Aerodynamic analysis and optimization of the futuristic Box-wing type Aircraft configuration

Shreya Giri[1], Suresh P[2], Vinutha G[3], Prathik S Jain[4]

[1,2,3,4] Department of Aeronautical Engineering, Dayananda Sagar College of Engineering, Kumaraswamy Layout, Bengaluru, Karnataka, India

Abstract: ***A conceptual design optimization was carried out for a long-range Box-wing aircraft. A baseline conventional cantilever wing aircraft was selected for the mission requirements as baseline box wing aircraft. Lift and drag coefficients for the fore and aft wings of the box wing aircraft was calculated and compared with the conventional cantilever wing aircraft. The results indicate that the box wing aircraft would generate less induced drag and greater lift than the conventional cantilever wing aircraft.***

Theoretical calculations were carried out to investigate the take-off and landing distance for box wing configuration and compared to that of conventional cantilever wing. Induced drag was calculated for box wing and cantilever wing by varying the geometric parameters like aspect ratio, span, surface area and sweep angle to achieve the best possible dimensions.

CFD studies were carried out to investigate the effect of stagger and gap and to optimize them. Numerical simulation was also carried out to study the static pressure and velocity distribution over the box wing.

Thus, it is observed that overall flight performance of the box wing seemed to be better than the conventional cantilever wing aircraft. Box wing type of futuristic aircraft configuration seemed to be fuel efficient as compared to the conventional cantilever wing type of aircraft configuration.

Keywords: design optimization, conventional cantilever wing aircraft, box wing configuration, fuel efficient.

1.1. INTRODUCTION

. It is found that the box wing design due to its superior aerodynamics characteristics compared to a conceptual aircraft, can help reduce the cost of a medium range aircraft. A systematic and general investigation about box wing aircraft including aerodynamics and performance characteristics has been performed. This design is efficient because of its high span efficiency, the box wing aircraft has a glide ratio of 20:4.

In order to reduce the over-increased fuel costs and CO_2 emission of transport airplane, the designers are reconsidering different unconventional configuration that were proposed and discarded many year ago. This effort is also being developed due to the fact that the conventional configuration is approaching its limits in productivity and capacity at a size around that of the airbus 380.

A number of configurations has been proposed in the past which can identified in terms of two variables, the number of positions of lifting surfaces and the solution selected for allocating the payload. By the combination of one of each variable, there is a different aircraft configuration maybe being the biplane the first configuration of all of them. Several studies were done and some progress was achieved, pointing out that aerodynamic performance could improve, overcoming that of the monoplane if the wings were placed properly. The most general wing configuration in this category is so called "BOX-WING". Aeronautical engineers are motivated to consider unconventional aircraft design concept in order to achieve a particular performance or operational improvement such as drag reduction, increased useful load, short airfield capability and/or combination thereof. External influences such as the fuel crisis of the early 1970's provided the impetus for a number of approaches toward the achievement of aircraft fuel efficiency including very large aircraft, LA air cargo concepts and variable and geometry design for normal 200 to 400 passenger- sized aircraft. The fuel crisis also provided the motivation for a concerted effort within NASA, the air force, and industrial on the application of advanced technology for the improvement in aircraft fuel efficiency. This effort includes the NASA aircraft energy efficiency.

The figure below box wing aircraft to give the clear difference between these two designs. Here it can be seen that box wing have extended horizontal tail which is joined to the main wing either a winglet thus giving it box shape. This project is going to show that box wing aircraft has the potential of being a viable replacement to the conventional cantilever aircraft**.**

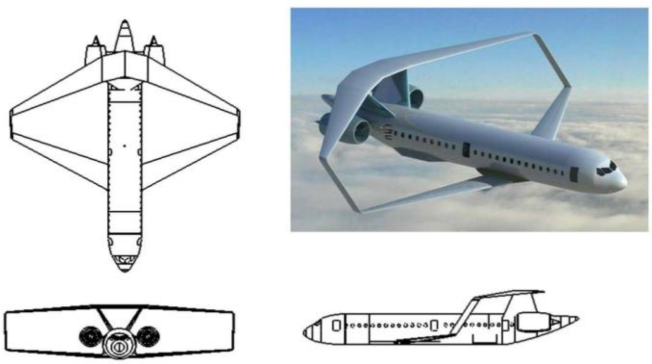


Fig. 1.1 Box wing aircraft

1.2 LITERATURE SURVEY

- Paul O Jemitola and John P fielding [1], investigated a conceptual design process for a medium range box wing aircraft is presented. The process begins with the initial estimates of component parameters followed by a constraint analysis to choose a design point structural consideration such as the appropriate wing mass estimation method for box wing, wing /tip fin joint fixities and tip fin inclination are then presented. Finally, a comparison is presented of how the box wing compares with a conventional cantilever wing aircraft designed for the same mission and payload.

- Stephan A. Andrews and Ruben E. Perez [2], carried out a study to achieve significant fuel saving for transport missions, unconventional design such as box wings are being considered for the next generation of civil transport aircraft. Previous studies have shown that non planar wings such as box wings can achieve superior aerodynamic performance relative to unconventional designs.

- Hugo Gaguon and David W. Zingg [3], investigated the aerodynamic trade off a Box wing aircraft configuration using high fidelity aerodynamic optimization. A total of five optimization studies are conducted where each study extends the previous one by progressively by adding a combination of design variables and constraints.

1.3. OBJECTIVE

In this present project work, an attempt has been made to study the aerodynamic characteristics of the futuristic Box wing type Aircraft configuration.

The main objectives of the project are as follow:

I To design and test an unconventional aircraft model i.e. Box wing model using software.

II To design a Box wing structure to bout up a desired mission requirement by varying its sweep angle, gap, stagger, aspect ratio, span and area.

III To select an airfoil suitable for mission requirement on the basis of aerodynamic coefficient, camber, stall angle at different Reynolds's number and then testing the selected airfoil at different angle of attacks in ANSYS FLUENT and CFX.

IV To perform numerical simulation (CFD) of Box-wing configuration in ANSYS FLUENT.

V To compare the results and data obtained.

2.1. THEORETICAL STUDY

Aerodynamic drag can be defined as the sum of its parasitic, induced and compressibility components. Non-planar configurations, such as the box-wing, take advantage of those two approaches. They can afford the higher structural exigency derived from the aspect ratio increase by distributing this increment in more than one lifting surface. In addition to that, higher Oswald efficiencies than one can be reached by them. And the span efficiency, that is, the ratio between the induced drag of the monoplane and the induced drag of a non-planar system of the same span and lift, for several systems with the same height to span value. Thus, box-wing shape reaches the maximum possible reduction in induced drag by means of connecting the wing tips to the stabilizer tips through some vertical elements.

3. METHODOLOGY

Aspect Ratio (AR)	13.319
Span (b) (m)	50
Wing-Area (S) (m^2)	187.70
Swept Angle (ʌ) (degrees)	32°
Lift slope of wing (a_W) (deg^{-1})	3.6509 rad^{-1}/0.0637 deg^{-1}
Lift coefficient of wing (C_{Lw})	2.0540
Total Induced Drag coefficient	0.0691

I Selection of suitable airfoil: On the basis of mission requirement i.e. civil transport aircraft cruising at maximum speed of 0.9M. For this purpose, a high-speed subsonic airfoil is used which have less camber and moderate thickness. Thirteen different airfoils are chosen from open domain and from that four different airfoils suitable for our requirements are selected. All four airfoils are analyzed on the basis of lift coefficient, camber, stall velocity etc. From those four airfoils the most suited one for our purpose came out to be CLARK-Y. Finally, CFD test on ANSYS FLUENT was performed on selected air foil and aerodynamic properties were obtained.

II Selection of reference aircraft: On the basis of long-range requirement, seven in use conventional aircrafts were selected and endurance was calculated for all of them. From those high endurance aircrafts BOEING 787-8 was

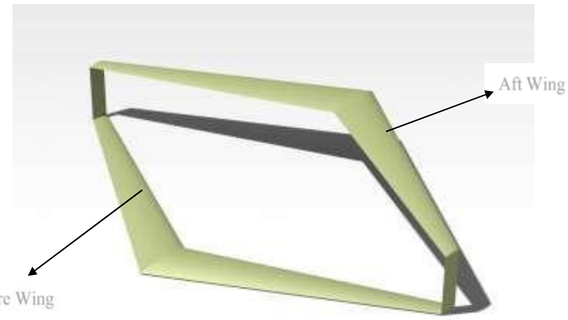
	BOX-WING	CANTILEVER WING	% Decrease
Take-Off(m)	1048.2	1338.92	27.72
Landing (m)	948.77	1047.08	10.36

selected.

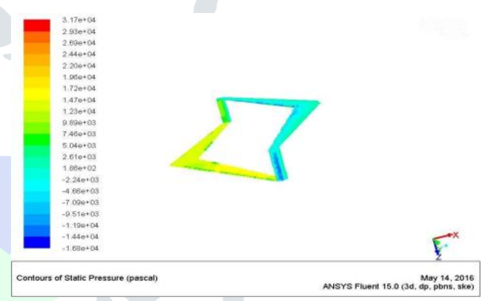
III. Design of box wing and reference wing configuration: For the purpose of comparison both wings i.e. box wing and reference wing were designed using CLARK-Y airfoil taking BOEING 787-8 configuration as reference.

IV. Calculation of Aerodynamic parameters: Using suitable formulae calculation of lift slope for airfoil and wing, lift coefficient and induced drag was done. Also, take-off and landing distance for both wing configurations were calculated for comparison.

V. CFD analysis: CFD analysis of box wing was performed to study the pressure and velocity distribution



over wing surface. vi. Comparison between conventional cantilever and box wing configuration: On the basis of above results obtained a comparison between box wing and cantilever wing was performed which can define that box wing provide better aerodynamic performance than



that of cantilever wing.

4.RESULTS AND DISCUSSIONS

Fig. 4.1 Isometric view of catia model

The following parameters for box wing configuration are selected:

Based on performance calculations, the following values are obtained.

So, from above values, it can be seen that take-off and landing distance for box wing is less from that of reference cantilever aircraft.

Various analysis was done, and contours were obtained as follows:

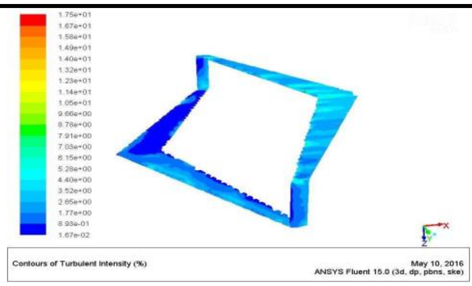


Fig. 4.2 Contours of Turbulent Intensity

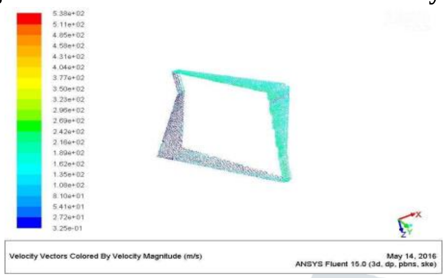


Fig. 4.3. Velocity vectors distribution

Fig. 4.4. Contours of static pressure (upper surfaces)

Fig. 4.5. Contours of static pressure (lower surfaces)

5. CONCLUSION

i. The objective set at the beginning of this report was to describe the box wing configuration, which is carried out with the variation in parameters like Aspect ratio, wingspan, Gap, stagger and sweep angle.

ii. With the help of software XFLR5 it is observed that for our objective requirement a gap of 0.7m and stagger of 0m i.e. straight winglet gives better result. As change of winglet does not have more influence on the final result.

iii. Suitable airfoil is selected for the mission requirement which is observed under ANSYS FLUENT & CFX and the results and graphs are plotted.

iv. The box wing is designed with the parameters shown below.

a) AR=13.3191

b) S=395.16m^2(Total) and (395.16/2) for one wing

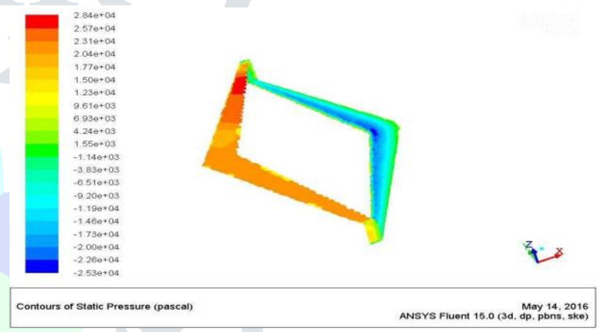
c) b=50m

v. With the design and using significant formula, it can be observed that the box wing has significant reduction in induced drag (C_{Di}). It has 27 % less induced drag (C_{Di}) than conventional cantilever wing of same parameters.

vi. The lift created by Box wing aircraft is also more because of the 'e' Oswald efficiency factor. The lift created by Box- wing is 3.65% more than Conventional cantilever wing aircraft

vii. The static pressure distance and velocity vectors are shown for Box-wing configuration which is shown at 200m/s. It is seen that the upper surface has less pressure and high velocity compared to the lower surface which result in generation of lift force.

viii. As we compared the performance parameters of Box-wing aircraft and conventional cantilever wing aircraft we



observed from the calculation that Box- wing has comparatively shorter Take- off and Landing distance. The takeoff distance for a cantilever wing.

Thus, from the results obtained we can finally say that the aerodynamic and performance parameters of Box- wing is better than the Conventional cantilever wing.

6. FUTURE SCOPE

There is a large amount of further research that can be done. With the field of non-planar aircraft lacking much study, there is room to possibly analyze different airfoils. In various other known planar design in addition, optimization of the airfoil can be conducted and a lower speed, more fuel-efficient commercial aircraft, or possibly a faster, supersonic transport. Lastly the various other parameters, such as tip joint vs. inboard joint, can be varied and optimized for the box wing aircraft, as this is simply a new field with much to study. The idea of having a disturbance model described by more than just (α, δ) could be further investigated both by mathematical trials and even through a remake of Olson's and Solberg's experiment. Copying the model biplane used, its configurations, test parameters needed, but varying the trials carried out, in order to properly investigate the downwash-Decalage correlation, and support any other development of the mathematical model, if needed.

Some of the future scope for Box Wing aircrafts can be listed as:

• The future of this type of aircraft is very promising in the field of civil as well as cargo-based aircraft.

• Mainly the passenger aircraft will be benefited the best by this configuration of aircraft because of massive reduction in the fuel which will lead to greater reduction in the price of the airlines.

• This configuration can also be implied by the military aircraft manufacturing industries.

• This design can also be used in Bomber military aircraft as it offers greater endurance and range.

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