Aerospace Science and Technology ••• (••••) •••–•••

Contents lists available at ScienceDirect

Aerospace Science and Technology

www.elsevier.com/locate/aescte

Unconventional hybrid airships design optimization accounting for added masses

A. Ceruti [a], D. Gambacorta [b], P. Marzocca [c]

[a] DIN Department, University of Bologna, Italy
[b] School of Engineering and Architecture, University of Bologna, Italy
[c] School of Engineering, RMIT, Melbourne/Bundoora, Australia

ARTICLE INFO

Article history:
Received 10 January 2017
Received in revised form 25 August 2017
Accepted 31 October 2017
Available online xxxx

Keywords:
Multidisciplinary optimization
Conceptual design
Added masses
Airships

ABSTRACT

This paper describes the implementation of a framework which can be used to optimize the external shape of an unconventional airship configuration. This framework includes the estimation of Added Masses (AM) which captures the contribution of the dynamic effect related to the acceleration of a body immersed in a fluid having a similar density to that of the body itself. A computationally efficient routine to compute AM has been implemented in a heuristic optimization loop based on a Particle Swarm Optimization (PSO) algorithm, and has been integrated into a simple model which provides hybrid airship's aerodynamics characteristics. As a case study, the take-off distance of a hybrid airship has been optimized by the methodology, and it is used to show the effect on the optimization loop and the errors arising from using conventional approximated AM evaluation methods. The proposed set of simulations clearly evaluates the errors expected on the unconventional airships performances when approximated methods are used in the evaluation of the AM.

1. Introduction

The interest in unconventional hybrid airships is increasing due to the need for reducing the environmental impact of the air transportation vehicles. The core idea, described in several works e.g. [1–3], is to cover the top surface of an airship with photovoltaic films: part of the energy collected during the day can be immediately used for propulsion, and part stored to be used during the night. This concept implies a radical change in the airships shape. The traditional axial-symmetric shapes, in fact, have been developed to reduce the drag of an airship, given a certain volume [2]. However, when dealing with solar propulsion, also the surface which could be potentially covered by films and its normal orientation respect to the sun rays should be considered. As a consequence, new shapes are being studied assuring a better trade-off between surface covered by photovoltaic film, drag, and internal volume [3,4]. The possibility of changing the airship shape opens new design scenarios and adds complexity to the problem since several new configurations have been proposed in recent literature, while the available conceptual design synthesis are mainly focused on the traditional shapes and are still lacking in addressing the new challenges that comes with innovative designs. In particular, methods for the evaluation of the aerodynamic loads should be revised to provide drag, aerodynamic moment and lift coefficients for unconventional shapes. The dynamics of the airship is also impacted by changes in the external shape due to the aerodynamic coefficients, inertia, and AM effect. About the latter effect, it is worth to note that the currently widely used formula for the computation of the AM have been developed and tested for the axial-symmetric shape [5], but the literature addressing this computation for unconventional shapes is quite scarce. Several sources propose to use for complex shapes the "equivalent ellipsoid" method [6]. However, it introduces errors which can lead to a rough evaluation of the dynamic properties of the airships. On the other hand, several papers (e.g. [7]) have been published on the multi-disciplinary optimization of unconventional shaped airships, but the precise impact of the AM on the dynamics properties are often neglected. It is worth to note that the AM effect is important only when the mass of the fluid displaced by the body is comparable to the density of the body itself [8], and that the AM effect enters only in the airship dynamics where linear or rotational accelerations are noticed.

Due to the complexity of the design problem at hand, the solution it is sought by using optimization algorithms to find an optimal trade-off point able to enhance the performances desired by the end-user. Consequently, this paper provides an optimization

---

E-mail address: alessandro.ceruti@unibo.it (A. Ceruti).

https://doi.org/10.1016/j.ast.2017.10.042

Please cite this article in press as: A. Ceruti et al., Unconventional hybrid airships design optimization accounting for added masses, Aerosp. Sci. Technol. (2017), https://doi.org/10.1016/j.ast.2017.10.042

framework for unconventional airship geometries, demonstrated on a three-lobes configuration that is morphed as to enhance its dynamic characteristics, which clearly depends on AM effect. Within the implemented recursive procedure, change in airship geometry are due to the computation of AM coefficients and of approximated values of drag and lift which are evaluated using methods useful to deal with three-lobed shapes. Several software packages have been sequenced in a loop to allow the rapid and efficient evaluation of several shapes suitable for conceptual design phases. Optimization is carried out using a Matlab® heuristic Particle Swarm Optimization (PSO) algorithm implemented by authors, providing very good performances and easiness of implementation [9].

The rest of the paper is organized as follows: Section 2 describes the optimization layout and software packages exploited to implement the procedure; Section 3 briefly introduces the mathematics under the computation of the AM and aerodynamics, together with some notes on the optimization algorithm used in these simulations; Section 4 presents a case study to show the usefulness of this procedure within the unconventional hybrids airship design process and gives an idea of the results which can be obtained with the "Design for Added Masses" approach. Finally, Section 5 provides concluding remarks and suggests prospects for multidisciplinary framework implementation.

2. Optimization methodology layout

The main aim of this paper is to present an optimization procedure that appropriately accounts for AM effect on the performances of an unconventionally shaped airship. The procedure is based upon the generation of an airship configuration, the accurate evaluation of the AM for such configuration, and the assessment of the aerodynamics and the computation of the fitness. A heuristic optimization algorithm closes the loop driving the changes of the geometrical parameters required to model the geometry of the envelope. The whole optimization loop has been implemented in Matlab® environment [10] in which the routines to compute the AM and the aerodynamics have been written; moreover, Matlab® manages the calls to FreeCAD® [11] which is the external software used to model in 3D the airship, and to MeshLab® [12] software, used to refine and fix the mesh in which the external surface of the airship CAD is discretized. Matlab® is a computing language useful in engineering and science to implement functions, codes and to process data. FreeCAD is an open-source, highly customizable, scriptable and extensible parametric 3D modeller software: it presents several environments which can be used to model 3D parts, to assembly components into groups and to perform simple FEM analysis. MeshLab is an open-source software useful to handle mesh and points clouds: several functions are embedded to help the user in fixing problems related to the discretization of geometrical model and filters can be used to reduce the complexity of meshes with a minimum loss in shape definition. A Python programming language based macro has been implemented in FreeCAD to sketch in 3D the airship model, using the dimensions saved by Matlab in an exchange file. The 3D model output of FreeCAD is an STL file which is used as input for MeshLab. The latter software is used to evaluate the STL mesh of the model and to reduce the number of triangular faces to a number allowed in the computation of the AM in times compatibles with conceptual design. As a result, a new optimized STL file is obtained, and the external surface of the airship is divided into triangles whose nodes positions are exported and listed in the output file. This generated STL file is then open in Matlab and the nodes/triangles position is stored in a set of variables and used for the computation of the AM. It is then possible to compute the fitness ratio, the aspect ratio and the aerodynamic characteristics of the airship; as a final step, the Matlab implemented Particle Swarm Optimization algorithm can drive the change of the design parameters in order to enhance the fitness, represented by a flight related performance of the airship. Fig. 1 presents the optimization loop.

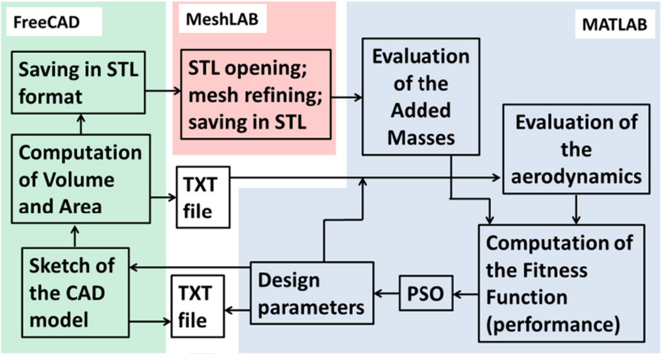

Fig. 1. Scheme of the optimization process.

The mathematical procedure to compute the airship AM and aerodynamic characteristics will be presented in the next sections. Fig. 2 shows the parameters selected to define the geometry of the airship (plan view in the left and rear view on the right), whose configuration is based upon a three-lobes unconventional shape, well described in [6] and being currently studied and tested by several aerospace Companies.

Fig. 3 presents a screenshot of the FreeCAD software in which the 3D model of an airship has been modelled through a macro which reads the values of the parameters introduced in Fig. 2 from a TXT file generated in Matlab. Once the airship has been modelled it is saved into an STL file.

This STL, whose number of triangles and features depends on the geometry of the model, is opened in MeshLab and the mesh is elaborated in order to reduce/increase the number of geometrical nodes to a sufficient number to well describe the shape, but small enough to allow the computation of the AM in a time compatible with the optimization process which often requires the evaluation of thousands of geometrical configurations (see Fig. 4).

3. Optimization mathematical framework

The present section describes the methodologies used to compute the AM, the aerodynamics, the fitness function, and the main features of the algorithm used as optimizer.

3.1. AM computation

As suggested by [13], the dynamics of an airship can be modelled:

$$(\boldsymbol{M}+\boldsymbol{M_A})\frac{d\boldsymbol{x_A}}{dt}=\boldsymbol{F_d}(\boldsymbol{x_A})+\boldsymbol{F_a}(\boldsymbol{x_A})+\boldsymbol{P}+\boldsymbol{G} \quad (1)$$

Herein $\boldsymbol{M}$ $[6\times 6]$ is the mass matrix of the airship and includes mass and inertias of the vehicle; $\boldsymbol{M_A}$ $[6\times 6]$ is the AM matrix; $\boldsymbol{x_A}=[V_X,V_Y,V_Z,p,q,r]$ $[6\times 1]$ is the state vector and includes V_x, V_y, V_z which are the velocities around the longitudinal, lateral and vertical axis of the airship and p, q, r, the respective rotational speeds; $\boldsymbol{F_d}$ $[6\times 1]$ is a vector including the effects related to the Coriolis and centrifugal acceleration; $\boldsymbol{F_a}$ $[6\times 1]$ is a vector listing the aerodynamic terms; $\boldsymbol{P}$ $[6\times 1]$ is a vector including the propulsion contribution to forces and moments; finally $\boldsymbol{G}$ represents the gravity vector, equal to the difference between the weight and the buoyancy. Also an additional $[6\times 1]$ vector $\boldsymbol{F_g}$ can be added to the right side of equation (1) to keep into consideration the forces due to the landing gear during take-off and landing of the airship. The reference system is centred in the Centre of Volume (CV), while