REDUCTION OF FUEL CONSUMPTION OF A 100 SEATER AIRCRAFT BY VARIATION OF CG DURING CRUISING PHASE

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Abstract:

The project aims to reduce the trim angle of the elevator during the cruise phase of flight. The elevator trim angle produces negative lift at the tail end and this negative lift produced is the major cause for drag induced on the overall aircraft during its cruise flight, in turn limiting the cruise speed, increased fuel consumption to produce the thrust required to overcome this drag and there by reduced fuel efficiency. The center of gravity location of the aircraft is the primary factor which governs the trim angle produced during the flight. By moving the center of gravity towards the aerodynamic center of the aircraft, the trim angle and the negative lift produced therefore can be reduced. The project's aim is to establish a theory for this, formulate a procedure and provide mathematical proof for the same. The project starts with the design of the aircraft from the scratch from the basic specifications of the aircraft. Since the focus is to design an elevator producing a reduced angle for trimming, the main focus is given on the longitudinal aspects of the design. The design calculation part is addressed in the project. The entire theoretical parameters required in designing a custom aircraft are calculated. Mat Lab programs are written to plot the graphs showing the reduction of elevator deflection and negative tail lift. This will provide a clear picture as to how much deflection has been reduced from the conventional design.

I. INTRODUCTION

1.1 CONTROL SURFACE ELEVATOR

A very fundamental requirement of a safe flight in longitudinal axis is the primary function of the elevators. An aircraft must be longitudinally controllable, as well as maneuverable within the flight envelope. In a conventional aircraft, the longitudinal control is primarily applied though the deflection of elevator (δ_E). Longitudinal control is governed through pitch rate (q) and consequently angular acceleration ($\ddot{\theta}$) about y-axis (or rate of pitch rate). Longitudinal control of an aircraft is achieved by providing an incremental lift force on horizontal tail. Thus, elevator which is classified as a primary control surface is considered as a pitch control device.

The incremental tail lift is generated by deflecting the entire tail elevator or by deflecting elevator is located at the tail trailing edge of aircraft. the horizontal tail located at some distance from the aircraft center of gravity, the incremental lift creates a pitching moment about the cg. Pitch control of control surface can be achieved by changing the lift on the horizontal tail in a conventional aircraft.

There are 2 groups of requirements in aircraft longitudinal controllability: 1. Pilot force, 2. Aircraft response to the pilot input. In order to deflect the aircraft elevator, the pilot must apply a force to stick, yoke or wheel and hold it in the case of an aircraft with a stick-fixed control system. In an aircraft a stick-free control system, the pilot force is amplified through a device as tab and spring.

1.2 DESIGN OF ELEVATOR

In a conventional aircraft, longitudinal control is not coupled with lateral-directional control. Thus, a design of the elevator is almost entirely independent of the design of the rudder and the aileron. This issue simplifies the design of the aircraft elevator. In the design of the elevator, four parameters should be determined. They are:

1) Elevator plan form area (S_E),
2) Elevator chord (C_E),
3) Elevator span (b_E),
4) Maximum elevator deflection ($\pm\delta_{Emax}$).

As a general guidance, the typical values for these parameters are as follows: S_E/S_h= 0.15 to 0.4, b_E/b_h = 0.8-1, C_E/C_h = 0.2-0.4, and$\delta_{Emax\ up} = -25\ degrees$,$\delta_{Emaxdown} = +20\ degrees$. [Aircraft Design: Systems Engineering Approach by Mohammad Sardraey]

Figure above shows the geometry of the horizontal tail and elevator. As a convention, the up deflection of elevator is denoted negative, and down deflection as positive. Thus a, negative elevator deflection is creating a negative horizontal tail lift while generating a positive (nose up) pitching moment.

Prior to the design of elevator, the wing and horizontal tail must be designed, as well as the most aft and most forward locations of aircraft center of gravity must be known. The principals of elevator design, design procedure, governing equations, constraints, and design steps are presented for typical transport aircraft

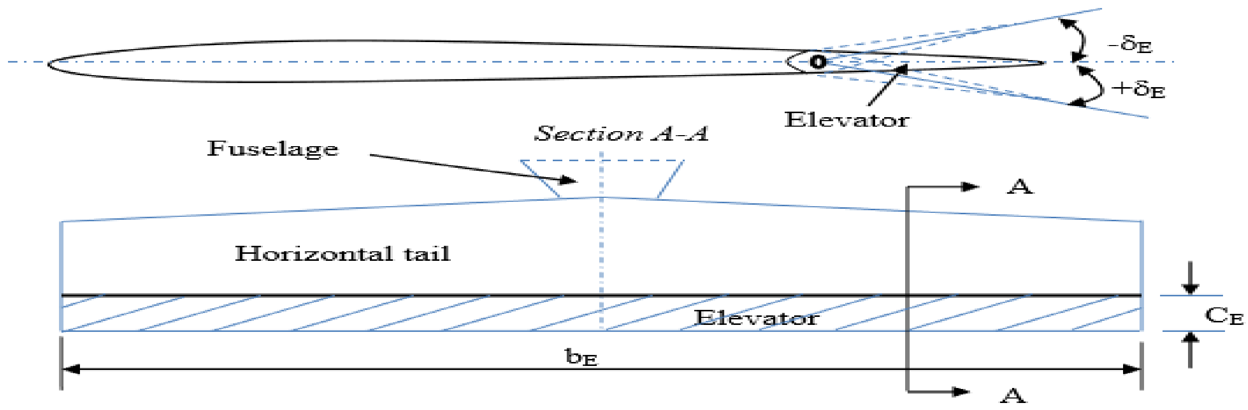

Figure 1 Top view of horizontal tail and Elevator

1.3 PRINCIPLES OF ELEVATOR DESIGN

Factors affecting the design of an elevator are elevator effectiveness, elevator hinge moment, and elevator aerodynamic and mass balancing. The elevator effectiveness is a measure of how effective the elevator deflection is in producing the desired pitching moment. The elevator effectiveness is a function of elevator size and tail moment arm. Hinge moment is also important because it is the aerodynamic moment that must be overcome to rotate the elevator. The hinge moment governs the magnitude of force required of the pilot to move the stick/yoke/wheel. Therefore, great care must be used in designing an elevator so that the stick force is within acceptable limits for the pilots. Aerodynamic and mass balancing deal with technique to vary the hinge moment so that the stick force stays within an acceptable range; and no aero-elastic phenomenon occurs.

The longitudinal control handling qualities requirements during take-off operation is stated as follows: in an aircraft with a tricycle landing gear, the pitch rate should have a value such that the take-off rotation does not take longer than a specified length of time. Since the take-off rotation dynamics is governed by Newton's second law, the take-off rotation time may be readily expressed in terms of the aircraft angular acceleration ($\ddot{\theta}$) about the main gear rotation point. For instance, in a transport aircraft, the acceptable value for the take-off rotation time is 3-5 seconds. The equivalent value for the angular rotation rate to achieve such requirement is 4-6 deg/sec2. This requirement must be satisfied when the aircraft center of gravity is located at the most forward location.

In the elevator detail design process, the following parameters must be determined:

1. Elevator-chord-to-tail-chord ratio (C_e /C_h)
2. Elevator-span-to-tail-span ratio (b_e /b_h)
3. Maximum up elevator deflection ($-\delta_{EMAX}$)
4. Maximum down elevator deflection ($+\delta_{Emax}$)

Prior to the design of an elevator, the wing horizontal tail must be designed, as well as the most aft and the most forward locations of aircraft center of gravity must be known.

Some of the calculations required for the elevator design is

1. Aircraft take-off weight.
2. Wing dimensions.
3. Fuselage Dimensions.
4. Landing Gear location.
5. Horizontal tail dimensions.
6. Estimating the CG location
7. Calculating the tail volume area.
8. Fuel weight estimation

II. METHODOLOGY

- Choose the specification of the aircraft and find the maximum take-off weight
- Obtain the sizing of fuselage, wing & horizontal tail
- Locate the aircraft CG location and the CG range (most aft and most forward CG locations)
- Choose the landing gear configuration and locate the main gear
- Sizing of elevator:
  1. Major elevator parameters
  2. Horizontal tail lift
  3. Elevator effectiveness
  4. Check the compatibility of elevator
  5. Elevator dimensions
- Establish a theory for reducing the tail negative lift and elevator trim angle
- Formulae the theory using mat lab programs.

III. RESULTS AND DISCUSSION

1. The project was able to formulate and establish a theory for reducing the negative tail lift by shifting small quantities of fuel to the tail end.
2. The maximum capacity of fuel that can be transferred to the tail fuel box-4714.06 kg of fuel.
3. graphical simulations show a decrease of 0.4-0.5 degrees in the required elevator trim angle at cruise speed.

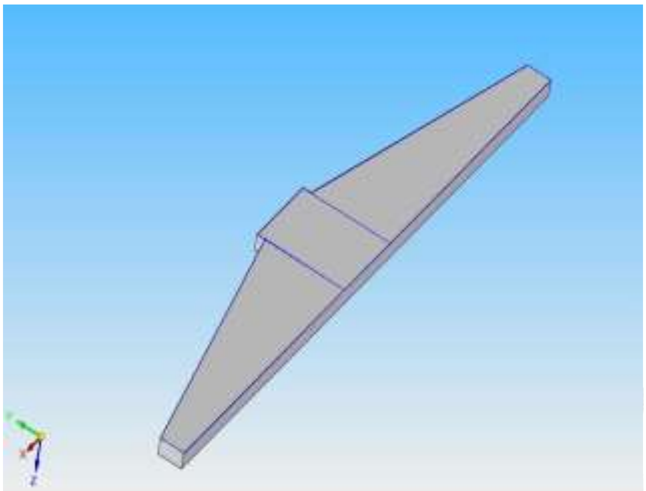

Figure 1 view of Tail box mounted in the tail end

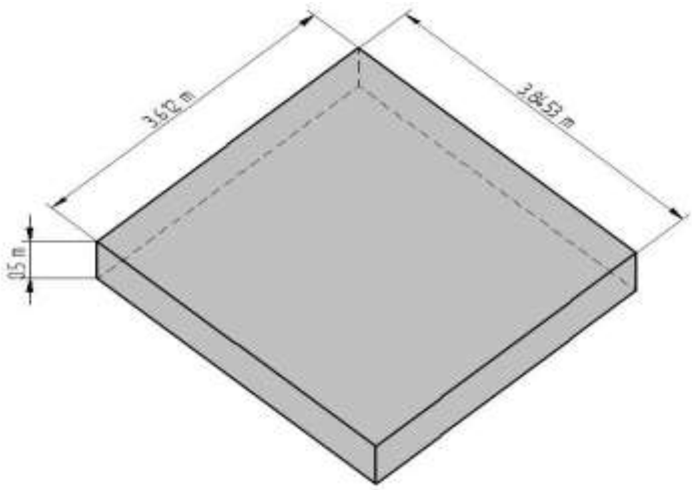

Figure 2 view of Tail box mounted in the tail end

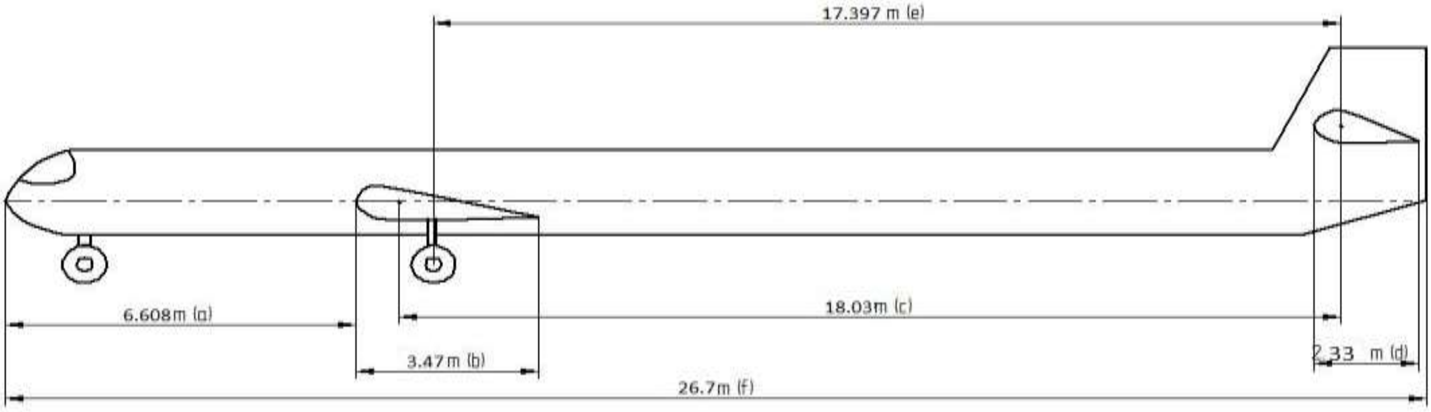

Figure 3. Side view sketch of the aircraft with the obtained dimensions

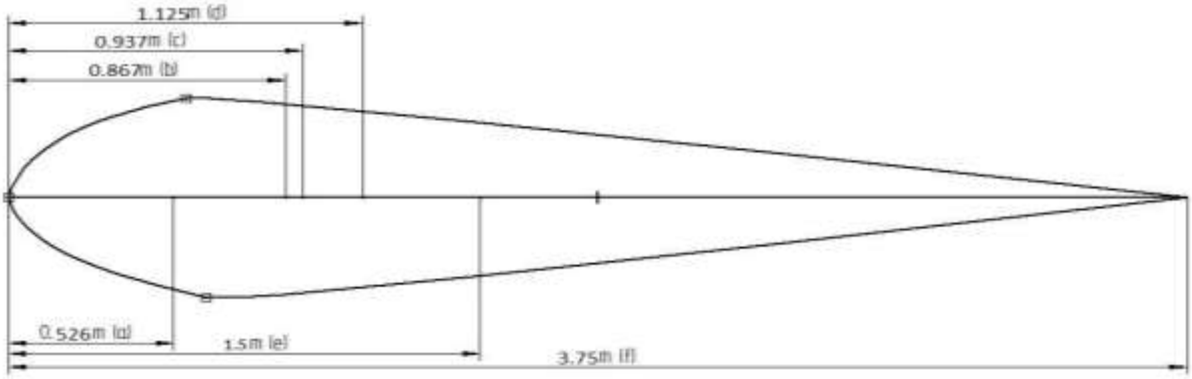

Figure.4. Mean Aerodynamic chord of wing

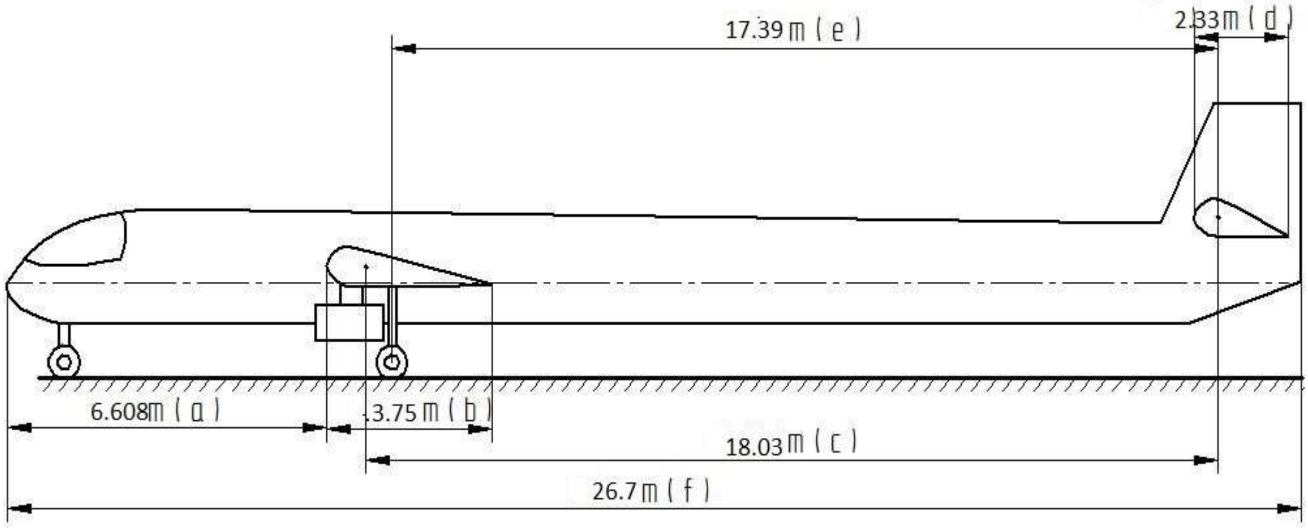

Figure 5. Aircraft side view sketch with chosen vertical distance for Engine and landing gear

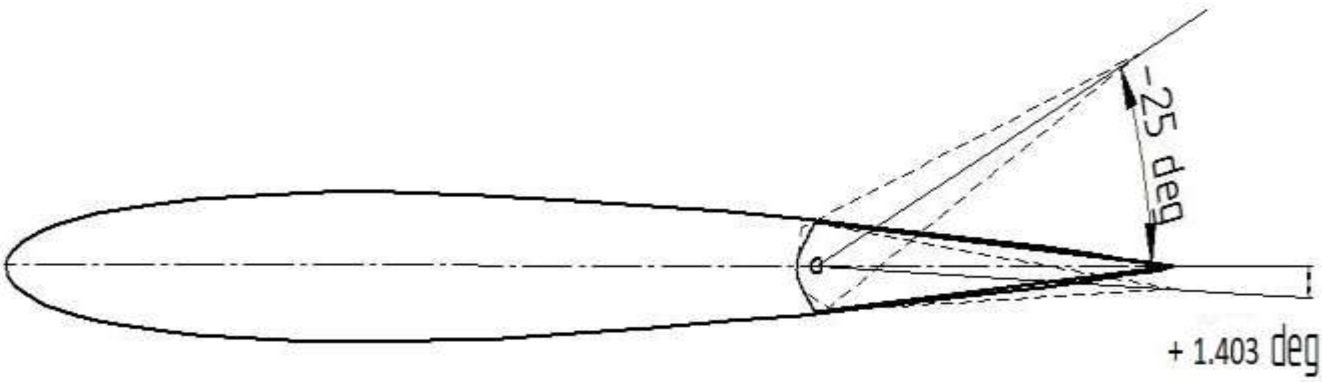

Figure 6. Elevator maximum up and down deflection

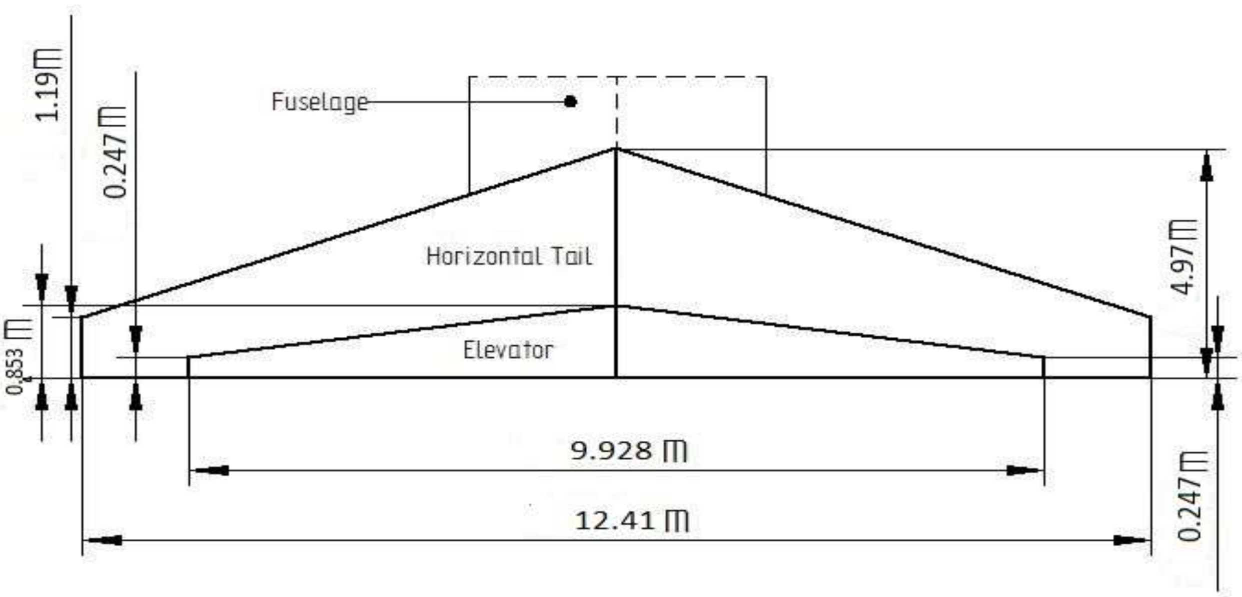

Figure 7. Geometry of Horizontal tail and elevator assembly

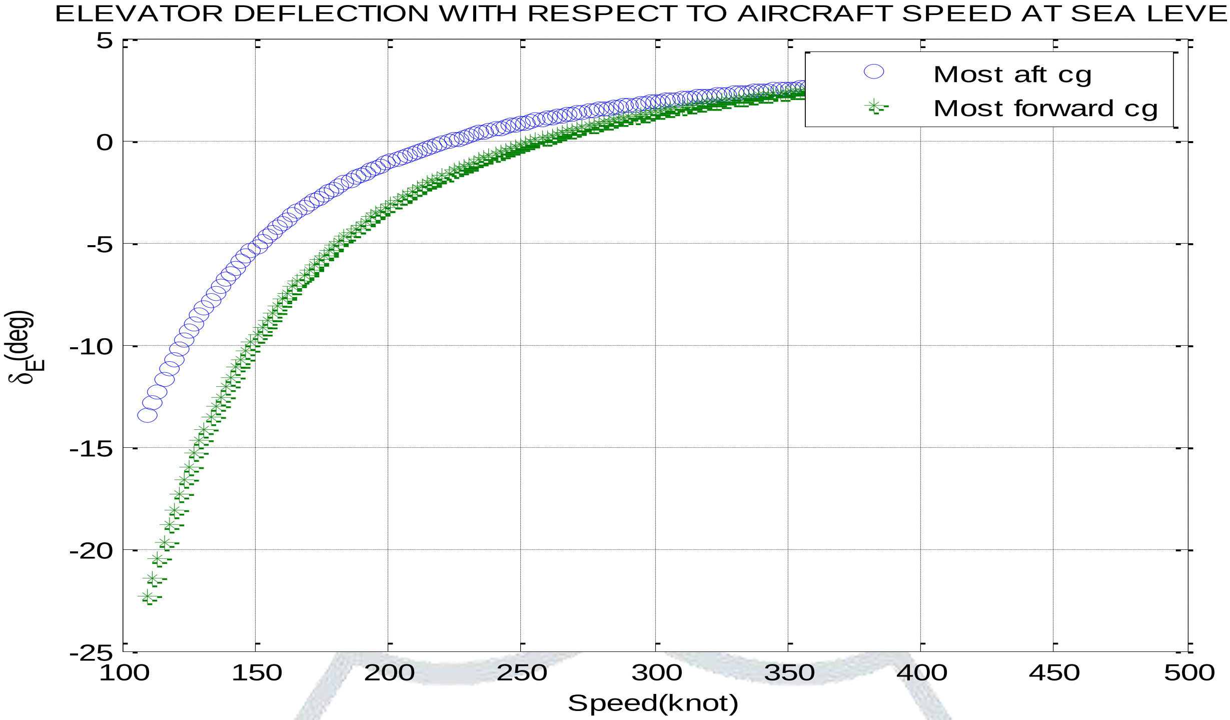

*Figure **3** Elevator deflection vs. aircraft speed at sea level*

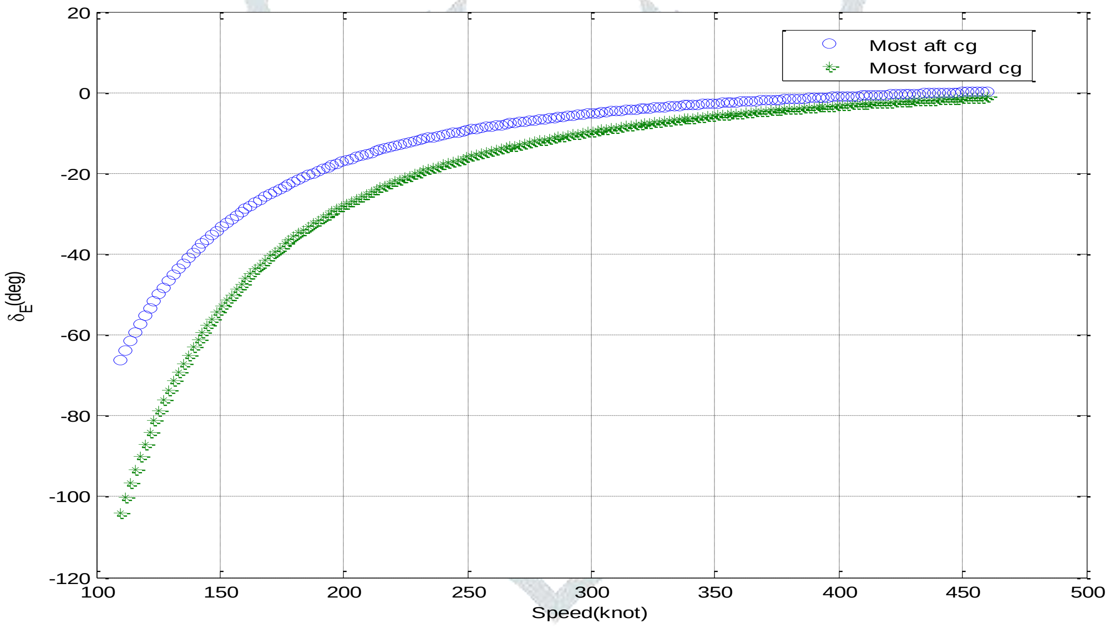

Figure 4. Elevator deflection vs. aircraft speed at cruise altitude

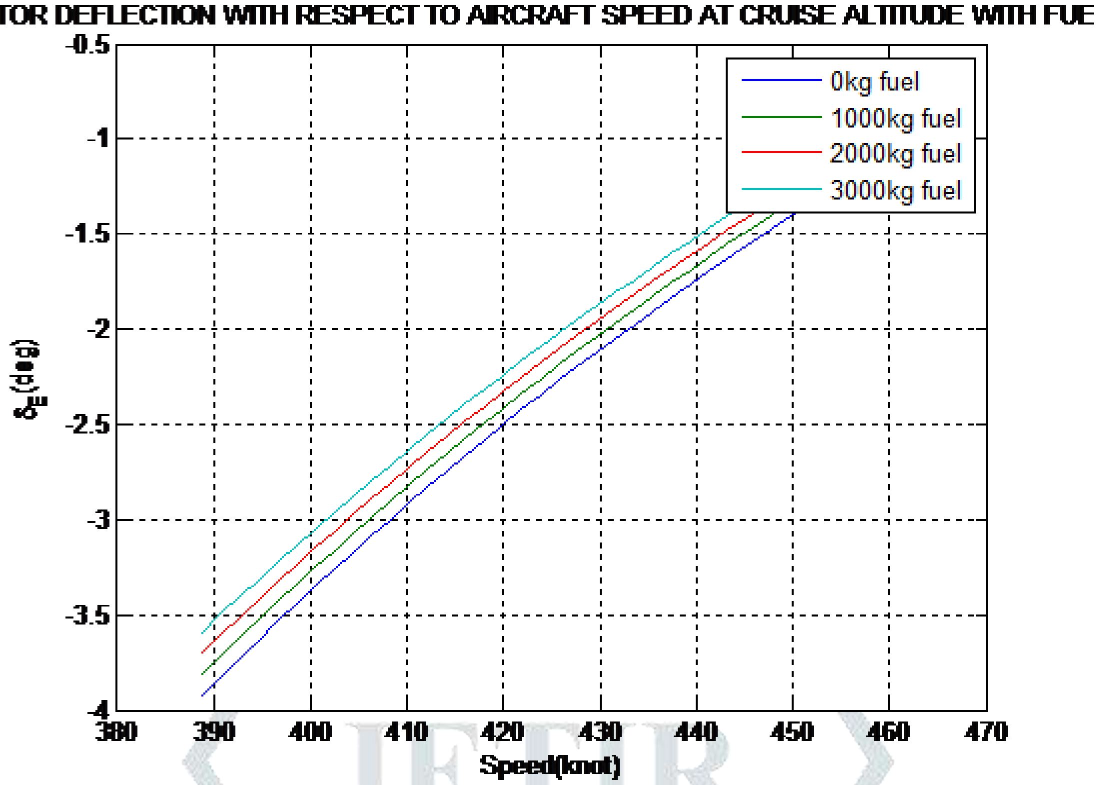

Figure 9.2. Elevator trim angle with fuel shift

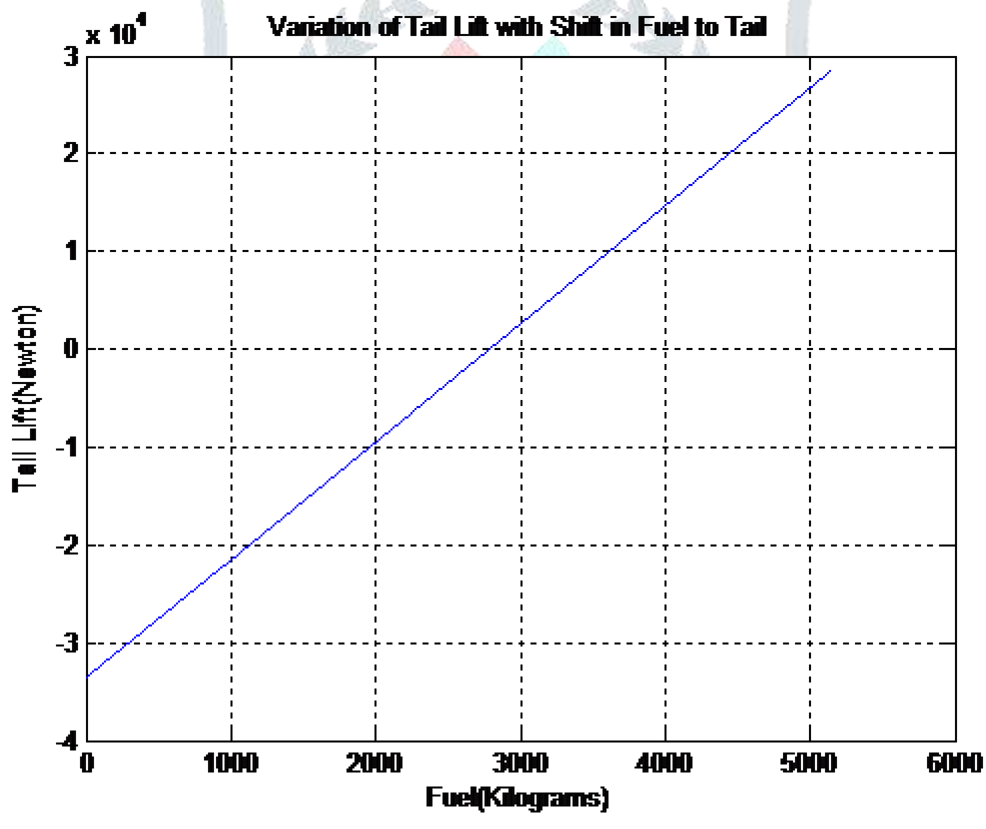

Figure 9.5. Variation of tail lift with shift in fuel

IV. CONCLUSION

Almost all the conventional commercial transport aircrafts are designed so as to satisfy the major constraint of maintaining its longitudinal stability through the out its flight. But the major price to pay for this maintenance of longitudinal stability is the overall increase in the aircraft drag, which will be ever present in its major flight phase which is cruise. The deflection of elevator during cruise is very important to maintain the longitudinal stability. The tail down force thus created produces this extra drag. The work carried out in this project focused on dealing with design calculations for an aircraft from the scratch and estimating almost all the longitudinal parameters. The custom specification of the aircraft was decided based on which weight estimation was done. The Wing, fuselage and tail dimension were calculated. The selection of landing gear, the location of aircraft cg and its range etc were deduced. In the final stage of aircraft sizing an elevator was designed. The calculations proved that the elevator designed was safe and do not stall the horizontal tail. MAT LAB program was written to plot the trim curve at sea level and at cruise altitude.

The reason was the presence of tail lift was identified to be the increase distance between aircraft cg and the aerodynamic center during cruise. Since aerodynamic center remained constant, the only way was to make changes in the cg location. The practical concept of transferring the fuel from the wing fuel box to a designed tail fuel box was established. The calculations proved that there is a large decrease in the trim angle required and thus the tail negative lift. An algorithm was written to generalize this design calculation and Mat lab was used to execute the algorithm. The plot obtained clearly showed the decrease in elevator trim angle with the increase in fuel transfer. The linear decrease in tail negative lift was established through the algorithm. The simple tail box was designed for this purpose at the tail end and its capacity was kept as the constraint in fuel transfer.

The project was able to bring out the design calculation involved in designing an elevator and formulating the method used to reduce the trim angle without affecting the longitudinal stability of the aircraft. This simple but practically possible technique proves to decrease the drag to a great extent. The project was able to successfully prove the same through its elaborate and in depth design calculations, formulate a method and develop an algorithm for the theory.

V. REFERENCE

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