Elevator Hinge Moment Design of N219-B12

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Abstract

The elevator hinge moment of N219-B12 was investigated based on the design criteria corresponded to the critical flight conditions for Stability and Control point of view. The criteria were adopted from Boeing criteria in its hinge moment design [1]. This criteria was not the only criteria in hinge moment design of aircraft, however, this criteria was implemented on N250-PA1 aircraft on its hinge moment design phase. In order to find the elevator hinge moment coefficients data, the wind tunnel testing was conducted in open jet type of subsonic wind tunnel LAPAN low speed tunnel. The model was 1: 6.3 scaled of an isolated half model of port horizontal tail plane (HTP) N219-B12 aircraft. The investigations showed that N219-B12 aircraft needed the servo tab to reduce the elevator stick force in order to meet the regulation of CASR 23 (commuter category aircraft) in its design. In addition, the servo tab and trim tab analyze were also described in this paper.

Key Words: Wind Tunnel Test, Elevator Hinge Moment, Servo Tab, Trim Tab,

1. INTRODUCTION

The N219 aircraft is a 19 seats twin-turboprop aircraft that can be operated in the region of aviation pioneer. This aircraft is unpressurized cabin which has maximum range of 840 nm (1554 km) and maximum operation speed of 210 knots. Moreover, the aircraft was designed to have capability to operate on short takeoff and landing (STOL) operation, multi hop capability and quick change configuration. The power was used twin engine of 850 SHP of Pratt & Whitney Aircraft Ltd. PT6A-42 Turboprop Engines with propeller Hartzell 4-Blade Metal Propeller.

In control surfaces design, it has been known that it was necessary to provide some means of balancing the excessive aerodynamic forces on the control surfaces. Aerodynamic methods of balance such as horns and insert hinge arrangements have been used to a considerable extent. N219-B12 aircraft uses the flight control system with fully mechanical linkage in its configuration, therefore the magnitude of hinge moment and control force became one of the important variable to be considered in its design phase.

In recent design, auxiliary airfoils attached to the control surfaces have been used for balance and also for trimming the airplane. Such an auxiliary airfoil has been referred as a tab and mounted on outriggers from the trailing edge of control surface. The tabs, when linked, move in the opposite direction to that of the control surface and thereby decrease the hinge moment for a given deflection of the control surface and it is referred as a servo-tab.

This paper analyzed the elevator hinge moment of N219-B12 aircraft from stability and control point of view. Whereas, the hinge moment coefficients data were taken from wind tunnel test which was conducted in Lembaga Penerbangan dan Antariksa Nasional (LAPAN) Low Speed Tunnel (LLST). The intention of this investigation was to clarify that the N219-B12 hinge moment configuration will result in elevator control force would comply the regulation of CASR 23 (commuter category aircraft).

2. EXPERIMENTAL SET-UP AND PROCEDURE

The whole hinge moment wind tunnel tests were executed at Pusat Teknology Penerbangan Lembaga Antariksa dan Penerbangan Nasional LAPAN low speed tunnel. This wind tunnel is an open jet type of subsonic wind tunnel with upstream cross-sectional area of 1.75 x 2.25 m^2 and downstream cross-sectional area of 1.75 x 2.35 m^2 respectively. The wind tunnel can be operated with maximum speed of 50 m/sec. and Reynold number of 6.64 million. This wind tunnel is not only used for testing the aeronautic model such as aircraft, rockets and so on, but it can also be used for non aeronautic model such as motor vehicles, bridges, wind turbine towers, ships, chimneys etc.

The elevator hinge moment wind tunnel test model was an isolated half model of port HTP aircraft which was scaled by 1:6.3 [2][4]. The geometry of horizontal tail, elevator and tabs geometries were shown in figures 2-1–2-2 respectively. Here, the horizontal tail planform used the mid tail configuration design concept with straight taper horizontal tail. The elevator can be rotated at the elevator hinge line which was located at 60% chord. The elevator trim and servo tab can be rotated at center of 90% of the local chord and nose was designed rounded and tangency to the horizontal tail airfoil surface. Elevator trim and Servo-tab plan-form definition were shown on Figure 2-1.

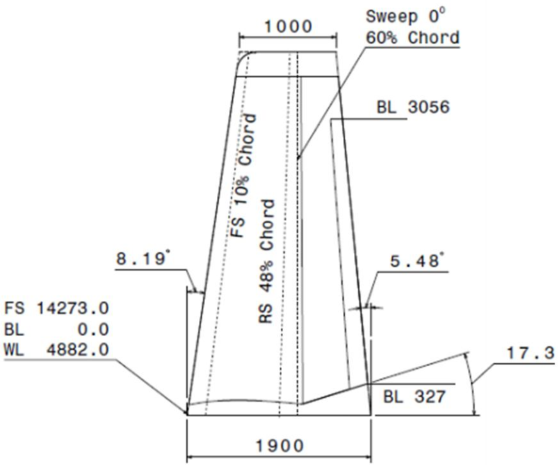

Figure 2-1 Horizontal tail geometrical definition

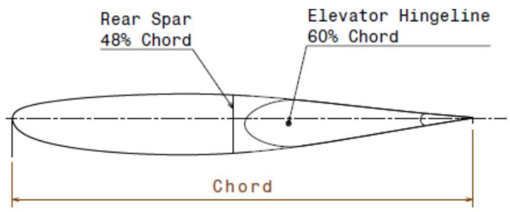

Figure 2-2 Elevator geometrical definition

3. ELEVATOR HINGE MOMENT OF N219-B12 AIRCRAFT

The elevator hinge moment of N219-B12 was analyzed based on the design criteria corresponded to the critical flight conditions for stability and control point of view as follow:

1. Takeoff rotation, dF= 10 deg, heavy weight, forward CG.
2. Maneuvering capability at diving speed (VD) and load factor (Nz) = 2.25
3. Maneuvering capability at VMO and load factor (Nz) = 2.0
4. Go – around @ 1.3 Vs.
5. Go around @ Stick Shaker
6. Landing Approach.
7. Maneuvering at VA.

The criteria were not limited only to the flight conditions mentioned above, but they still have possibility to be expanded to others. However, the criteria have been demonstrated on hinge moment prediction of N250-017 and proved that the flight conditions above were the critical conditions in design perspective.

3.1. N219-B12 elevator hinge moment coefficients determination

Generally, the elevator hinge moment was calculated based on the simple equations as follow:

$$H_{M_E} = C_{H_E} * q * S_E * \bar{c}_E$$
$$F_E = GR_E * H_{M_E} \tag{3.1}$$

Basically $C_{H_E} = f(\alpha_h, \delta_E, \delta_{tab})$ is function of local angle of attack, elevator deflection and balance tab deflection. However, in linear region is valid:

$$C_{H_E} = C_{H_0} + C_{H_{\alpha h}}\alpha_h + C_{H_{\delta E}}\delta_E + C_{H_{\delta tab}}\delta_{tab} \quad (3.2)$$

α_h = $\alpha + ih - \varepsilon$

C_{H_E} = *Elevator hinge moment coefficient*

C_{H0} = *Elevator hinge moment coefficient at* $\alpha_h = 0$

$C_{H\alpha h}$ = *Elevator hinge moment coefficient as function of* α_h

$C_{H_{\delta tab}}$ = *Tab hinge moment coefficient*

δ_{tab} = *Tab deflection*

q = *dynamic pressure* = $\frac{1}{2}\rho V^2$

S_E = *Area of the elevator aft of the hinge line,* m^2

c_E = *Average chord of the elevator aft of the hinge line, m*

Here, the elevator hinge moment coefficients could be found by theoretical approach or wind tunnel test results.

The N219-B12 elevator hinge moment coefficients were resulted from the wind tunnel test result which was conducted at LAPAN Low Speed Tunnel (LLST). The wind tunnel test model was scaled 1: 6.3 of horizontal tail shown in fig. 2-1 and was mounted stand on the test section. The model applied isolated HTP which has various horn balances to see its effects on the hinge moment and confirmed that unshielded horn balance was accepted in our elevator hinge moment design. Basically, the CH_0 could be found from the wind tunnel test as shown in figure 2-1, however, this CH_0 was inconsistent for various horn configurations (not shown), therefore the CH_0 was assumed to be adopted from theoretical prediction **i.e. -0.0035**. Since the CH_0 was constant value, so the coefficient of elevator hinge moment (CH_E) was only a function of HTP angle of attack (α_h) and elevator deflection (δe), respectively. Figures 3-1 and 3-2 displayed the wind tunnel test results of elevator hinge moment coefficient (CH_E) as a function of angle of attack (α) and elevator deflection (δe), respectively. Actually, the data can be used directly for calculating the hinge moment, however, the figures showed that the wind tunnel test results on Ch_α and $Ch_{\delta e}$ were quite varied. Therefore, we have taken engineering adjustment by taking the average value and confirmed that Ch_α was **-0.1506** per rad. and $Ch_{\delta e}$ was **-0.31784** per rad., respectively.

The elevator configuration of N219-B12 was also equipped by the servo and trim tabs, both with span of 40% of elevator span and 10% of elevator chord for port and starboard elevators, respectively. Figure 3-3 displays the wind tunnel test result of elevator hinge moment (CH_E) versus angle of attack (α) for various tab deflection (δ_{tab}). By taking the ratio of CH_E for various tab deflections, it can be found the elevator tab coefficient ($CH_{\delta tab}$) for definite angle of attack (α). Since the ($CH_{\delta tab}$) were quite varied for various angle of attack (α), therefore, by taking the average value, the elevator tab coefficient ($CH_{\delta tab}$) was found to be **-0.649**per rad. As mention above that the configuration of N219-B12 servo and trim tabs have the same size, so the elevator tab coefficient ($CH_{\delta tab}$) was used for both elevator servo and trim tabs, respectively.

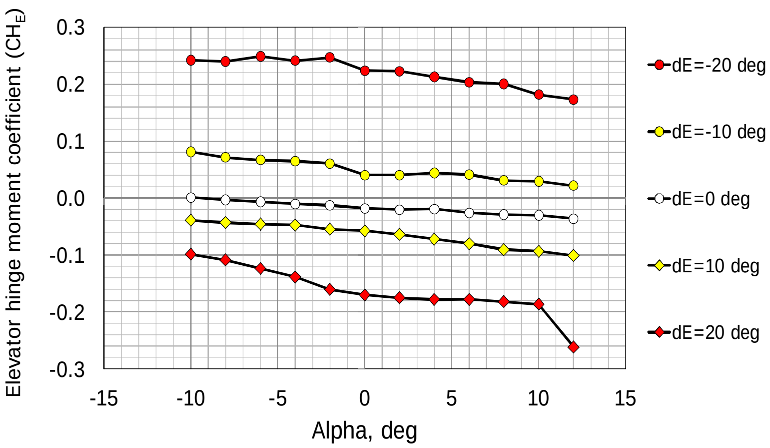

Figure 3-3 Elevator hinge moment coefficient vs alpha of N219-B12 wind tunnel result

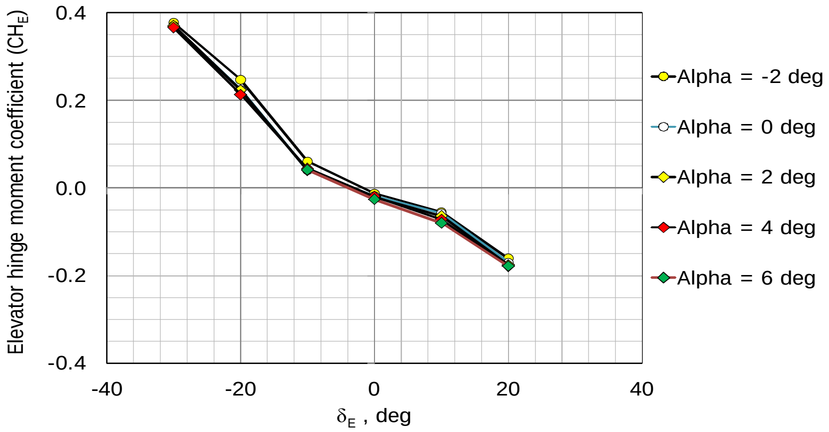

Figure 3-4 Elevator hinge moment coefficient vs δ_e of N219-B12 wind tunnel result

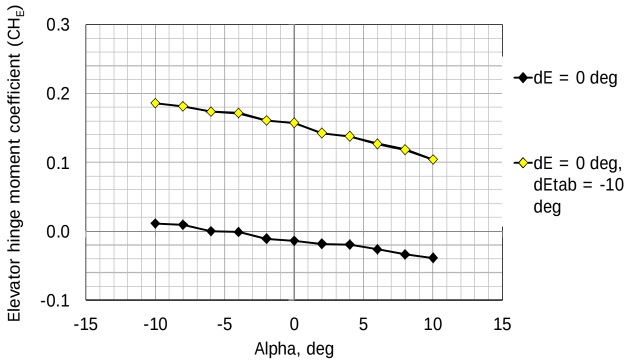

Figure 3-5 Elevator hinge moment coefficient vs alpha, deg for various δ_{tab} of N219-B12 wind tunnel result

3.2 N219-B12 elevator hinge moment calculation

In this section, the calculation of elevator hinge moment was done without considering effects of the servo or trim tabs, on its calculation. Here, the hinge moment and elevator force of N219-B12 was calculated based on the critical of flight conditions from stability and control point of view as mention above. The gearing ratio (GE) was taken from Flight Control System Department and the value was **3.1** rad/m. The data of flight conditions such as TO-Rotation, go around 1.3 Vs, go around with stick shaker and landing approach was referred to "Technical Report for Horizontal Tail Plane Sizing of N219-B07Aircraft" [3]. The summary of elevator hinge moment calculation was tabulated in table 3-1. It was shown that for the existing nose balance, the largest hinge moment was obtained at diving speed maneuvering with**-419 Nm** and stick force of **-292 lb**. In regard to the stick force limitation which has maximum stick force of 75 lb stated in CASR 23, it was clear that elevator hinge moment designed was out of limitation. Therefore, it was needed to apply the servo tab to reduce the stick force to the range of available limitation stated in the requirement.

Table 3-1 N219-B12 Elevator hinge moment calculation results

CASE	Flight Condition and Configuration (for Maximun HM)	Hinge Moment (Nm)/ Stick Force (lb)
Takeoff Rotation	δe = -20˚ , αH = -6.1˚ , V = VR = 77.4 KEAS , δf = takeoff flap deflection = 10˚, Forward CG = 16.0 % mac , Heavy weight = 15500 lb	312 Nm/217.5lb
Maneuver limit at VMO	NZ = 2.0 g, VMO = 190 KEAS, SL, δe = 5˚ , αH = -2.747 ˚.	-365 Nm/-255lb
Maneuver limit at Diving Speed (VD)	NZ = 2.5 g, VD = 265 KEAS, SL, (a) δe = 5.16 ˚, αH = -6.837˚.	**-419 Nm/-292lb**
Go – around @ 1.3 Vs	δe = -18˚, αH = -7.05˚., V = 1.3 V Stall = 76.8 KEAS , δf = Landing flap deflection = 40 ˚,	286 Nm/200lb

	Forward CG = 16.0 % mac, Heavy weight(MLW) = 15500 lb	
Go – around @ Stick Shaker	δe = -30 ˚ , α_H = -3.2˚. V = 1.07 V Stall = 63.5 KEAS δf = Landing flap deflection = 40 ˚ Forward CG = 16.0 % mac Heavy weight(MLW) = 15500 lb	291.5 Nm/203lb
Landing Approach	δe = -11 ˚ , αH = -5.6 ˚. V = 1.3 V Stall = 76.7 KEAS δf = Landing flap deflection = 40 ˚ Forward CG = 16.0 % mac Heavy weight(MLW) = 15500 lb	179 Nm/125lb
Maneuver at VA	δe = -3.2 ˚ , αH = -2.7˚., VA = 130 KEAS , δf = cruise flap deflection = 0 ˚, critical weight (1.25 OEW) = 11811 lb	152 Nm/106lb

a. Elevator servo tab of N219-B12 aircraft

Based on calculation of elevator hinge moment on section 3.2, it could be summarized that the largest hinge moment and maximum stick force were achieved when the flight condition was in maneuver diving speed (VD). This stick force value was beyond the limitation of available stick force of 75 lb as stated in CASR 23. In order to meet the requirement, the N219-B12 elevator configuration was equipped by servo tab which has span of 40% elevator span and 10% elevator chord.

The servo tab deflection was designed to have balance tab gearing ratio (GNE)**-0.32** of control surface deflection and it was geared to move in the opposite direction of control surface deflection. Table 3.2 showed the elevator hinge moment (HM) and stick force of N219-B12 with servo tab was considered in the calculation. It was shown that by using the servo tab, the largest stick force (at diving speed, VD) was reduced from **-292lb to -94 lb**. Note: minus sign here represented the direction.

Table 3-2 N219-B12 Hinge moment of elevator with balance tab calculation results

CASE	**Flight Condition and Configuration (for Maximun HM)**	**Hinge Moment (Nm)/ Stick Force (lb)**
Takeoff Rotation	δe = -20˚ , αH = -6.1˚ , V = VR = 77.4 KEAS , δf = takeoff flap deflection = 10˚, Forward CG = 16.0 % mac , Heavy weight = 15500 lb	129 Nm/90lb
Maneuver limit at VMO	NZ = 2.0 g, VMO = 190 KEAS, SL, δe = 5˚ , αH = -2.747 ˚.	-90 Nm/-62.6lb
Maneuver limit at Diving Speed (VD)	NZ = 2.5 g, VD = 265 KEAS, SL, a. δe = 5.16 ˚, αH = -6.837˚.	**-135 Nm/-94lb**
Go – around @ 1.3 Vs	δe = -18˚ , αH = -7.05˚., V = 1.3 V Stall = 76.8KEAS , δf = Landing flap deflection = 40 ˚, Forward CG = 16.0 % mac, Heavy weight(MLW) = 15500 lb	123.5 Nm/86lb
Go – around @ Stick Shaker	δe = -30 ˚ , α_H = -3.2˚. V = 1.07 V Stall = 63.5 KEAS δf = Landing flap deflection = 40 ˚ Forward CG = 16.0 % mac Heavy weight(MLW) = 15500 lb	106.5 Nm/74lb
Landing Approach	δe = -11 ˚ , αH = -5.6 ˚. V = 1.3 V Stall = 76.7 KEAS δf = Landing flap deflection = 40 ˚ Forward CG = 16.0 % mac Heavy weight(MLW) = 15500 lb	80 Nm/56lb

Maneuver at VA	δe = -3.2 ˚ , αH = -2.7˚., VA = 130 KEAS , δf = cruise flap deflection = 0 ˚, critical weight (1.25 OEW) = 11811 lb	70 Nm/49lb

According to the table 3-2 above, it was shown that there were several maneuver cases that have magnitude beyond the limitation stated in CASR 23 i.e. 75 lb. Therefore, the additional amount weight distributed around nose of control surface so called static unbalance could become one solution to be considered.
By adding the static unbalance, the stick force was found to be:

$$Fe = CHe \times GRe + FEw$$

Where, FEw was static unbalance in Newton.

The N219-B12 aircraft was added 98 N of static unbalance with balance tab gearing ratio (GNE) of **-0.32,** this value was resulted by iteration and proven that the gradient stick force/speed (dFE/dV) was negative for the entire speed regime for light weight-aft CG and heavy weight-forward CG. Moreover, the additional of this static unbalance of **98N** reduced the stick force described on table 3-2 by **22 lb**, therefore, all the maneuver were within the limitation stated in CASR 23.

b. Elevator trim tab of N219-B11 aircraft

The trim tab was used in steady state flights to reduce the hinge moment and therefore the control force, to zero. The trim tab must be designed, so that, when any connecting or transmitting element in the primary flight control system fails, adequate control for safe flight and landing (CASR 23.667). The elevator trim tab travel of N219-B12was designed based on the most critical condition from stability and control point of view i.e. takeoff rotation. Moreover, the trim tab should also be designed to take over the primary control when it was floating to safety landing.

As mention in section 3.3, the elevator stick force for takeoff rotation with static unbalance was found to be **68 lb** and the maneuver of go around @ stick shaker was **52 lb**, so that the elevator trim tab should be designed to reduce this stick force to zero. Figure 2-4 showed the elevator stick force reduction when the trim tab was deflected in takeoff rotation maneuver and go around @ stick shaker, respectively. It showed that by deflecting the trim tab **5** degrees, the stick force has reached zero and therefore the trim tab designed were sufficient to meet the requirement. In order to design the minimum travel of elevator trim tab, the aircraft maneuver at VMO was considered. The analysis resulted that by deflecting elevator trim tab by **-0.5** deg was sufficient enough to reduce the stick force to zero. Based on the calculation above and considering the safety factor of our design, therefore, it can be concluded that, the elevator trim tab travel of N219-B12 was designed to be **-2** deg to **10** degrees, respectively.

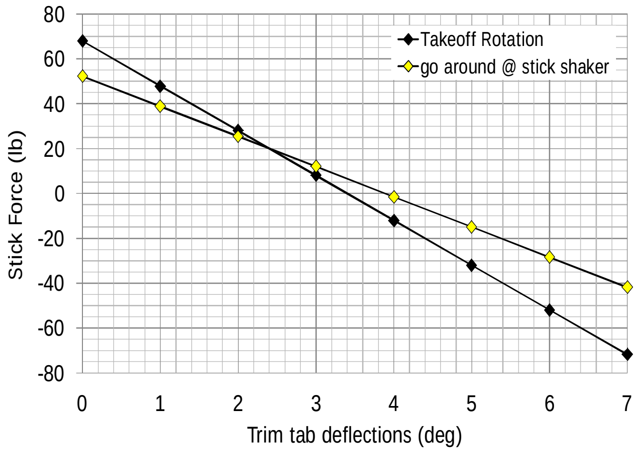

Figure 3-6 Effect of trim tab on stick force of N219-B11 aircraft

c. The elevator trim tab green band of N219-B12 aircraft

The elevator trim tab green band of N219-B11was designed to prevent the stick force felt by the pilot was too heavy when the maneuver takeoff rotation was conducted. Figure 3-5 displayed elevator stick force for heavy and light weight from forward to aft CG during takeoff rotation, respectively. The figure also exhibited the effect of static unbalance for this configuration. The figure showed that during the takeoff rotation maneuver the maximum stick force of N219-B12 with static unbalance was found to be **68 lb** for heavy weight and forward CG.

In regard to CASR 23, basically this value has already fulfilled the requirement; therefore, the green band designed here was intended for pilot comfortable when operated in takeoff rotation. The elevator trim tab green band of N219-B12was designed from **1° - 2.5°**. By these values, the maximum stick force was reduced from **68 lb to 48 lb** for 1° trim tab and **18 lb for 2.5°**, respectively.

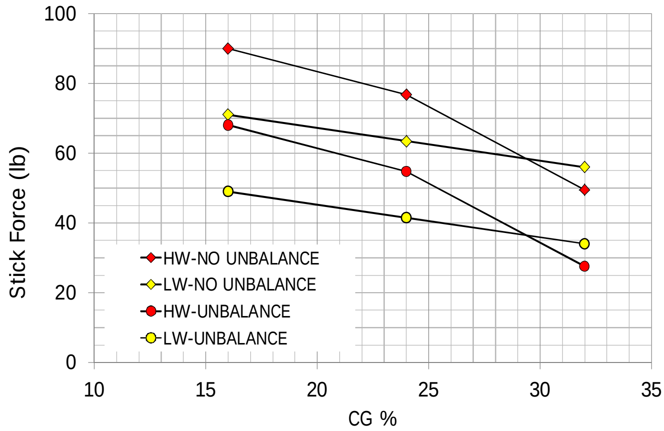

Figure 3-7 Effect of weight and CG on the stick force of N219-B12 aircraft during maneuver takeoff rotation

4. CONCLUSIONS

The elevator hinge moment of N219-B12 has been analyzed experimentally based on wind tunnel test which was conducted in LAPAN Low Speed Tunnel (LLST). The hinge moment was investigated considering the critical flight conditions from stability and control point of view. The analyses was done to verify that the configuration which was designed by theoretical perspective meet the requirements stated by the regulation of CASR 23(commuter category aircraft).

The results showed that the maximum elevator hinge moment was achieved when the flight condition was at diving speed (VD) i.e.-94 lb. However, this value was beyond the maximum of stick force stated on CASR 23, therefore, the additional of servo tab and or static unbalance was needed to fulfil the requirements. By implementing the servo tab in elevator trailing edge with **-0.32** balance tab gearing ratio (GNE)and static unbalance **by 98 N (22 lb)** around elevator nose were available to reduce the largest stick force in entire aircraft maneuvers to meet within the requirements stated by CASR 23, which has stick force maximum of 75 lb.

In case of trim tab design, the critical flight condition was chosen to be takeoff rotation and or go around @ stick shaker maneuver condition. In addition, the maneuver at VMO was also considered in this design perspective to see the elevator minimum travel of elevator trim tab and confirmed that the trim tab deflection designed of **-2 to 10** was available to reduce the stick force to zero and comply the requirement.

In addition, the green-band of elevator trim tab was also designed. The designed was intended for pilot comfortable when the takeoff rotation maneuver was conducted. Here, the elevator trim tab green-band was designed from **1° - 2.5°**. By these values, the maximum stick force was reduced from **68 lb to 48 lb** for 1° trim tab and **18 lb for 2.5°**, respectively.

ACKNOWLEDGMENTS

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