ANALYSIS OF ELEVATOR HINGE MOMENT IN AN UNMANNED AERIAL VEHICLE DESIGNED FOR SAE AERODESIGN COMPETITION USING CFD SIMULATION

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Abstract: This study had the general objective to analyze the resulting values of hinge moment in the elevator for the PM-03 project, of an unmanned aerial vehicle, dedicated for participation in the SAE Aero Design 2020 Competition. From 2D CAD modeling of surfaces using Solidworks, the hinge moment was analyzed in Ansys Fluent after generating an appropriate mesh and adjusting the initial flow settings. The validation of the CFD analysis was performed by comparing experimental results from another study and using USAF Datcom data and correlations. The results obtained by CFD and USAF DATCOM diverge, however, those allows to correctly estimate the order of magnitude of the hinge moment, allowing an optimized selection of the servo motor for the project.

Keywords: hinge moment; CFD analysis; numerical simulation; Aerodesign.

ANÁLISE DO MOMENTO DE ARTICULAÇÃO DO PROFUNDOR DE UM VEÍCULO AÉREO NÃO TRIPULADO PROJETADO PARA A COMPETIÇÃO SAE AERODESIGN USANDO SIMULAÇÃO CFD

Resumo: Este estudo teve como objetivo geral analisar os valores resultantes de hinge moment no profundor para o projeto PM-03, de um veículo aéreo não tripulado, dedicado para participação na Competição SAE Aero Design 2020. A partir da modelagem CAD 2D das superfícies usando Solidworks, o hinge moment foi analisado no Ansys Fluent após a geração de uma malha apropriada e ajustando-se as configurações iniciais de escoamento. A validação da análise CFD foi efetuada comparando-se resultados experimentais de outro estudo e através de dados e correlações do USAF Datcom. Os resultados obtidos pelo CFD e pelo USAF Datcom divergem, no entanto, permitem estimar corretamente a ordem de magnitude do hinge moment, permitindo uma seleção otimizada do servo motor para o projeto.

Palavras-chave: momento de articulação; análise CFD; simulação numérica; Aerodesign.

1. INTRODUCTION

During the development of an aeronautical project to participate in the SAE BRASIL Aerodesign Competition, one of the activities to be performed by the participating teams consists in the project and evaluation of the aircraft's Stability and Control. Summarily, the stability project must include the determination of the plane's center of gravity (G.C.), followed by a sizing process of the horizontal and vertical stabilizers so that, after a complete analysis, its ability to return to its flight equilibrium state after a disturbance, the so-called static stability, can be ensured. The stability analysis is addressed separately for the three axes adopted by the aeronautical industry: longitudinal, vertical and lateral [1].

In most cases, an aircraft designed to participate in the SAE Aerodesign Competition have the deflection of the surfaces driven by a micro-servo motor. This actuator must overcome an existing moment around the articulation axis (hinge) of the control surface in question, the hinge moment. The hinge moment is caused by the resulting aerodynamic forces acting on the pressure center of the control surface, as explained by [2]. The dimensionless coefficient for the hinge moment is obtained by equation 1 below:

$$C_h = C_{h\alpha}\alpha + C_{h\delta}\delta \qquad (1)$$

In the above equation, C_h is the dimensionless coefficient of the hinge moment,$C_{h\alpha}$ is the rate of change of C_h with the angle of attack, $C_{h\delta}$ is the rate of change of C_h with the deflection, α is the angle of attack of the wing in which the surface is coupled and δ represents deflection of the control surface. In this project case, the hinge moment is evaluated by fixing the control surface at its critical deflection, causing the highest resulting moment.

The ability to estimate the magnitude of the hinge moment is important in the execution of an aircraft project, since it allows to optimize the selection of the micro-servo motor. The eventual oversizing of this component in an attempt to supply the required torque may result in undesirable volume, energy consumption, weight and increase in the final price of the actuator. However, as approached by [3], the parameters $C_{h\alpha}$ and $C_{h\delta}$ to obtain the hinge moment coefficient of equation 1 above are very difficult to be analytically predicted and, in general, are evaluated through experimental results of tests in wind tunnels. With the advances of the last decades in modeling by computational fluid dynamics (CFD), there is also the possibility of reproducing the design conditions, such as the geometry of the control surface, the angle of attack and the positioning of the articulation axis, and simulating the real flow conditions. Typically, the results are used to guide the sizing and positioning of the surfaces still in the design phase, and must later be validated with test data in a wind tunnel with a model.

Starting from these initial considerations, it is proposed as a general objective of the present study, to analyze the values resulting from hinge moment in the elevator for the PM-03 unmanned aerial vehicle (UAV) project, of the Prometheus Aerodesign team of SENAI CIMATEC, destined to participate in the SAE BRASIL Aerodesign 2020 Competition. The specific objectives to be accomplished in order to carry out this analysis are: 1) to model the middle sections of the horizontal stabilizer and elevator using computer-aided design (CAD); 2) evaluate the resulting hinge moment in the elevator applying the CFD method; 3) validate the CFD results through correlations with bibliographic experimental data and other studies.

2. METHODOLOGY

2.1 CAD Modeling

Using the CAD modeling feature of Solidworks, the two-dimensional geometries of the plane's elevator and horizontal stabilizer (figure 3 below) were created using the ‘Surface’ feature of the software, based on the dimensions shown in Table 1 below. The 2D modeling for the simulation is consistent because the data and correlations for aerodynamics characteristics used for comparison in step 2.3, CFD validation, are also applied for 2D middle sections, and later, the resulting moment is obtained by multiplying the value found by the span of the control surface.

Table 1. Characteristic Dimensions of the Elevator

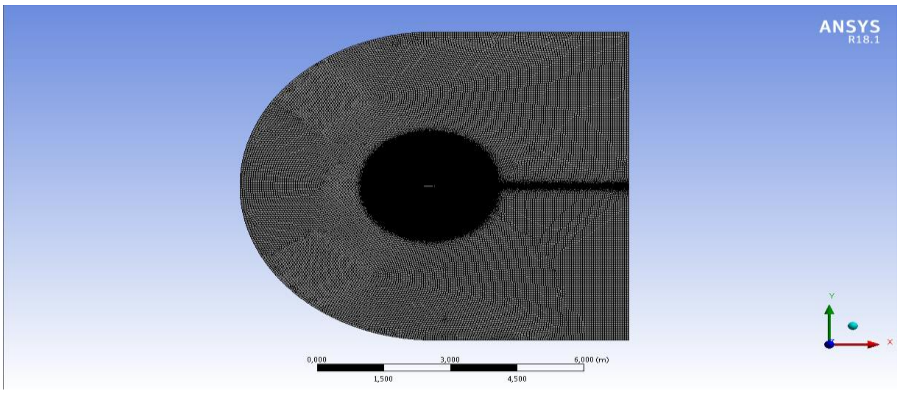
Characteristic Dimension	Elevator	Elevator + Stabilizer
Mean Aerodynamic Chord (mac)	0.12 m	0.35 m
Aspect Ratio	6.58	2.3
Wingspan	0.8 m	0.8 m
Surface Area	0.1 m^2	0.28 m^2
Hinge line position (% mac)	16.67%	71.74%

2.2 CFD Analysis

To perform the simulations, the CFD analysis feature of the ANSYS 18.1 software was used, through the Fluent tool. In the first stage of the analysis, it was necessary to define the geometry of the control surfaces, for this purpose the 2D elevator and stabilizer were imported into the Design Modeler.

With the imported surfaces, the domain for the evaluated flow was created, with the borders having a distance of 12.5 times the characteristic chord formed by the stabilizer and elevator. The type of mesh chosen for the analysis was hexahedral, as this allows an optimization of the fluid flow direction. As a quality criterion for forming the mesh, proximity to the real shape of the control surfaces was used. With that, it was possible to guarantee that the curves on the surface borders were preserved, avoiding the appearance of wedges in the simulation geometry, which can interfere considerably in the results.

Figure 1. Simulations domain



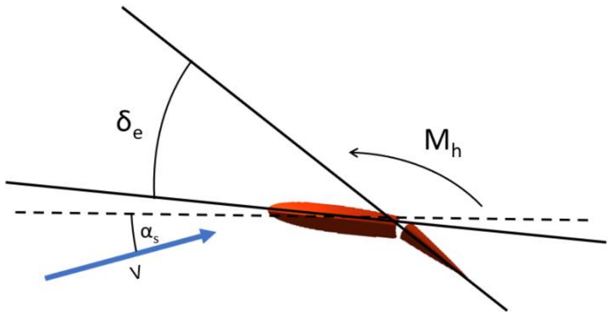
In the stage of setting the simulation conditions, which occurs after the definition of the meshes, the parameters for the simulation were inserted. The resolution model for turbulence adopted was Spalart-Allmaras, this model being recommended for aerospace applications and for requiring less computational resources and resolution time [4], considering that the team does not have computers that can dedicate themselves only to simulations for long periods of time, the application of this model being justified. For the simulation, the following configurations were considered:

Table 2. Parameters utilized in the calculations and simulations

Parameters	Values
Relative Velocity (V)	13.6 m/s
Elevator Deflection (δ_e)	20º
Maximum air attack angle over the aircraft (α_w)	19.11º
Resulting air attack angle on the horizontal stabilizer (α_s)	8.25º
Residual Error of the Monitored Values	1 e -03

The representation of the hinge moment to be found can be seen in figure 3 below, as well as the angle of deflection of the elevator (δ_e) and the angle of attack in the horizontal stabilizer (α_s).

Figure 3. Resulting air flow over the tail



The flight parameters in the Table 2 above were considered for the analysis, once they are resultant from the most critical possible situation for the elevator control: the airplane is in a dive speed (V) and the elevator is totally deflected upward (δ_e) in order to increase the resultant moment that will bring the plane back to straight-and-level flight condition. In that case, the effects of gravity will be adverse to control maneuverability.

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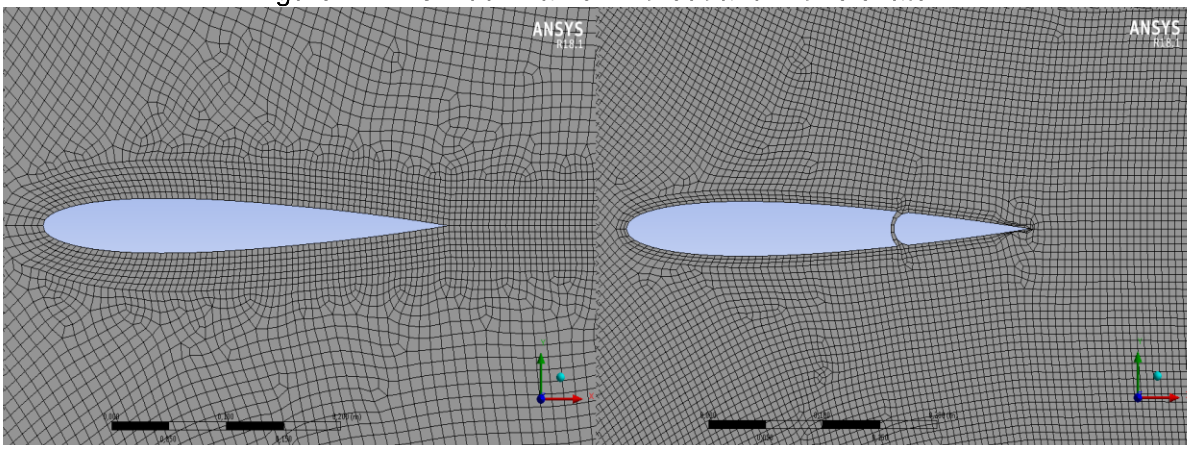
2.3 Results Validation

Typically, designers in the aeronautical industry seek to validate their simulation data through tests with a model of the designed aircraft [3]. However, in view of the impossibility of accessing the institution's Energy Laboratory to use the wind tunnel equipment, due to the current social isolation situation due to COVID-19, it was used as an alternative to validate the results of the CFD analysis the following two steps: 1) validation of the boundary conditions by comparison of the aerodynamic coefficients of non-deflected elevator with the work of [5]; 2) comparing the hinge moment results with the calculated when applied the correlations and data from [6].

For the first step, the values of the lift and drag coefficients were compared, first for simulation results using the NACA 0012 profile without the elevator, against another CFD and experimental NACA 0012 data, allowing to evaluate the mesh quality and boundary conditions. The results were compared with the study by [5], which used the same turbulent model and similar Reynolds numbers applied in this analysis.

Figure 4. NACA 0012 airfoil without and with elevator



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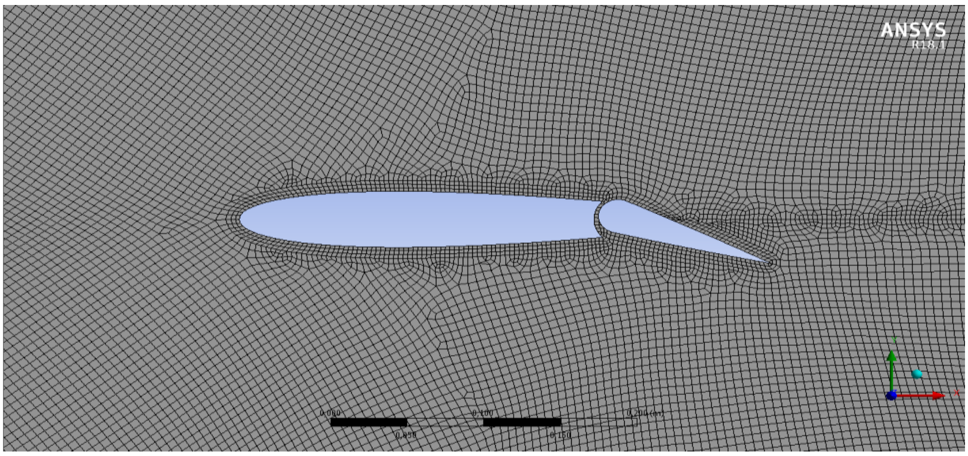
Then, the same coefficients were extracted for the tail with the non-deflected elevator, as shown in the figure 4 above. After that, once the boundary conditions were validated, the origin of the simulation was positioned on the axis of rotation of the elevator, thus defining the positioning of the hinge line and now, the moments exerted by the incidence of air on the surfaces will coincide with the torque required for the servos to move the control surfaces, as they will be acting on the same axis of rotation.

Figure 5. NACA 0012 airfoil with the deflected elevator



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Setting up the required elevator deflection (δ_e) as shown in Figure 5 above, the second step of validation was performed: with the deflected elevator, the results were compared with the values obtained using the DATCOM procedures [6] for the calculation of the Hinge Moment. The USAF Stability and Control DATCOM is a compendium of data and methods for estimating quantities for applications in stability projects and aircraft control, developed by the US Air Force, to estimate the $C_{h\alpha}$ and $C_{h\delta}$ values of the hinge moment of the elevator in equation (1).

Using the dimensions evaluated for Ansys Fluent (Table 1), $C_{h\alpha}$ and $C_{h\delta}$ for the hinge moment could be obtained using [6], consulting its series of curves for the experimental values corresponding to the dimensions and geometries of the control surface here evaluated and, applying the following empirical correlations:

$$C_{h\alpha} = \left(\frac{A_t cos\Lambda_{c4}}{A_t + cos\Lambda_{c4}}\right) C_{h\alpha b} + \Delta C_{h\alpha} \quad (2)$$

$$C_{h\delta} = cos\Lambda_{c4} cos\Lambda_{HL} (C_{h\delta b} + \alpha_\delta C_{h\alpha b}) \left(\frac{2cos\Lambda_{c4}}{A_t + cos\Lambda_{c4}}\right) + \Delta C_{h\delta} \quad (3)$$

where, $C_{h\alpha b}$ and $C_{h\delta b}$ are the nose swing contributions of the section, $\Delta C_{h\alpha}$ and $\Delta C_{h\delta}$ are the induced camber corrections, A_t is the aspect ratio of the control surface and Λ_{c4} and Λ_{HL} are the sweep angles with respect to a quarter of the chord line and to the hinge line, respectively. Since the aircraft has no sweep angle for its control surfaces, the Λ_{c4} and Λ_{HL} angles were neglected.

3. RESULTS AND DISCUSSION

For the results, a comparison between the simulation with the airfoil NACA 0012 and the results obtained through [5] in the graphics of lift and drag coefficient by alpha was made and the results have shown to be near.

In the comparison between the CFD modeled airfoil without the elevator and the airfoil with the elevator, the following coefficients of lift and drag were obtained, as shown in table 3:

Table 3. Coefficients of the NACA 0012 airfoil simulations, with and without elevator

Airfoil/Property	Lift	Drag
NACA 0012	0.16455751	0.00032024
NACA 0012 with elevator	0.15684119	0.00430888

Comparing the lowest value with the highest value in both, the results of the lift coefficient proved to be close, with a difference of less than 5%. However, in the results of the comparison of the drag coefficient, the difference was much greater, this occurred probably because the mesh of the analysis using only the airfoil needed to be refined. In numerical drag analysis, it is required to apply a higher mesh refinement in order to present more faithful results for the drag. As better computational resources were not available, the analysis continued nonetheless, taking into account the proximity of the results of the lift coefficient.

For the comparison between the results of the airfoil simulation with the deflected elevator and the method provided by [6], the following values of Hinge Moment were obtained:

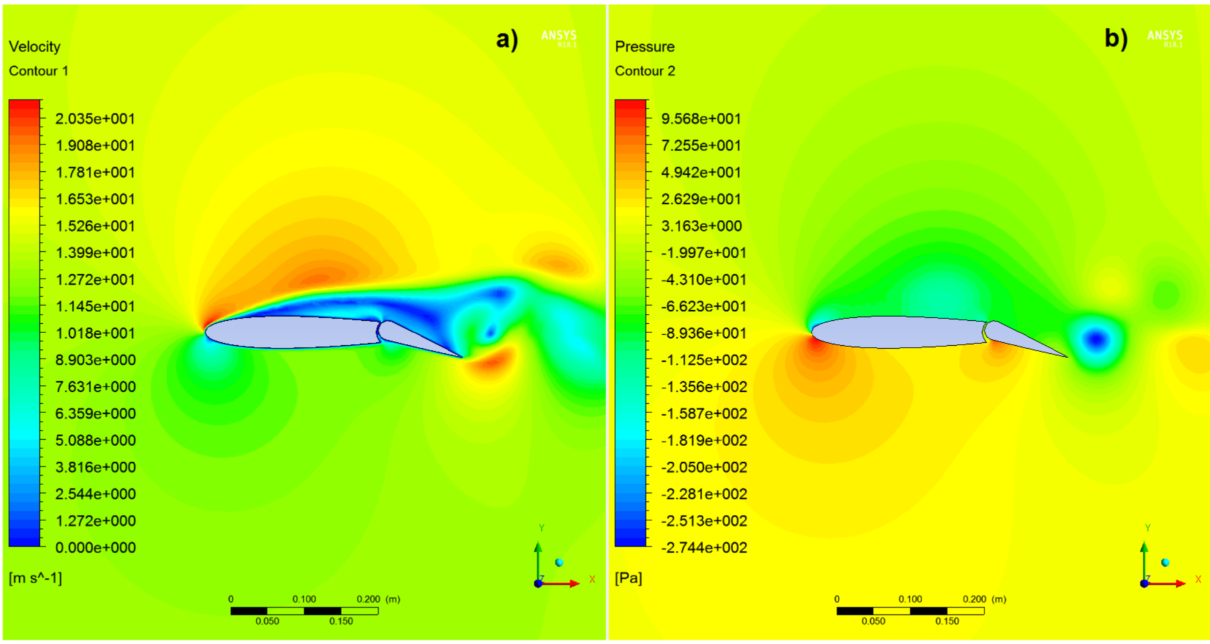
Table 4. Hinge Moment values obtained through CFD and DATCOM method

Method	Hinge Moment
CFD Simulation	0.239 N.m
DATCOM	0.121 N.m

The results of the hinge moment for the two methods were shown to be different, this is justified due to the difference in the way each one is obtained: DATCOM method provides the results by using historic experimental data, while using CFD numerical method, approximated equation models are applied. Such discrepancy when using different methods is also obtained from previous works in the literature, as the study carried out by [7]. For the current project, the value of 0.239 N.m provided by CFD analysis in Table 4 will be adopted, since it is more conservative and will ensure that the aircraft has greater controllability in face of the most critical conditions that can be achieved during the flights of the competition.

The corresponding pressure and velocity fields generated from CFD analysis are shown, respectively, on the following figures 4a and 4b:

Figure 4. (a) Resulting Velocity Field (b) Resulting Pressure Field.



In figure 4a, the formation of vortices is noticeable in the region of the trailing edge of the elevator. It is possible to observe in figure 4b, containing the pressure distribution contours, that a region of high pressure was formed at the bottom of the junction between the elevator and the stabilizer, the hinge moment being derived from the pressure distribution at this location.

4. CONCLUSION

From the analysis carried out in this study, it was possible to evaluate the resulting hinge moment under the flight conditions predicted for the PM-03 UAV project by the Prometheus Aerodesign team, which were replicated for a CFD simulation performed. Despite the divergence between the hinge moment resulting from the CFD simulation and the hinge moment evaluated by the data and correlations, the study allowed to evaluate the order of moment magnitude that must be overcome by a servo motor acting upon a designed elevator according to dimensions that were analyzed in this study. The study made it possible to estimate the minimum torque to be applied by a micro-servo motor, corresponding to the maximum estimated value of the hinge moment from the CFD results.

As a suggestion for future investigations, the results here seek to be compared with the wind tunnel tests with the scale model, serving for possible improvements to be implemented in the modeling and definition of meshes and configurations for future CFD analysis, be it the hinge moment or other aerodynamic characteristics for Prometheus Aero Design projects.

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