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A STUDY ABOUT CANARD TYPE AIRPLANE STABILITY

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Abstract. *The study of stability and control is one essential in the conceptual design of an aircraft. The definition of the initial dimensions in the preliminary design is strongly related with the assumptions in the stability and control study. The goal of this project is to determine the correct assumptions of stability and control that are relevant during the preliminary design of a canard type airplane (an airplane which the horizontal empennage is placed in front of the wing) and develop a simple method to inquire stability and control of this configuration. The first part in this study consists in obtain the physical parameters that define the flight envelope. With this envelope, it is simple to apply the theory to obtain extreme operational conditions for the force in the stick and deflection of the elevator in steady flight and maneuvering. Based in this analysis it is possible to define in the preliminary design if it is relevant or not the utilization of the canard configuration and in which conditions this configuration can be better than the conventional one.*

Keywords: *canard stability and control, canard, aircraft stability and control.*

1. INTRODUCTION

The problem of ensuring that and aircraft has sufficient stability and that it can be easily maneuvered has been part of the prerequisites of design since the beginning of aviation. Particularly, the first attempt to fly involved unstable aircraft, which led to the first controlled flight to happen only in 1903, with the Wright Brothers in USA.

Even today, during the conceptual design, it is of extreme importance preliminary stability calculations. Since in current literature it is rare to find grounded procedures directly applicable to Canard airplanes, the goal of this paper is to develop a simple procedure to evaluate stability and control of canard type airplane that can be employed in airplane design.

In this paper it is intended to describe a simple method to evaluate the stability and control for canard type airplane to be used in preliminary design.

2. METHODOLOGY

In the study of dynamic systems we see that stability is the capacity of the system to return to a state of equilibrium. In other words, a system is said to be stable if after a perturbation, the system return, by itself, to equilibrium after a period of time. In study of aircraft stability we divide the study of stability in two, the dynamic stability, which has the same definition for general stability in dynamic systems, and the static stability. The static stability is the tendency that the system has due to a perturbation to return to equilibrium. Hence, if given a perturbation the system tend to return to equilibrium it is said to be statically stable. See that static stability is a simplification of the study of stability. Since the study of complete stability of airplanes considering all transient period can be much elaborated, it is often sufficient to consider only the instant after the perturbation. In fact, practice shows that for many cases, it is sufficient to ensure static stability for a safe flight.

2.1 Longitudinal Equilibrium for Canard airplanes

To begin the analysis of stability, we first analyze the equilibrium of the aircraft, which is given by:

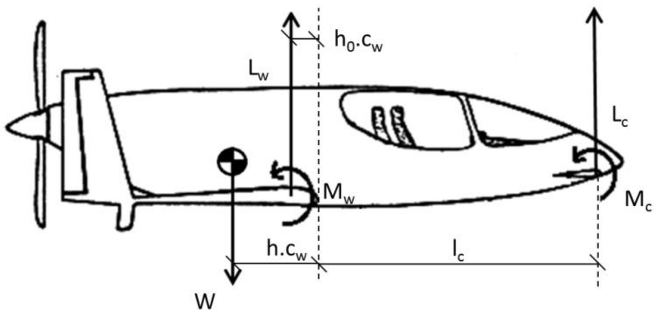

Figure 1- Free-body diagram on a canard type airplane

The net pitch moment around the center of gravity is given by:

$$m = m_c + m_w + L_w(h - h_0)\bar{\bar{c}}_w + L_c(h\bar{\bar{c}}_w + l_c) \quad (1)$$

Where

m_c is the resultant moment in the aerodynamic center of the canard.

m_w is the resultant moment in the aerodynamic center of the wing (MAC)

L_w is the wing lift.

L_c is the canard lift.

$\bar{\bar{c}}_w$ is the wing aerodynamic mean cord.

h is the ratio of the distance between the CG and the leading edge and the $\bar{\bar{c}}_w$

h_0 is the ratio of the distance between the CMA and the leading edge and the $\bar{\bar{c}}_w$

Dividing both sides of equation (1) by ½ $\rho V^2 S_w \bar{\bar{c}}_w$, and rearranging it is obtained:

$$C_m = C_{m_0} + C_{L_{we}}(h - h_0) - \overline{v_c} C_{L_c} \quad (2)$$

Where:
$\overline{v_c} = \frac{l_c S_c}{\bar{\bar{c}}_w S_w}\left(1 - \frac{\bar{\bar{c}}_w}{l_c}\right)$ is the canard volume coefficient.

The lift coefficient of the wing, if we consider that the aircraft is fling far from the stall, is a linear function of the angle of attack.

$$C_{L_w} = a\alpha \quad (3)$$

The lift coefficient of the canard depends not only in its angle of attack but, also, in the deflection of the elevator and trim.

$$C_{L_c} = a_1\alpha_c + a_2\eta + a_3\delta \quad (4)$$

Where a_1, a_2 and a_3 are the variations of the Canard Lift coefficient in respect to the angle of attack, the elevator deflection and compensator deflection, respectively.

When studding canard airplanes, that is an interaction between the airflow in the wing and in the canard. The angle of attack of the canard is subjected to an upwash due to the lift of the wing. The angle of attack of the wing is decreased due to the downwash generated by the canard.

This last effect will be neglected, because, once the lift of the wing is, in most cases, significantly bigger than the canard, it will be less affected. In this case, the angle of attack of the canard will be:

$$\alpha_c = \alpha + \epsilon + i_c \tag{5}$$

Where i_c is the canard incidence and ϵ is the upwash angle.
The upwash angle is a function of the wing angle of attack. This expression can be very complex, but writing it in a Taylor series and neglecting the superior order terms:

$$\epsilon_{(\alpha)} = \sum_{i=0}^{\infty} \frac{\alpha^{i-1}}{i!} \left|\frac{\partial^i \epsilon}{\partial \alpha^i}\right|_{\alpha=0} \approx \epsilon_{(0)} + \alpha \left|\frac{\partial \epsilon}{\partial \alpha}\right|_{\alpha=0} \tag{6}$$

Since the upwash for null angle of attack is zero, the canard angle of attack is:

$$\alpha_c = \epsilon_\alpha \frac{C_L}{a} + i_c \tag{7}$$

Where:

$$\epsilon_\alpha = \left|\frac{\partial \epsilon}{\partial \alpha}\right|_{\alpha=0} + 1$$

Substituting (4) and (7) in (2) we have:

$$C_m = C_{m_0} + C_{L_{we}}(h - h_0) - \overline{v}_c \left[a_1 \left(\epsilon_\alpha \frac{C_L}{a} + i_c\right) + a_2\eta + a_3\delta\right] \tag{8}$$

2.2 Stability and control

The derivation of eq. (8) is sufficient to use the theory described in BABISTER (1961). In fact, equation (8) is analogous to Babister's equation 3.12.

This way it is possible to inquire stick free and stick fixed stability. It is also possible to inquire control qualities such as elevator deflection for equilibrium, stick force for equilibrium, normalized stick deflection, normalized stick force, increase in elevator deflection to perform a maneuver and increase in elevator deflection to perform a maneuver.

2.2.1 Stability

2.2.1.1.1 Stick fixed stability

The stick fixed hypothesis considers null elevator deflection. It is defined stick fixed neutral point the center of gravity position in which the stick fixed stability margin is null.

$$h_n = h_{0wb} + \overline{v}_c \cdot a_1 \frac{\epsilon_\alpha}{a_{wb}} \tag{9}$$

2.2.1.1.2Stick free stability

The stick free hypothesis considers null stick force. It is defined stick free neutral point the center of gravity position in which the stick free stability margin is null.

$$h_n{}' = h_{0wb} + \overline{v}_c \cdot \bar{a}_1 \frac{\epsilon_\alpha}{a_{wb}} \tag{10}$$

Where

$$\bar{a}_1 = a_1 - \frac{a_2}{b_2} b_1$$

2.2.2 Canard control and flight qualities

2.2.2.1 Stick fixed maneuver point

The stick fixed maneuver point is the position of the center of gravity in which there is not necessary to impose any additional deflection of the elevator to perform a maneuver.

$$h_m = h_{0wb} + \bar{v}_c \cdot a_1 \left(\frac{\epsilon_\alpha}{a_{wb}} + \frac{1}{2\mu}\right) \quad (11)$$

Where:

$$\mu = \frac{W}{g\rho l_c S_w}$$

2.2.2.2 Stick free maneuver point

The stick free maneuver point is the position of the center of gravity in which there is not necessary to impose any additional force on the stick to perform a maneuver.

$$h_m{}' = h_{0wb} + \bar{v}_c \cdot \bar{a}_1 \left(\frac{\epsilon_\alpha}{a_{wb}} + \frac{1}{2\mu}\right) \quad (12)$$

2.2.2.3 Canard flight qualities

2.2.2.3.1 Elevator deflection for equilibrium

The elevator deflection for equilibrium is obtained similarly to the traditional theory, MARTINS (2011):

$$\bar{\eta} = A_1 \bar{C}_L + A_2 \quad (13)$$

Where:

$$A_1 = \frac{1}{a_2}\left[\frac{(h - h_0)}{\bar{v_c}} - a_1 \frac{\epsilon_\alpha}{a_{wb}}\right]$$

$$A_2 = \frac{1}{a_2}\left[\frac{C_{m_0}}{\bar{v_c}} - a_1 i_c - a_3 \delta\right]$$

2.2.2.3.2 Stick force for equilibrium

The Stick force for equilibrium is obtained similarly to the traditional theory, MARTINS (2011):

$$\bar{P}_e = B_1 + B_2 V^2 \quad (14)$$

Where:

$$B_1 = m_e S_\eta \bar{\bar{c}}_\eta \left(b_1 \frac{\epsilon_\alpha}{a_{wb}} + b_2 A_1\right)\frac{W}{S_w}$$

$$B_2 = \frac{1}{2} m_e \rho S_\eta \bar{\bar{c}}_\eta \left\{C_{H_0} + b_1 i_c + \frac{b_2}{\bar{v_c} a_2}\left[C_{m_0} - \bar{v_c}(a_1 i_c + a_3 \delta)\right] + b_3 \delta\right\}$$

2.2.2.3.3 Increase in elevator deflection to perform a maneuver

The Increase in elevator deflection to perform a maneuver is obtained similarly to the traditional theory, MARTINS (2011):

$$\Delta\eta = \frac{1}{\bar{v_c} a_2}\left[h - h_0 - \bar{v_c} a_1 \left(\frac{\epsilon_\alpha}{a_{wb}} + \frac{1}{2\mu}\right)\right](n-1)\bar{C}_L \quad (15)$$

2.2.2.3.4 Increase in stick force to perform a maneuver

Increase in stick force to perform a maneuver maneuver is obtained similarly to the traditional theory, MARTINS (2011):

$$\Delta P_e = \frac{1}{2} m_e \rho V^2 S_\eta \bar{\bar{c}}_\eta \frac{b_2}{\bar{v_c} a_2}\left[h - h_0 - \bar{v_c} \bar{a}_1 \left(\frac{\epsilon_\alpha}{a_{wb}} + \frac{1}{2\mu}\right)\right](n-1)\bar{C}_L \quad (16)$$

2.3 Example: Stability and control calculations of a prototype aircraft

To validate the proposed equations, the stability and control of a canard type airplane will be calculated. Due to the difficulty of finding enough data of canard airplanes, the dimensions were estimated.

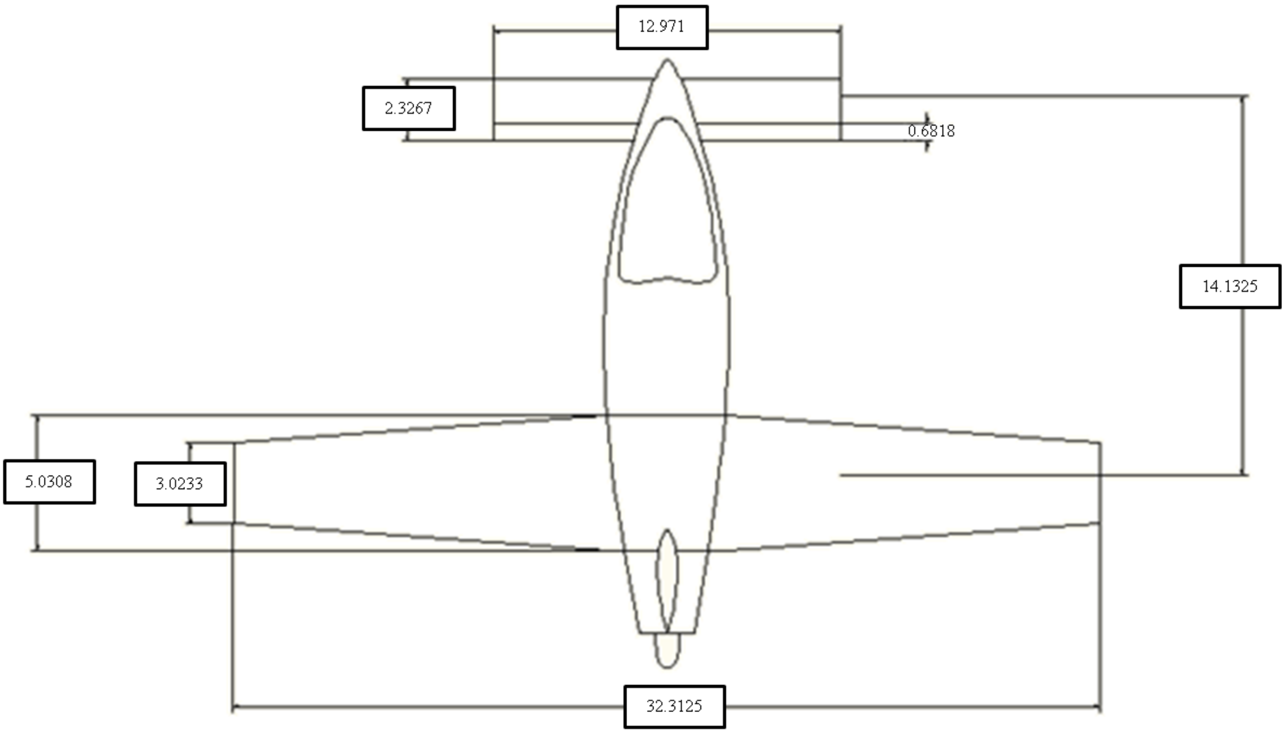

Figure 2- Top view of the prototype aircraft (dimension in ft) – Martins(2011)

Table 1 – Aircraft Dimensions

Wing Aspect Ratio	8
Wing Area	130 ft^2
Wing tapering	0,6
Wing sweep angle	0º
Wing Dihedral	0º
Wing Airfoil	NACA 63(3)418
Canard Aspect Ration	3
Canard Area	16,22 ft^2
Canard tapering	1
Canard sweep angle	0º
Canard Dihedral	0º
Canard Airfoil	NACA 63-009

2.3.1 Flight Envelope

The flight envelope is composed by the V-n diagram of gust and maneuver. It was determined according to the FAR23 subparts 335 to 341.

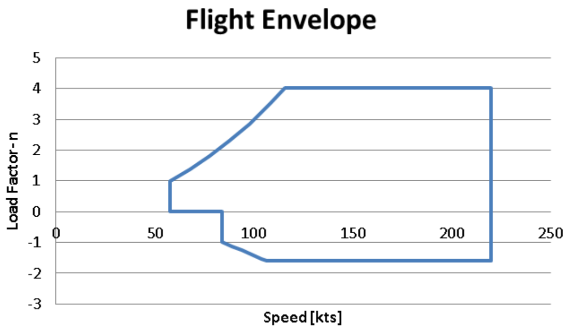

Figure 3- Aircraft flight envelope – Martins(2011)

2.3.2 Aerodynamic Coefficients

The estimation of the aerodynamic coefficients was made using ESDU 86021. A list of the results is show below:

Table 2 – Aerodynamic coefficients

Wing lift curve slope	a_w	5.8rad^{-1}
Wing null lift angle	α_{0_w}	-5.81°
Mean aerodynamic chord	$\bar{\bar{c}}$	1254mm
Aerodynamic center position	h_{0_w}	0.255
Wing moment coefficient for null wing lift	C_{m0_w}	-0.0465
Wing-fuselage lift curve slope	a_{wb}	5.79rad^{-1}
Wing-fuselage null lift angle	$\alpha_{0_{wb}}$	-4.99°
Moment coefficient increase due to the fuselage	$C_{m_{wb}}$	0.0049
Fuselage influence in airplane neutral point	$h_{0_{wb}}$	0.148
Carnard lift curve slope due variation of angle of attack	a_1	3.43
Carnard lift curve slope due variation of elevator deflection	a_2	4.05
Hinge moment curve slope due variation of angle of attack	b_1	-0.149
Hinge moment curve slope due variation of elevator deflection	b_2	-0.56
Upwash coefficient	ϵ_α	1.2019

2.3.3 Stability and maneuverability

The neutral and maneuver points are shown in table 2.

Table 2 – Neutral and Maneuver Points

Stick fixed neutral point $h_n = 44.13\%$	Stick free neutral point $h_n{}' = 34.90\%$
Stick fixed maneuver point $h_m = 57.27\%$	Stick free maneuver point $h_m{}' = 43.90\%$

2.3.3.1 Canard flight qualities

Figure 3 shows the control and flight qualities using the equations from BABISTER and the aerodynamic data found in section 2.3.2.

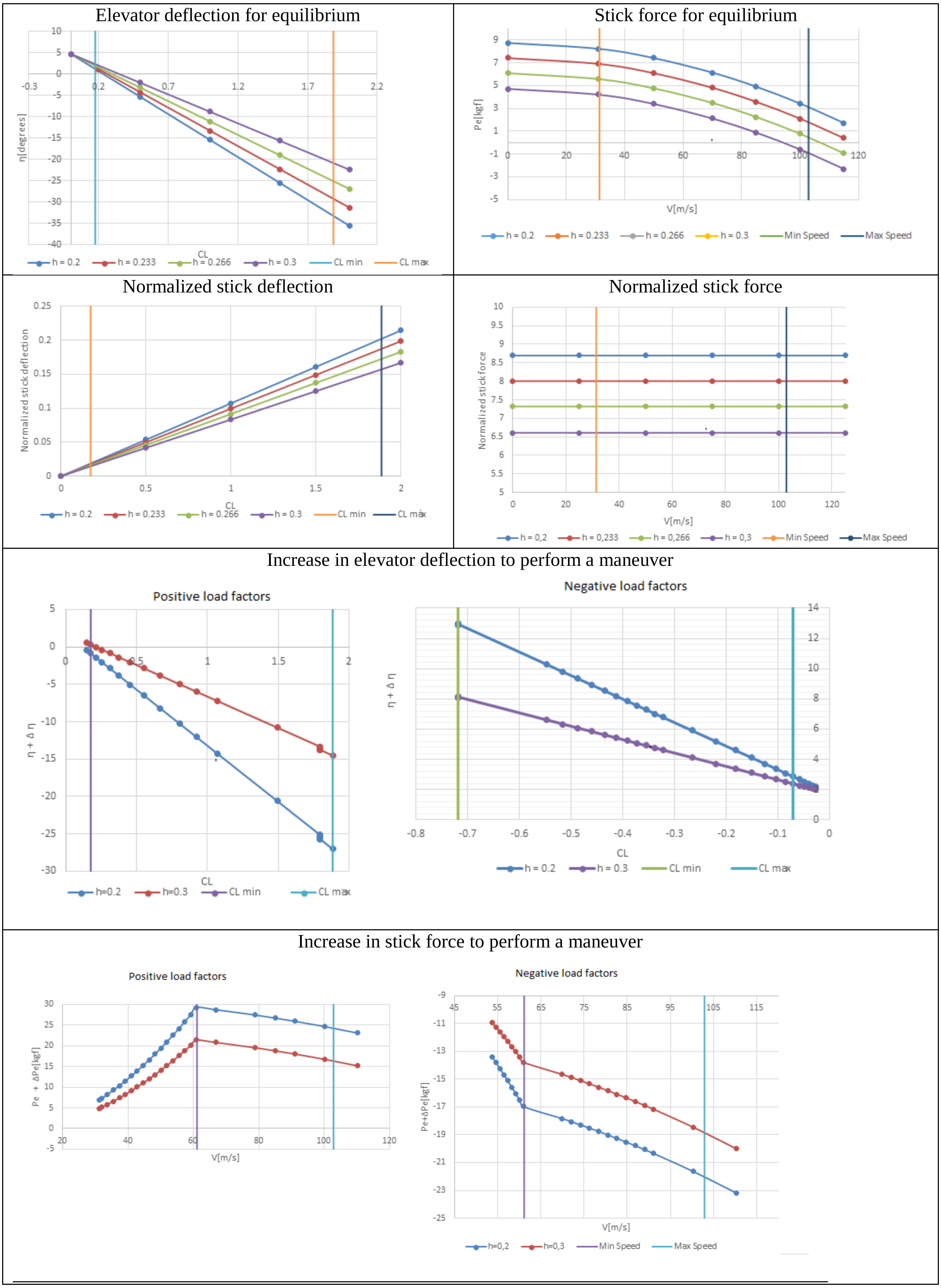

Figure 3- Airplane stability and control behavior

2.3.4 Stability and control conclusions

Through the obtained results, it is observed that the aircraft in question, present as foward limit to the center of gravity, the stick free neutral point (34.90% of the mean aerodynamic chord). But the stick fixed neutral point is well ahead of the upper limit of CG (44.13% of the mean aerodynamic chord). The estimated value is higher than the estimated limit CG (30% average aerodynamic chord). Thus, it did not exceed the stick free neutral point and it is static stable for the entire operating envelope of the aircraft.

The elevator deflection graph to balance deflection showed very high values, it is suggested that the elevator should be increased in area to achieve a greater effectiveness in the command.

The graph Pe x V to suggest that the stick force decreases when the CG tends to get forward. Additionally, this force also tends to decrease when there is an increased speed. Based on the criteria for application of force on the stick of up to 5 kgf for medium and long distances (continuous efforts) and 15 kgf to maneuver (intermittent efforts), it is observed that the aircraft does not meet the standard. However, these values for force on the stick are not exaggerated and achieve the reduction of these forces, we have options like the use of a tab or use of a lower gear ratio.

Through the graphic "normalized stick deflection", it is clear that as the CG approaches the maneuver points (hm and hm ') increases the sensitivity of the stick, allowing small movements impose high load factors. As the speed increases the sensitivity also increases.

Through the graphic "normalized stick force" which we have a V function, we can see that the force on the stick by "g" remains constant with the change in velocity, and increase sensitivity as the CG becomes forward.

3. CONCLUSIONS

The results were quite satisfactory. It was derived a simplified model that can be used in preliminary design. It is a very similar method when compared to the model for conventional aircraft whose adaptations boil down to a change in the definition of tail volume ratio and the downwash parameter (ϵ_α). In the case of canard it is actually upwash. Other than that, it can be used the exactly same equations of the traditional formulation.

A major limitation of the study is that it was not taken into account the aerodynamic interactions between the wing and the canard, except for the estimation of the upwash caused by the wings in the canard, unilaterally.

In fact, considering that the canard type stabilizers, compared with conventional stabilizers are larger and are closer, it is expect significant mutual interaction.

To continue the work it is suggested studying the feasibility of incorporating in the model interactions between wing and canard analyzing the implications of the interactions in the stability and control.

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