profile, could be used for any type of autonomous system. This effort not only impacts the UAV and UGV fields, but can also apply to other fields such as data analysis interfaces[2].

Du Yu Go et.al [3] have been investigation that employed GIS as reference data. GIS is an information system that stores, edits and displays geographic information. GIS data represents real world objects with digital data and needs less storage compared to reference images or terrain contour maps. Moreover, it is easy to have the surrounding information for UAV planning due to the semantic description in GIS. Therefore, they choose GIS as reference data and propose a novel vision-aided navigation approach for accurate UAV localization. The approach firstly extracts and delineates the widely distributed object features including roads, rivers, road intersections, villages, bridges et al. from aerial images. Then, GIS model is constructed by corresponding geographical object information from GIS data to offer the reference data. Finally, visual geometrical features are registered with GIS model to obtain the absolute position of the image, and thus to eliminate the errors of INS.

Flying wing configuration has been considered as an ideal configuration of the future unmanned aerial vehicles (UAV) due to its potential benefits over conventional configurations in stealth capability, aerodynamic performance, and structural efficiency**.** Compared with the conventional configuration, flying wing aircraft has become the research hotspot of advanced aircraft in recent years [4], and the number of flying wing aircrafts which have been developed successfully is far less than the number of aircrafts with the conventional configuration**.**

Currently, the objective of an aircraft design is to determine an optimum design considering multiple analysis disciplines. The process of aircraft design is a complex process that is composed of many different disciplines. From the early 1960s, it was clear that optimization of a single discipline cannot guarantee the overall optimum design[5]. The concept of multidisciplinary design optimization (MDO) was introduced in the 1980s to manage interdisciplinary connections in design optimization. Since then, MDO has been widely used in different fields of engineering design**.**

Aircraft wing design using Multidisciplinary Design Optimization (MDO) techniques is a complex task which involves different disciplines, mainly aerodynamic and structure. Different levels of analysis are used for wing design and optimization. Typically simple empirical methods are used in the earliest stages of the concept design. The design task proceeds towards the final design by increasing the complexity of the analysis methods. For instance, a variety of methods are available for aerodynamic analysis of a wing; from a simple lifting line theory or a vortex lattice method up to complex Euler and Reynolds-Average Navier-Stokes methods. Similarly for structural weight estimation, various methods with different levels of fidelity are available. The difficulty lies in the quest or development of analysis methods which are sufficiently simple to be used thousands of times during the optimization. At the same time, these methods should be sophisticated enough to capture changes in the local geometry. Multidisciplinary Design Optimization or MDO, is a methodology for the design of systems in which strong interaction between disciplines motivates designers to simultaneously manipulate variables in several disciplines[6]**.**

Cramer et al [7] suggested , the multidisciplinary feasible (MDF) method is the traditional MDO approach and it involves solving a single optimization problem that calls a multidisciplinary analysis (MDA) when objective or constraint values are required. The MDA solves the governing equations for all disciplines. The MDA module takes the design variables solves all governing equations until the coupling variables have converged. The values of the objective and constraints can then be computed. By requiring the solution of the MDA at each design point, MDF ensures that each optimization iteration is multidisciplinary feasible. This is a very desirable property, since if the optimization is terminated prematurely, a physically realizable design point is at hand. The effort required to implement MDF for a given problem is directly related to the effort required to build an appropriate MDA module.

Antoine and Kroo [8] introduce environmental performance in a MDO framework for preliminary aircraft design and the results obtained had shown that significant environmental impact reduction can be achieved by flying slower and at lower altitudes**.** Noise reduction has also been included in multidisciplinary optimization[9] [10] [11]. Henderson et al. [12] have also reported an aircraft environmental design and optimization framework.

A flying wing UCAV MDO problem was formulated and successfully solved using two different approaches. The first approach was optimization using a low-fidelity design framework. The second approach was variable fidelity optimization with MDO implementation of the GVFM algorithm. Variable fidelity optimization exhibited more design improvement with an acceptable computational cost compared to low-fidelity optimization[13].

The goal of the present study is to optimize the range of a regional UAV using a monolithic MDO technique. The wing of **E bee x** fixed wing GIS UAV as shown in Fig. 1, is chosen and its specification shows in Table 1. Expanded propylene was considered as the material used in the manufacturing of the wing. The Breguet range and Endurance are considered as objective function and to maximize it, both wing structure weight should be minimized and simultaneously maximized the lift to drag ratio of wing.

To do this type of optimization, Multidisciplinary Feasible (MDF) method is selected which could couple both structure and aerodynamic equations.

Figure 1. E beex GIS UAV

Table 1- specification of E bee x fixed wing GIS UAV

Range	162km
Wing span	1.16m
Thickness/chord ratio	0.87
Mach	0.089
sweep	35.7deg
Thick root	0.0372
W battery	1.32 kg
e_bat	613512 j/kg

2. EQUATIONS

The paper use Breguet range calculate fuel consumption as a function of structural weight and aerodynamic performance that showed in Eq1.

$$R = \frac{e\_bat}{g} \frac{L}{D} ln\left(\frac{W_{initial}}{W_{final}}\right) \qquad (1)$$

For a wing with sweep $\Lambda = 35.7^0$, a taper ratio $\lambda = 0.87$, and an aspect ratio AR=4, and the combination of jig twists and spar thicknesses that maximize the range of this wing, while ensuring that the wing structure will not fail at a maneuver condition with a load factor n 2.07**.**
In this investigation, Multidisciplinary Feasible (MDF) is chosen and all results are obtained from this approach.
The aim of present work is to modify the wing of **E bee x** fixed wing GIS UAV that is reached to the maximum range. Standard form of the problem can be mathematically stated as,

$$\text{Maximize} \quad R\,, \left\{R = \frac{e_{bat}}{g}\frac{L}{D} ln\left(\frac{W_{initial}}{W_{final}}\right)\right\}$$

With respect to x

Subject to L-W=0

$$n\sigma_j - \sigma_{yield} \leq 0$$

Where x is design variable and contains spar thickness (t) and jig twists (γ). L and W are lift force and weight of wing, individually. Load factor is called (n), too.
Problem statement in the form of MDF can be expressed as;

$$\text{Minimize } -R\,,\ \left\{R = \frac{e_{bat}}{g}\frac{L}{D}\ln\left(\frac{W_{initial}}{W_{final}}\right)\right\}$$

$$\text{With respect to} \qquad t,\gamma$$

$$\text{Subject to} \qquad n\sigma_j(u) - \sigma_{yield} \le 0$$

$$L(\Gamma) - W(t) = 0$$

Where the aero-structural analysis is as,

$$\text{Aerodynamic governing equation:} \quad A\Gamma = v(u)$$

$$\text{Structural governing equation:} \quad Ku = f(\Gamma)$$

The angle of attack at which the wing flies is returned to the wing to see the resulting lift (= weight of the spar + fixed non-spar weight). In addition, the program will return the lift and elastic twist distributions, and the stress distribution on the spar. The stress distributions can be used to specify material failure constraints.

Moreover, the objective function, design variables, and constraints are clearly identified in table 2.

Table 2- classification of objective function, design variables, and constraints

Objective function	$-R\,,\ \left\{R = \frac{e_{bat}}{g}\frac{L}{D}\ln\left(\frac{W_{initial}}{W_{final}}\right)\right\}$
Design variable	Spar thickness= t Twist= γ
Constraints	$n\sigma_j(u) - \sigma_{yield} \le 0$ $L(\Gamma) - W(t) = 0$

Furthermore, Fig. 2 illustrates flow chard of the problem with MDF approach and data flow. As shown in the figure, the initial values of design variables are given and then the coupled governing equations of structure and aerodynamic parts is solved. Subsequently, the objective function would be calculated based on the results of MDA. The optimization algorithm will try to find the best output and finally the algorithm will check the answer of optimization process. If the optimized output is matched with the solution of governing equations, the simulation would be stopped otherwise the optimized output will be mentioned a new design variables and run the procedure again.

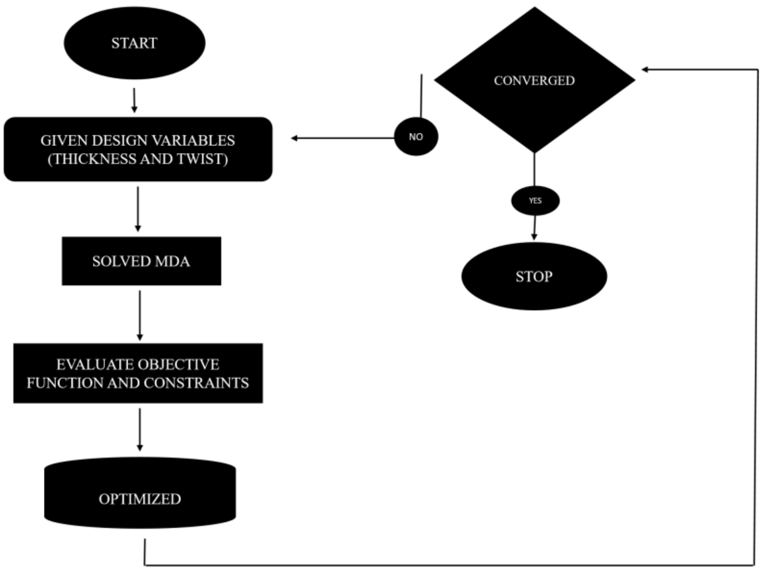

Figure 2. MDF flowchart

3. RESULTS

This investigation is also solved by using Vortex Lattice Method (VLM) for aerodynamic governing equation and coupled it to structure equation thus, the MATLAB function, Fmincon is the final step of converging of this program. Therefore, the maximum range of the mentioned aircraft will be **349** (n.mi) that means **647** km.

Moreover, lift, drag forces, and weight of wing, which are obtained in maximum range, are represented in table 3.

Table 3- Loads characteristic at maximum range

Lift	Drag	Range
4.75	0.37	647 km

According to the MATLAB's results, maximum range increase from 87.47 to 349 (n.mi). Furthermore, lift distribution extracted from MATLAB in Fig. 3 and showed us the optimized wing and base wing's lift distribution.

For an optimum aerodynamic performance of a wing, the desired lift distribution would be elliptic; because this distribution generates the lowest induced drag, ensuring optimum aerodynamic performance of the wing. As shown in the Figure 3 , it matter how oval the lift diagram is, means we have better lift force.

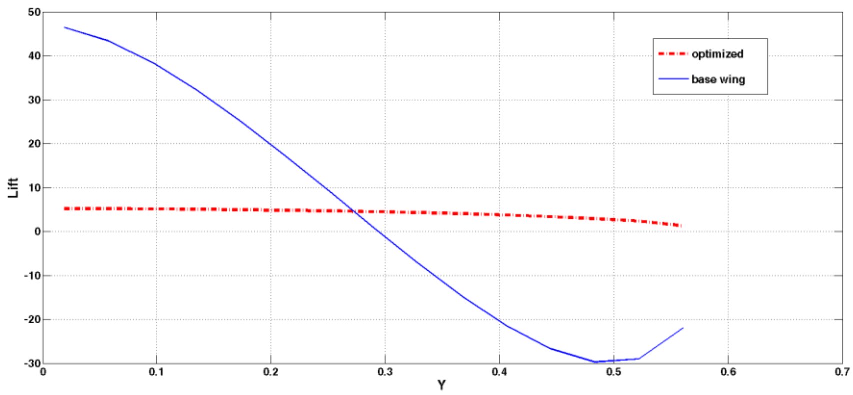

Figure 3. Lift distribution according to wing span

In this research, aerodynamic is not just considered; structure of wing should be regarded, too. Therefore, the lift distribution will not be an elliptic.

Actually, wing weight reduction and stress play an important role in this problem. Stress is high in the wing root and thicker spar is sufficient. Therefore, weight of wing in the root rises. On the other hand, any increase in drag would bring a large penalty in weight especially in a long-range aircraft. Therefore, lift curve shifts towards and it becomes triangular and induced drag is declined.

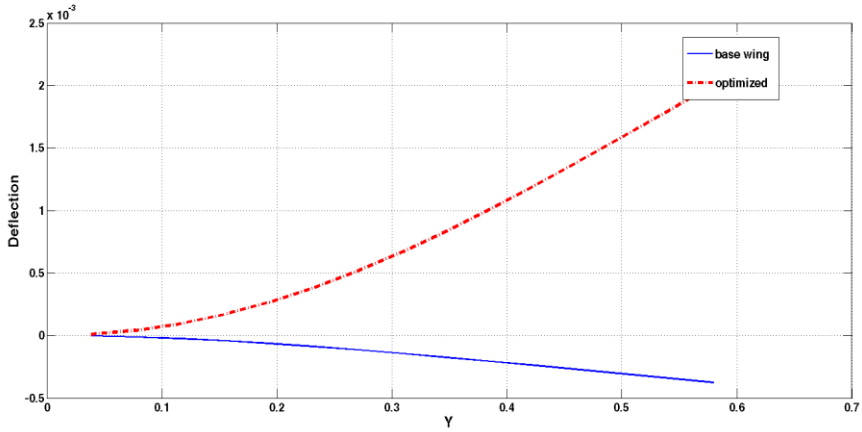

Figure 4. deflection distribution across wing span

According to the figure 4 the investigation has higher deflection after optimizing. Aerodynamic performance depends of deflection, thus the tip of the wing (the end of the wing) is so light because of this the wing has so much deflection.

4. CONCLUSIONS

this paper optimize the **E bee x** fixed wing GIS UAV by multidisciplinary design optimization to achieve the best range.
With supplying Breguet range and coupling aerodynamic and structural governing equation MDA and MDF the Branch of MDO completed and finally lead the results to maximum range of the flight and optimum aerodynamic performance of a wing such lift and the desired lift distribution would be elliptic lift. Hence it leads to optimum deflection on structural performance. wing weight reduction and stress play an important role in this problem thus after optimize weight of wing in the root increases.

5. REFERENCES

[1] M. Mangiameli, G. Muscato, … G.M.-I.P., undefined 2013, A GIS application for UAV flight planning, Elsevier. (n.d.). https://www.sciencedirect.com/science/article/pii/S147466701540285X (accessed December 3, 2021).

[2] N. Rackliffe, H. Yanco, J.C.-2011 I.C. on, undefined 2011, Using geographic information systems (GIS) for UAV landings and UGV navigation, Ieeexplore.Ieee.Org. (n.d.). https://ieeexplore.ieee.org/abstract/document/5753497/ (accessed December 3, 2021).

[3] D.Y. Gu, C.F. Zhu, J. Guo, S.X. Li, H.X. Chang, Vision-aided UAV navigation using GIS data, Proc. 2010 IEEE Int. Conf. Veh. Electron. Safety, ICVES 2010. (2010) 78–82. https://doi.org/10.1109/ICVES.2010.5550944.

[4] H.X. Zhou, B. Liu, Characteristics Analysis and Optimization of Flying-Wing Vehicle Structure, Adv. Mater. Res. 1077 (2014) 177–184. https://doi.org/10.4028/www.scientific.net/amr.1077.177.

[5] S. Kodiyalam, J. Sobieszczanski-Sobieski, Multidisciplinary design optimization - Some formal methods, framework requirements, and application to vehicle design, Int. J. Veh. Des. 25 (2001) 3–22. https://doi.org/10.1504/ijvd.2001.001904.

[6] J. Sobieszczanski-Sobieski, R.T. Haftka, Multidisciplinary aerospace design optimization: Survey of recent developments, 34th Aerosp. Sci. Meet. Exhib. (1996). https://doi.org/10.2514/6.1996-711.

[7] E.J. Cramer, J.E. Dennis, Jr., P.D. Frank, R.M. Lewis, G.R. Shubin, Problem Formulation for Multidisciplinary Optimization, SIAM J. Optim. 4 (1994) 754–776. https://doi.org/10.1137/0804044.

[8] N.E. Antoine, I.M. Kroo, Framework for aircraft conceptual design and environmental

performance studies, AIAA J. 43 (2005) 2100–2109. https://doi.org/10.2514/1.13017.

[9] A. Diedrich, J. Hileman, D. Tan, K. Willcox, Z. Spakovszky, Multidisciplinary design and optimization of the silent aircraft, in: Collect. Tech. Pap. - 44th AIAA Aerosp. Sci. Meet., 2006: pp. 16083–16097. https://doi.org/10.2514/6.2006-1323.

[10] L. Leifsson, MULTIDISCIPLINARY DESIGN OPTIMIZATION OF WING.pdf, 2005. (n.d.). https://vtechworks.lib.vt.edu/handle/10919/26327 (accessed January 22, 2021).

[11] C. Werner-Westphal, W. Heinze, P. Horst, Multidisciplinary integrated preliminary design applied to unconventional aircraft configurations, in: J. Aircr., American Institute of Aeronautics and Astronautics Inc., 2008: pp. 581–590. https://doi.org/10.2514/1.32138.

[12] R.P. Henderson, J.R.R.A. Martins, R.E. Perez, Aircraft conceptual design for optimal environmental performance, Aeronaut. J. 116 (2012) 1–22. https://doi.org/10.1017/S000192400000659X.

[13] M. Tyan, N. Van Nguyen, J.W. Lee, A tailless UAV multidisciplinary design optimization using global variable fidelity modeling, Int. J. Aeronaut. Sp. Sci. 18 (2017) 662–674. https://doi.org/10.5139/IJASS.2017.18.4.662.