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Aerodynamical Optimization of Adaptable Span Wing of Telescopic Spar and Foldable Wing Tip using Computational Fluid Dynamics

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Abstract— ***The project aims to analyze aerodynamic coefficients of adaptable span wing, which increases the lift of the aircraft at various flight conditions by increasing the span of the wing and also decreases its span to adapt Group V airport gate, which is restricted to a maximum 65 m wingspan of aircraft. Present days there is no adaptable wing that changes its shape or its span. All the commercial airplane wings are only fixed wings. To increase more lift at the time of takeoff or landing, the pilot has to stay with the ailerons and flaps. But at the time of the cruise, flaps give more induced drag. Adaptable span wing paves a way to have a lift at any time with less induced drag. Airports are 6 types based on the maximum span of their gates. To increase the lift, it is easy to increase the span of a wing and to keep it fixed, but if the span is more than 65 m, it falls under the category of Group VI airports. These Group VI airports are less available, and Group V airports are mostly available worldwide. This project aims to increase the span beyond 65 m and also to accommodate in Group V airports. Methods of Telescopic spar expansion and foldable wingtip are used. For this work Boeing 777-300 ER Wing with its airfoil is taken as a reference. One side of the wing is taken for analysis, and the models have made in CATIA V5 of various length from its original half span 29.3m to 34.3m by increasing one by one metre. Also, with foldable wingtip span is increased at its unfolded state with 2m. Each and every model is analyzed with a variable angle of attack, and lift curves were obtained. These curves help us to determine the optimized span of the adaptable wing.***

Keywords – Adaptable span, telescopic, aerodynamics, spar

I. INTRODUCTION

Adaptive wings that change its geometry makes the airplane to do more flight dynamics.

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Decreasing fuel utilization is the significant worries within the aeronautical enterprises[1]. There have been numerous models proposed to create the fuel-efficient airplane. Changing the lift to drag ratio is one of the methods to increase the lift. To make it happen, changing wing geometry has to be done.

Large span wing aircraft will have high aerodynamics performance, but poor maneuvrability whereas small span wing aircraft have excellent manoeuvrability but poor aerodynamic design.[4] Adaptive span wing will eliminate those limitations in long span and small span wings.

A variable aspect ratio wing will increase the lift and manoeuvrability of the aircraft during its flight missions.[2][11]

The aerodynamic properties of conventional aeroplane wings can be changed by using the flaps, slats and ailerons only in the exterior surface of the wing, and this will increase some drag and affects the fuel efficiency. The variable span wings will help for the flight to adapt different flight conditions and mission profiles.[5]

There are many lift generating techniques in fixed wings such as alternating camber wing flaps, differential twists, sweep angle, variable aspect ratio, control surface morphing, out of plane morphing and non – geometric morphings.[3][12] In this we are doing variable aspect ratio technique[6].

In this technique telescopic spar mechanisms[13] and foldable wing tip mechanisms helps to increase the span of the wing thus the area of the wing increased.[7] This paper is intended to show the increase in lift with those mechanisms.

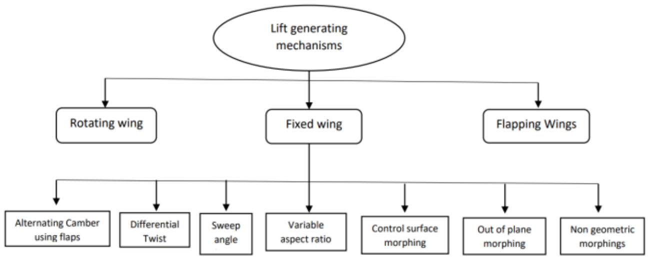

Fig.01. Lift gnenerating mechanisms[16]

Winglets are installed in aircraft in order to reduce the induce drag and tip vortex formed during flight. Fixed winglets can be eliminated by keeping wingtip to be foldable.[10]

Ailerons work can be reduced or eliminated by the use of asymmetrical span adaptive method. 36% of increase in semi-span increases the overall roll capability of the aircraft.[9] Span increasing models are usually made with telescopic mechanism where this concept is first introduced by Ivan Makhonine.[8] The concept have telescopic panels to move inside and outside. This will reduces the camberness and chord of the cross section.

Foldable wing tips were used to adapt our aircraft wing in the Airport gates. As per U.S Department of Transportation, Federal aviation administration Advisory circular Dated: 26/02/2014 – ACNO: 15/5300-13A, the airports have been categorized into

Group	Wingspan (m)
I	15
II	15-24
III	24-36
IV	36-52
V	52-65
VI	65-80

Table-I: FAA Airport Category[15]

Thus our airplane span will changes from 64.8 m to 74.8m due to span extension and unfolded wings and also changes its category of airport from Group V to Group VI. To adapt the same category of airport Group V, and also to increase the lift (reducing the spanwise lift distribution) telescopic spar and foldable wings are used.

II. PROBLEM DEFINITION

Models were taken for investigation with its folded and unfolded wingtips. As taking cruise Mach number 0.84, the flow is laminar as the Reynolds number (Re) is 773. Altitude taken as a reference is its cruise altitude 10668 m with pressure 22632.10 Pa, air density 0.36391 kg/m^3, and the temperature is 216.65 K. Angle of attack ranging from -4^0 to 20^0 were taken. As the extension is done inside the wing, it doesn't show any variation in the outer structure. Therefore plain extended models were made for ANSYS FLUENT analysis. Those models were done in CATIA V5 software. The model is made in the scale ratio of 1:200.

III. AIRFOIL SELECTION

The airfoil selected is b-737. It is unsymmetric airfoil.
There are totally four different types of airfoil with different camberness and thickness. They are b737a-il, b737b-il, b737c-il and b737d-il. These are airfoil for root, two midspan and outboard respectively.

- b737a-il airfoil have its maximum camber 0.2% of c at a distance 5%of c and also have a maximum thickness at 15.4% of c at a distance of 19.6% of c.
- b737b-il airfoil have its maximum camber 0.8% of c at a distance 10%of c and also have a maximum thickness at 12.5% of c at a distance of 29.7% of c.
- b737c-il airfoil have its maximum camber 1.5% of c at a distance 20.4%of c and also have a maximum thickness at 10% of c at a distance of 39.9% of c.
- b737d-il airfoil have its maximum camber 1.6% of c at a distance 20% of c and also have a maximum thickness at 10.8% of c at a distance of 40% of c.

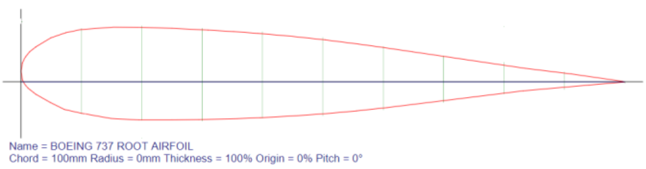

Fig. 02 . b737a-il

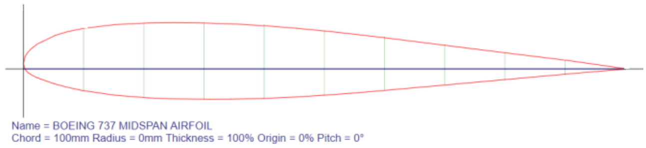

Fig. 03. b737b-il

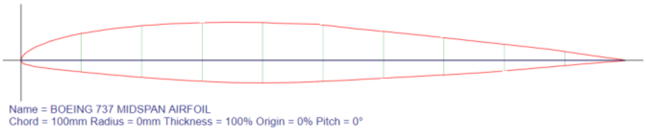

Fig. 04. b737c-il

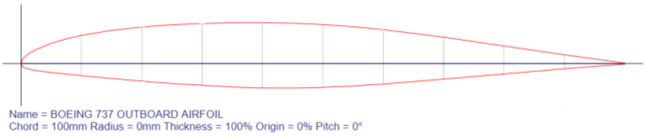

Fig. 05. b737d-il

IV. WING DESIGN

Wing model taken from Boeing 777-300ER. It has the maximum span of 64.8m. The half of the span excluding the fuselage is 29.29m. Half wing is taken for analysis with the airfoil b737 type.

Span (m)	64.8
Chord length (m)	14(Root) and 2(Tip)
Wing area (m^2)	484
Aspect Ratio	8.67
Taper ratio	0.1428
Twist angle (degree)	0
Sweep angle (degree)	31.64

Table- II: Conventional wing parameters

The wing is taken as 5 parts. They are Root, Mid span 01, Mid span 02, Tip 01 and Tip 02.

The extension of telescopic spar has been carried out in the various area also the foldable wing tips were provided at the Tip 02. Extension is provided with 5m half span of the wing, so totally thee whole span increases to 74.8m. Also at the unfolded state of foldable wing tip, the span further increases to 5 m, so total span is 79.8 m.

Span (m)	74.8
Chord length (m)	14(Root) and 2(Tip)
Wing area (m^2)	604
Aspect Ratio	9.25
Taper ratio	0.1428
Twist angle (degree)	0
Sweep angle (degree)	31.64

Table- III: Modified wing

parameters

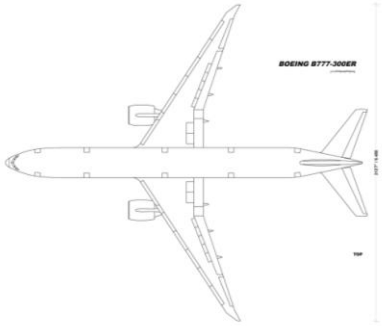

Fig. 06. Boeing 777-300ER plane design

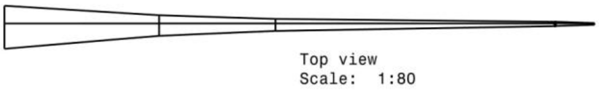

Fig. 07. Top view of wing

Fig. 08. Side view of wing

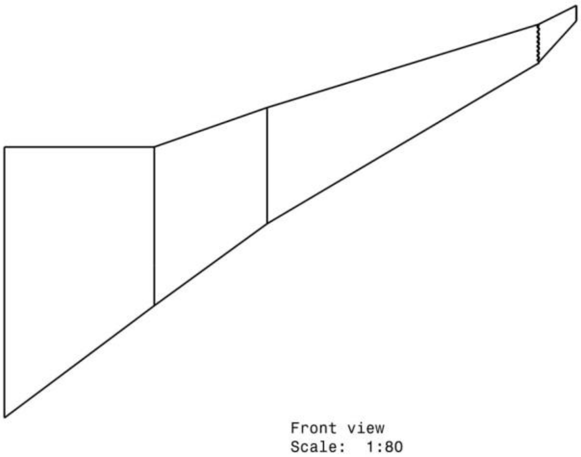

Fig. 09. Front view of wing

Fig 07, 08, 09 represents the new wing design with foldable wing tips, but the span extension is not made there.

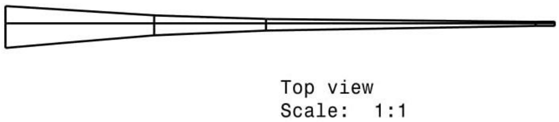

Fig. 10. Top view of Telescopic Increment wing

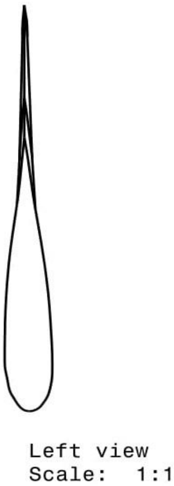

Fig.11. left view of Telescopic wing

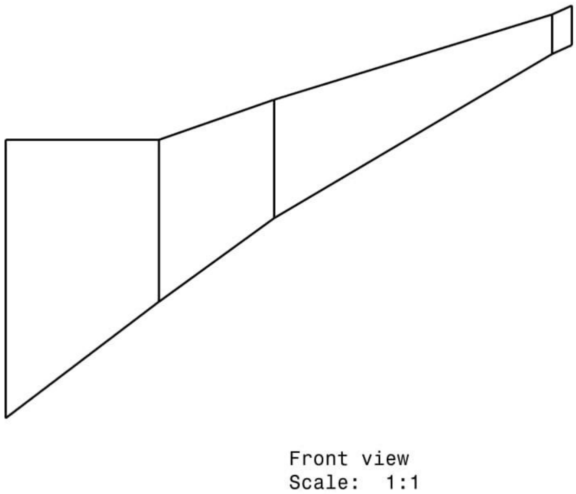

Fig. 12. Front view telescopic wing

Figures 10,11 and 12 are the modified wings with the extension of telescopic spar.

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V. SOFTWARE DEFINITION

Softwares used for this project are CATIA V5 R17 for modelling the wing and also ANSYS 19.1 Fluent for Computational fluid analysis.
Three types of models were made in Catia, one model will have the telescopic spar extension and other model will have the foldable wing tips, the last model will have both telescopic wing extension and the foldable wing tip.
First type of model is made with 15 variants, Tip span expansion of 5mm is increased in one model and next 10 mm is increased in other, so as to increase totally 25 mm. This will have 5 variant models
Mid span 02 is increased of 5 + 5 + 5 + 5 + 5 mm , totally 25 mm span increment is made. This have 5 variants
Mid span 01 is increased of 5 + 5 + 5 + 5 + 5 mm , totally 25 mm span increment is made. This have 5 variants
Each and every section have different chord length and camberness, so there is difference in increase in area.

VI. CALCULATIONS AND ANALYSIS

Conventional wing (b737 airfoil and Boeing 777-300ER wing dimensions)
The dimensions of the wing is taken for calculation is 1:200 ratio model
Half of the wing is taken for analysis. It helps the computer for fast analysis and calculation

Total wing span (mm)	324
Half span (mm)	146.45
Total span - fuselage span (mm)	293
Total surface area (mm^2)	0.0201568
Planform area (mm^2)	0.0100784
Aspect Ratio	8.518

Table- IV: Parameters for Analysis

VI. 1.1 TIP SPAN INCREMENT

The wing span is increased by 5 by 5 mm. The span of the wing and area is of follows.

Span (m)	Area (m^2)	Aspect Ratio
0.1515	0.00508988	9.018778439
0.1565	0.00514056	9.529020185
0.1615	0.00519124	10.04856258
0.1665	0.00524192	10.57713586
0.1715	0.0052926	11.1144806

Table- V: Aspect ratio of Tip span increment

From the analysis done is ansys it is to be found that the Lift is increased upto 5.02 % than the original.
The following graph shows the Lift curve Vs Angle of attack of both conventional and modified wing (tip extension)

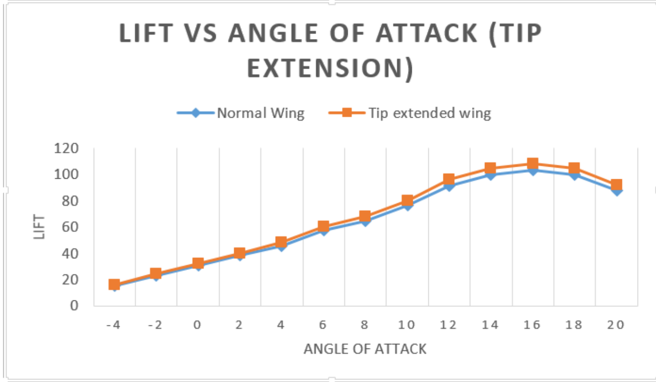

Fig. 13. Lift vs AoA (Tip Extension)

VI. 1.2 MID SPAN 02 INCREMENT

Keeping all other values constant , midspan 02 is increased 25 mm. The span, area and aspect ratio of new modified wing is as of follows

Span (m)	Area (m^2)	Aspect Ratio
0.1515	0.005191	8.842953276
0.1565	0.005343	9.168036848
0.1615	0.005495	9.493348087
0.1665	0.005647	9.81886862
0.1715	0.005799	10.144582

Ansys results shows that the lift is increased upto 15% than the original.
The following graph shows the Lift curve vs Angle of attack of both conventional and modified wing (Mid section 02 extension)

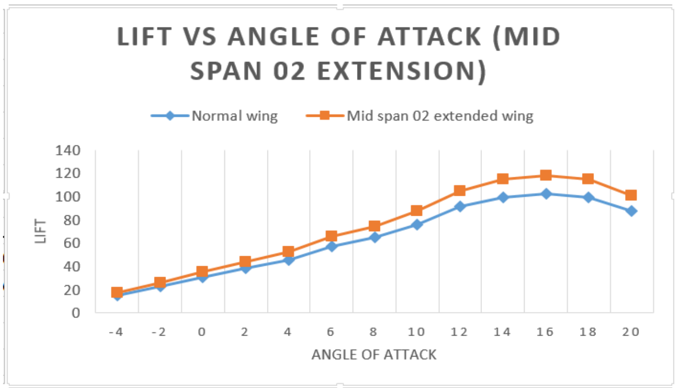

Fig. 14. Lift vs AoA (Mid span 02 Extension)

VI. 1.3 MID SPAN 01 INCREMENT

Keeping all other values constant , midspan 01 is increased 25 mm. The span, area and aspect ratio of new modified wing is as of follows

Span(m)	Area(m^2)	Aspect Ratio
0.1515	0.005248863	8.745609168
0.1565	0.005458525	8.973944426

0.1615	0.005668188	9.203030069
0.1665	0.00587785	9.432785798
0.1715	0.006087513	9.663142375

Table- VII: Aspect ratio of Mid span 01 Increment

Ansys results shows that there is an increment in lift upto 20.8% of original wing

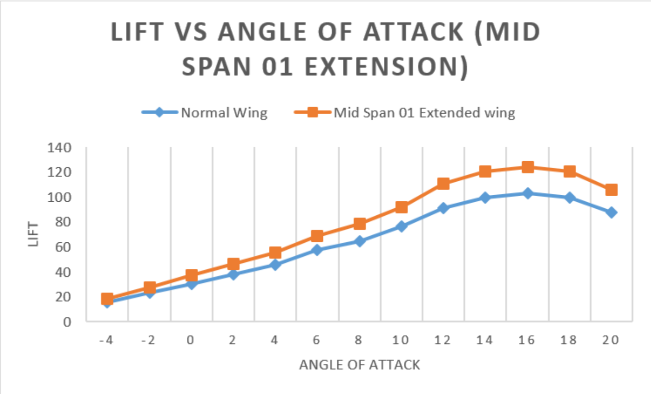

Fig.15. Lift vs AoA (Mid span 01 Extension)

VI. 1.4 EXTENSION WITH THE UNFOLDED STATE OF WING TIP

The wing tip having 1 m at each side thus the total span increases by 2 m which changes the total span of wing to 77 m. This increment further increases the lift of the wing.
While converting this to our 1:200 ratio, it increases 5 mm on each side of the wing. Thus with the telescopic extension and wing tip unfold the total span increases to 30 mm.

VI. 1.5 TIP SPAN + WING TIP UNFOLD

Aspect ratio = 10.66
Wing area = 0.005546
Span = 0.172
The ansys results shows that 10.05 % of the lift than the original wing. This is double of the lift when compared to only telescopic expansion. It shows that unfolded wing tips helps to increase the lift further The below graph shows the comparision of lift vs Angle of attack for both conventional and modified wing (tip extension + unfolded wing tip)

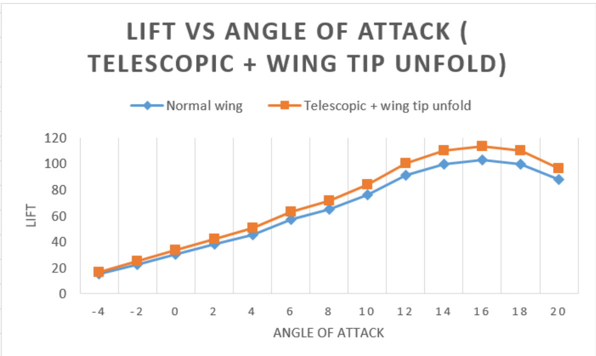

Fig.16. Lift vs AoA (Telescopic + Wing tip unfolded)

VII. CONCLUSION

The paper presented a new concept of blending telescopic spar and foldable wing ideas. The aerodynamical analysis shows that there is a significant increase in lift due to this extension (morphing) techniques. The span extension can be done for the lift increment whenever there is a need for an extra lift. The analysis in the span extension (only using telescopic spar) itself shows a dramatic increase in lift. The lift is increased by 5% than the original on the expansion of the wingtip area. Whereas the increment of lift is more while increasing the Midspan 02 and Midspan 01 section. This high increment in the lift is due to the high cross-sectional area. Those areas except the wing tip are essential for carrying fuel. For Unmanned aerial vehicles, the adaptable span techniques can be used in the mid-span 01 and 02 as there is no fuel space needed in the wing. But while considering to design a commercial aircraft, carrying fuel is to be considered so only tip span extension to be done. Unfolded wing tip with tip extension provides a 10.05% increase in lift, therefore making the wingtip to be folded and extendable doubles the lift. It is quite possible than the increasing span of other sections because the wingtip doesn't touch the fuel area of the wing. Without more modifications and also to have a high lift at various flight conditions, the adaptable span extension using telescopic spar and foldable wingtip can be used. Mechanisms of the hydraulic system can be used in commercial aircraft, and servo motors can be used in unmanned aerial vehicles.

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