Role of Winglets in Boeing-737 Aircraft

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Abstract— The winglets in an aircraft wing plays an important role in improving aircraft efficiency in terms of aerodynamic and fuel. With the help of winglets, the resulting drag of an aircraft can be reduced. This article describes whether the winglets is able to reduce drag or not - mathematically. Moreover, this article compares the situation of an aircraft with and without winglet. This article describes about the aspect ratio of an aircraft. Aspect Ratio may be defined as the ratio of the square of wing span by the wing area. Therefore, a long narrow wing will have high aspect ratio because the span length of the wing increases and the wing area decreases whereas a short wide wing has low aspect ratio because the wing span length effectively decreases and the wing area effectively increases. This article also focuses on the fact as the evolution of aircraft occurred the wing of the Boeing aircraft became long narrowor short wide.

Keywords: AIRCRAFT

I. Introduction

The performance of an aircraft highly depends on coefficient of lift and coefficient of drag. Because Lift of an airplane depends on the coefficient of lift and drag of an airplane depends on the coefficient of drag and both the parameters drag and lift are very important for an airplane to fly. Therefore, the relationship between the coefficient of drag and the coefficient of lift is known as Drag Polar. The drag of an airplane is the sum of the drags produced by the individual parts of an airplane. The individual parts include wing, fuselage, horizontal tail, vertical tail, nacelles, landing gear, external elements and interference drag. Therefore, the total drag of an airplane is the sum of the individual drags induced by the individual parts on the airplane. To overcome this, drag sufficient amount of thrust needs to be generated for the aircraft to fly in a particular direction. In the similar way the lift of the airplane is the sum of the lift induced due to wing-fuselage combination and the lift induced to horizontal tail. Also, the drag polar is inversely proportional to Aspect Ratio and Oswald Efficiency Factor. Aspect Ratio may be defined as the ratio of the square of wing span by the wing area. Clearly, the aspect ratio is inversely proportional to the wing area and directly proportional to the square of the wing span length. Therefore, a long narrow wing will have high aspect ratio because the span length of the wing increases and the wing area decreases whereas a short wide wing has low aspect ratio because the wing span length effectively decreases and the wing area effectively increases. Higher the aspect ratio more efficient the aircraft is in terms of fuel. With the help of aspect ratio, the aerodynamic efficiency of a wing of an aircraft can be determined because the lift-to drag ratio generally increases with aspect ratio which means that the amount of lift generated by the wing of the aircraft divided by the drag it induces while moving through air can be determined through aspect ratio. Lift-to-drag ratio is a very important parameter in an aircraft because the amount of lift to be generated in an aircraft depends on the weight of the aircraft and producing the required lift with lower amount of drag results in better fuel consumption. Thus,winglets play an important role in reduction of drag. In earlier aircrafts the absence of winglets resulted in large drag production due to which the required amount of thrust to be generated was greater and as a result fuel consumption was more. In order to save the fuel and make the aircraft efficient for flying the winglets was introduced. The winglets reduce the drag and increases the aspect ratio of the aircraft which results in good aerodynamic efficiency.

II. Data of Boeing – 737 Family

Type of airplane	C_{D0}	A	e	Typical polar
Low speed (M <0.3)	0.025 to 0.04	6 to 8	0.75 to 0.85	$0.025 + 0.06C_L^2$
Medium speed (M around 0.5)	0.02 to 0.024	10 to 12	0.75 to 0.85	$0.022 + 0.04C_L^2$
High subsonic (M around 0.8, Swept wing)	0.014 to 0.017	6 to 9	0.65 to 0.75	$0.016 + 0.045C_L^2$

Aircraft Family	737-100	737-200	737-300	737-400	737-500
Span (m)	28.35	28.35	28.88	28.88	28.88
Gross Area (m^2)	102.0	102.0	105.4	105.4	105.4
Aspect Ratio	8.83	8.83	9.16	9.16	9.16
Taper Ratio	0.266	0.266	0.240	0.240	0.240
Root Chord (m)	7.32	7.32	7.32	7.32	7.32
Tip Chord (m)	1.60	1.60	1.62	1.62	1.62
Aircraft Length	28.65	30.53	33.40	36.45	31.01
Fuselage Length (m)	27.66	29.54	32.30	35.23	29.80
Cabin Width (m)	3.53	3.53	3.53	3.53	3.53

III. Formulas

$C_d = C_{d0} + KC_L^2$
K = 1/3.14 * A.R * e
$b_e = b + C_t/2$
A.R = (Wing Span)^2/ Wing Area
where,
A.E = Aspect Ratio
KC_L^2 = Induced drag coefficient

IV. CALCULATION

For Boeing 737-100
Aspect Ratio of wing of Boeing 737-100 = (Wing Span)^2 / Wing Area
= $(28.35)^2$ / 91.04 = 803.7225 / 91.04 = 8.83
Now, K = 1 / 3.14 * A.R * e
= 1 / 3.14 * 8.83 * 0.65
= 1 / 18.02203
= 0.055
Therefore, $C_d = C_{d0} + KC_L^2$
= 0.014 + 0.055 * $(1.75)^2$
= 0.1824375
With winglets the wing span effectively increases to, $b_e = b + C_t/2$
b_e = 28.35 + 1.60 / 2
= 58.3 / 2 = 29.15
Therefore, the Aspect Ratio becomes, $A_e = (29.15)^2 / 91.04$
= 849.7225 / 91.04
= 9.33350725
Consequently, the drag polar approximately changes to: -
$C_{d0} + 1 / (\pi * A.R * e) * C_L^2$
= 0.014 + 1 / 3.14 * 9.33 * 0.65 * $(1.75)^2$
= 0.174824218
Reduction in drag coefficient = 0.1824375 – 0.174824218
= 0.007613282 = 0.76%
For Boeing 737-200
Aspect Ratio of Boeing 737-200 = (Wing Span)^2 / Wing Area
= $(28.35)^2$ / 91.04 = 803.7225 / 91.04 = 8.83

Now, K = 1 / 3.14 * A.R * e
K = 1 / 3.14 * 8.83 * 0.66
= 1 / 18.299292
= 0.054646923
Therefore, $C_d = C_{d0} + KC_L^2$
= 0.014 + 0.054646923 * $(2.07)^2$
= 0.2481566
With winglets the wing span effectively increases to, $b_e = b + C_t/2$
b_e = 28.35 + 1.60 / 2
= 58.3 / 2 = 29.15
Therefore, the Aspect Ratio becomes, $A_e = (29.15)^2 / 91.04$
= 849.7225 / 91.04
= 9.33350725
Consequently, the drag polar approximately changes to: -
$C_{d0} + 1 / (\pi * A.R * e) * C_L^2$
= 0.014 + 1 / 3.14 * 9.33350725 * 0.66 * $(2.07)^2$
= 0.235524742

Reduction in drag coefficient = 0.2481566 – 0.235524742
= 0.012631858 = 1.26%
For Boeing 737-300
Aspect Ratio of Boeing 737-200 = (Wing Span)^2 / Wing Area
= $(28.88)^2$ / 91.04 = 834.0544 / 91.04
= 9.16
Now, K = 1 / 3.14 * A.R * e
= 1 / 3.14 * 9.16 * 0.68
= 1 / 19.558432
= 0.051128843
Therefore, $C_d = C_{d0} + KC_L^2$
= 0.015 + 0.051128843 * $(2.16)^2$
= 0.25354673
With winglets the wing span effectively increases to, $b_e = b + C_t/2$
b_e = 28.88 + 1.62 / 2
= 29.69
Therefore, the Aspect Ratio becomes, $A_e = (29.69)^2 / 91.04$
= 881.4961 / 91.04
= 9.68251428
Consequently, the drag polar approximately changes to: -
$C_{d0} + 1 / (\pi * A.R * e) * C_L^2$
= 0.015 + 1 / 3.14 * 9.68251428 * 0.68 * $(2.16)^2$
= 0.24067362
Reduction in drag coefficient = 0.25354673 – 0.24067362
= 0.01287311 = 1.28%
For Boeing 737-400
Aspect Ratio of Boeing 737-200 = (Wing Span)^2 / Wing Area
= $(28.88)^2$ / 91.04 = 834.0544 / 91.04
= 9.16
Now, K = 1 / 3.14 * A.R * e
= 1 / 3.14 * 9.16 * 0.7
= 1 / 20.13368
= 0.049668019

Therefore, $C_d = C_{d0} + KC_L^2$
= 0.015 + 0.049668019 * $(2.02)^2$
= 0.015 + 0.202665385
= 0.217665385
With winglets the wing span effectively increases to, $b_e = b + C_t/2$
b_e =28.88 + 1.62 / 2
= 29.69

Therefore, the Aspect Ratio becomes, $A_e = (29.69)^2 / 91.04$
= 881.4961 / 91.04
= 9.68251428
Consequently, the drag polar approximately changes to: -
$C_{d0} + 1 /(\pi * A.R * e) * C_L^2$
= 0.015 + 1 / 3.14 * 9.68251428 * 0.7 * $(2.02)^2$
= 0.206728601
Reduction in drag coefficient = 0.217665385 – 0.206728601
= 0.010936784 = 1.09%
For Boeing 737-500
Aspect Ratio of Boeing 737-200 = (Wing Span)^2 / Wing Area
= $(28.88)^2$ / 91.04 = 834.0544 / 91.04
= 9.16

Now, K = 1 / 3.14 * A.R * e
= 1 / 3.14 * 9.16 * 0.72
= 1 / 20.708928
= 0.0482883518

Therefore, $C_d = C_{d0} + KC_L^2$
= 0.015 + 0.0482883518 * $(2.06)^2$
= 0.21991645

With winglets the wing span effectively increases to, $b_e = b + C_t/2$
b_e = 28.88 + 1.62 / 2
= 29.69
Therefore, the Aspect Ratio becomes, $A_e = (29.69)^2 / 91.04$
= 881.4961 / 91.04

= 9.68251428
Consequently, the drag polar approximately changes to: -
$C_{d0} + 1 / (\pi * A.R * e) * C_L^2$
$= 0.015 + 1 / 3.14 * 9.68251428 * 0.72 * (2.06)^2$
= 0.208858188
Reduction in drag coefficient = 0.21991645 – 0.208858188
= 0.011058262 = 1.1%

V. CONCLUSION

From the above calculation it has been observed that there is a difference between drag coefficient before the introduction of winglet and after the introduction of winglet in an aircraft. In each and every Aircraft Family (Boeing-737 in this case) there is a difference in drag coefficient and in each case with the introduction of with the introduction of winglet the coefficient of drag gets reduced. Now, as the drag coefficient gets reduced the drag also gets reduced because drag is directly proportional to drag coefficient. Therefore, at a given coefficient of lift the drag coefficient reduces to its minimum value making the aircraft aerodynamically efficient and also the fuel efficiency of the aircraft enhances. Also, from the above calculation it may be noted that the coefficient of drag is directly proportional to induced drag coefficient. Now, in case of Boeing 737-400 the reduction in coefficient of drag was 1.1% whereas in case of Boeing 737-300 the reduction in coefficient of drag was 1.28%. This is due to the induced drag coefficient parameter. Hence, the coefficient of drag also depends on the induced drag parameter. Therefore, winglet is an important part of an aircraft wing with which the drag of an aircraft can be reduced and the aircraft can be aerodynamically more efficient and also in terms of fuel. Also, as the evolution of Boeing 737 Aircraft family progressed the wing became long and narrow as the aspect ratio kept increasing and as aspect ratio increases the wing span length increases and the wing area decreases which makes the wing as a long narrow wing which resulted in increase in fuel efficiency of Boeing 737 Aircraft Family.

REFERENCES

[1] Debargha Saha, “Role of Winglets in Boeing – 737 Aircraft, Volume 1, February 2021.