# The Role of Laminar Separation Bubbles on the FX 63-137 Airfoil

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**Abstract** Low Reynolds number airfoils are prone to be adversely affected by the presence of laminar separation bubbles (LSB). But at relatively high Reynolds number (based on the chord of the airfoil) in the range of 100,000–200,000, suppression of LSB, by a boundary layer trip, caused the performance of the airfoil to deteriorate further. In this particular case boundary layer trip does not result in an overall drag reduction due to suppression of the laminar separation bubble, as conventional wisdom would have suggested. The trip causes the turbulent boundary layer to separate early, at relatively high angles of attack, and augmenting the form drag.

## 1 Introduction

Laminar separation bubbles (LSB) are almost always linked to the degradation of the performance of low Reynolds number airfoils. A steady laminar boundary layer on an airfoil is prone to flow separation as it encounters an adverse pressure gradient. The separated shear layer is inviscidly unstable because of the presence of a single or even multiple inflection points in the velocity profile. As a matter of fact, the velocity profile becomes inflectional even upstream of the separation point causing the Tollmien-Schlichting waves to amplify upstream of the laminar separation point as observed by Diwan and Ramesh [1]. The laminar shear layer quickly transitions into turbulent shear layer, and the ensuing turbulence transports momentum towards the wall to enable the flow to reattach itself back onto the airfoil surface, resulting in a recirculating flow within the separation and reattachment points.

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At very low Reynolds number, based on the chord, the flow does not seem to reattach back onto the surface after it has separated from a laminar state, thus preventing the formation of the LSB. For Reynolds number greater than 60,000, one can expect the formation of LSB and at these Reynolds numbers the length of the LSB could be about 30–50 % of the chord. LSB can be classified as long and short bubbles depending on how much the coefficient of pressure distribution along the surface of the airfoil deviates from the inviscid one. Long bubble has a global effect on the flow field and affecting the coefficient of pressure distribution for most of the chord, whereas short bubbles merely act as a trip which helps the flow to quickly break-down into turbulence.

FX 63-137 is a 13.7 % thick airfoil and it is considered to be relatively a thick airfoil at these Reynolds numbers. As expected, the stall characteristics of this airfoil is predominantly that of a typical trailing edge stall as described aptly by McCullough and Gault [2]. At stalling angles turbulent separation kicks in and it moves progressively upstream as the angle of attack (AoA) is increased. The trailing edge stall is characterised by a very rounded $C_L$ versus AoA curve and the loss of lift and increase of the drag is smooth, as described by McCullough and Gault. All the above characteristics were observed in the present experiment.

In the literature, for moderately high Reynolds numbers (in the range of 100,000–200,000), LSB had been reported as something undesirable and held responsible for the augmentation of drag in the system (for Reynolds number of 100,000 or more). Selig, Donovan and Fraser [3] reported that it is due to the presence of LSB that there is an increase in drag (referred to as bubble drag) contributed by the LSB. Their experiments were performed for Reynolds number of greater than 100,000 (primarily 300,000). They concluded that the drag due to LSB is considerable and deteriorates the performance of the airfoil, not only at these Reynolds numbers, but also at lower Reynolds numbers of around 50,000.

Very recent Particle Image Velocimetry (PIV) studies of McArthur [4] over airfoils indicated otherwise. McArthur found that the drag increase at moderate lift coefficients was due to simple laminar separation with no immediate transition to turbulence and no reattachment at a Reynolds number of 60,000. The subsequent drag decrease at higher angle of attack (AoA) is caused by the formation of an LSB which is supported by the PIV measurements. This fact is in distinction with the observation stated just above at Reynolds numbers of 100,000–200,000.

In the present work, the effect of laminar separation bubble on the drag coefficient $C_d$ and several other parameters have been studied. For Reynolds number range of 100,000–200,000 we have performed experiments whereas for the smaller Reynolds number range of 30,000–60,000 our conclusions are purely based on calculations made with the Xfoil code (and validated against the experiments of Mc Arthur at those Reynolds numbers).We find that LSB is actually not detrimental as far as the performance of the airfoil is concerned in the Reynolds number range of 100,000–200,000, for angles of attack ranging from 0 to 12° (stalling angle) . This observation is in contradistinction to the results of Selig et.al. On the other hand, in the Reynolds number range of 30,000– 60,000, the presence of LSB is found to reduce the drag (as compared to the tripped case when there is no LSB) for angles of attack larger than


**Fig. 1** FX 63-137

11° (i.e. in the post stall regime); for angles of attack less than 11° the tripped case results in a lower drag as compared to the untripped case. These trends are consistent with the experimental results of McArthur.

## 2 Experimental Details

The airfoil that is considered for the present study is FX 63-137 and is shown in Fig. 1.

In the present work, measurements for Reynolds number range of 100,000–200,000, were taken on clean (untripped) airfoils. The LSB was subsequently suppressed by placing a trip wire, of 400 microns lateral dimensions at the leading edge of the aerofoil.

All the experiments were carried out in a closed circuit wind tunnel with the test section cross-section of $1 \times 1$ m. The airfoil's chord lengths was 0.25 m with a span of 1 m. The Reynolds numbers based on the chord were 100,000 and 200,000. The measurements consisted of surface pressure distribution and wake traverse.

The pressure measurements were performed using a projection manometer with a least count of 0.1 mm of alcohol.

## 3 Results and Discussions

The coefficient of pressure, $C_p$ distribution curve for the clean airfoil (FX 63-137) for AoA = 0° is shown in Fig. 2, which is also being compared with the Xfoil results. The match of the $C_p$ curve is quite satisfactory. The difference of the reattachment point, predicted by Xfoil, from the experiments can be advocated to the fact that the transition model used by the viscous code might not be exactly simulating the conditions exactly in this case. The $e^N$ transition model is incorporated in Xfoil, where $N_{crit} = 9$. Drela [5] had assumed, as it is generally seen, the $N_{crit}$ for wind tunnels is about 9. The dead air region is accompanied by a pressure plateau in the $C_p$ versus x/c curve, which can be clearly observed from the $C_p$ curve shown in Fig. 2.

To check the relative importance of LSB, it is suppressed by a boundary layer trip placed near the leading edge of the airfoil. The $C_d$ values for the tripped airfoil is always higher than the untripped counterpart as shown in Fig. 3. Since the bubbles at these Reynolds numbers are weaker, the suppression of the LSB does not cause the pressure distribution to vary much from the distribution of pressure for the clean airfoil. Thereby, the coefficient of lift is fairly the same for both the cases (tripped

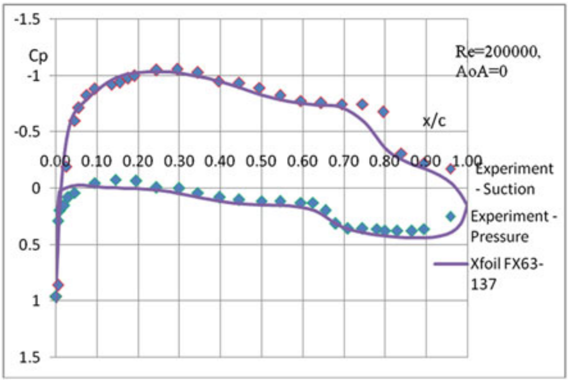


**Fig. 2** The pressure distribution at Re = 200, 000 and AoA = 0°

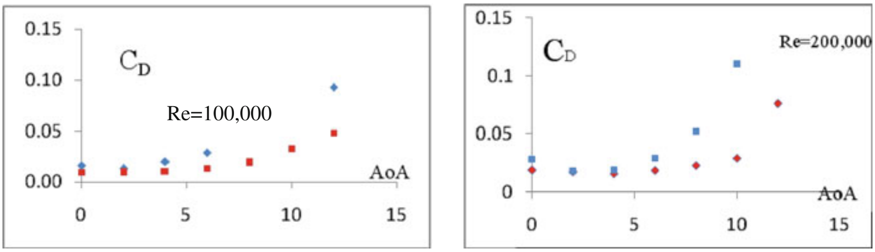


**Fig. 3** Drag coefficient variation with angle of attack at chord Re = 100,000 and 200,000 for clean and tripped FX 63-137

as well as clean airfoil) for moderate angles of attack (until turbulent separation sets in).

The fact that the LSB is suppressed for the tripped airfoil and the flow is turbulently attached for most of the airfoil surface for moderate angles of attack, indicates that the rise in the coefficient of drag is actually due the augmentation of the skin friction drag due to turbulent attached flow ( in the tripped case). Whereas, for the clean airfoil the LSB at these Reynolds numbers (where the LSB is relatively weak) just act as a placeholder and a switch for the flow to transition to turbulence late, reducing the wetted area of the turbulent attached flow thereby possibly explaining the increase of the coefficient of drag in the tripped airfoil case. Passive suppression of the LSB does not help improving the performance at $Re = 2 \times 10^5$ and $10^5$ and it seems that LSB formation is a favorable phenomena at these Reynolds number.

At higher angles of attack, the LSB is seen to shrink in size and minimally affect the coefficient of lift of the airfoil when compared to the inviscid $C_L$. At these angles of attack the LSB can justifiably be called as a short bubble. But when the bubble (at these angles of attack) is suppressed, it causes the drag to go up about two folds but, not affecting the lift much. If one sees broadly, a short LSB and the trip have got an operational similarity in the fact that both make the flow transition from a laminar

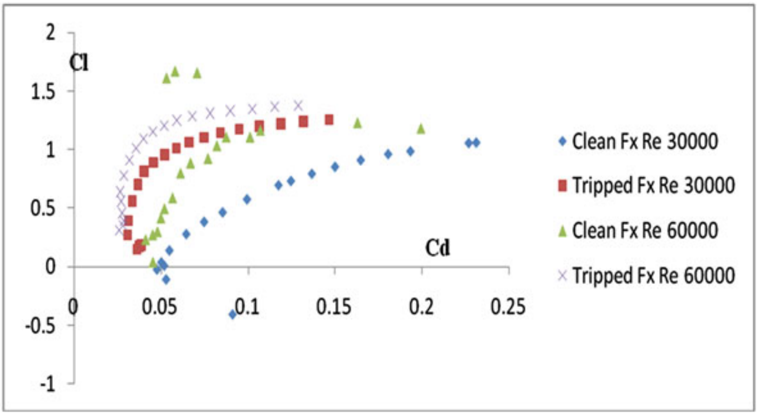


**Fig. 4** Computed using Xfoil [4]. Cd is considerably lower at Re = 60,000 when compared to Re = 30,000

state to a turbulent one. So, given this, one can infer that a small LSB is very efficient in making the flow go from a laminar state to a turbulent one than a passively placed boundary layer trip at the leading edge of the airfoil. A small LSB seems to be a very efficient switch for the oncoming attached laminar flow to transit to an attached turbulent flow.

Flows at low Reynolds numbers of about 30,000 and 60,000 seems to behave differently. Separation for most of the angles of attack considered is open. For Reynolds number of 60,000, the laminar separation bubble forms at an angle of attack of 11°. And the formation of the LSB causes a sharp drop in the value of the coefficient of drag indicating LSB as something that is not unfavourable even at these Reynolds numbers. But, the fact is the flow finds it difficult to reattach itself once it has laminarly separated at these Reynolds numbers and moderate angles of attack. Suppression of LSB at these Reynolds numbers (around 30,000) causes something exactly opposite to the case of Re = 200,000 and 100,000. The performance of the airfoil improves by the fact that the drag decreases when LSB is suppressed. Figure 4 shows the drag polars at these Reynolds number.

Figure 5 shows the apportioned $C_D$ values and its variation with angle of attack at Reynolds number of 60,000. The dominant drag component being the pressure drag, the boundary layer trip seems to work for most of the angles of attack as it is successful in keeping the flow attached for a longer downstream extent consequently bringing down the pressure drag. The important thing to note here is what happens at AoA of 11°–13°. The $C_D$ for untripped airfoil is lower than the tripped airfoil and it is at these AoAs that the formation of LSB is observed [4].

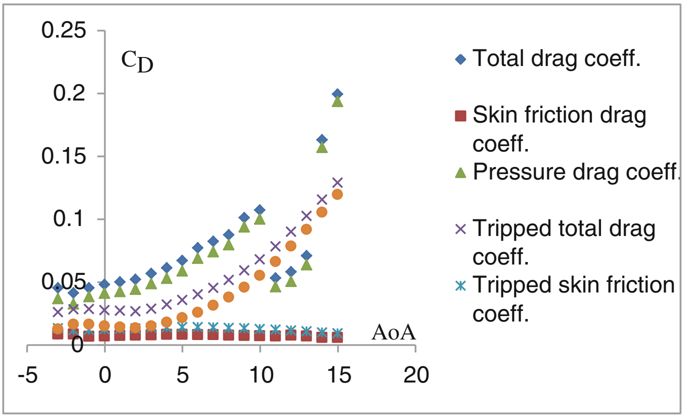


**Fig. 5** Computed using Xfoil [4]. $C_D$ versus AoA at Re = 60,000

## 4 Conclusion

The formation of LSB, at Reynolds numbers of about 50,000, improves the performance of the airfoil in comparison to fully separated flow, which is distinctly evident from the present calculations and also supported by McArthur's measurements. The trip improves the performance but, when the Re is increased (thus weakening the LSB), suppression of LSB with a trip wire placed near the leading edge of the airfoil does not seem to improve the performance, on the contrary the $C_D$ shoots up while the $C_L$ is not much affected. Formation of LSB might be a very efficient switch for the flow to become turbulent from a laminar state at moderately higher Reynolds numbers of 100,000–200,000, without affecting the performance of the airfoil a great deal.

Suppression of weak LSB causes deterioration of the aerodynamic performance of the airfoil. This is in contrast to the conventional wisdom according to which LSB is thought to be always detrimental from the perspective of aerodynamic efficiency. Here, on the contrary, it was found that suppression of the weak LSB at Re = 200,000, causes the $C_D$ to rise. At higher angles of attack, the form drag due to the turbulent separation might play an important role.

## References

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