External Tank- Drag Reduction Methods and Flow Analysis

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Abstract – This article presents a study of drag reduction methods for external tanks (fuel tanks) usually mounted on the tip of aircraft wing or beneath it. For light to medium range jet aircrafts and especially fighter aircrafts, the range can be increased by having external tanks which not only helps carry more fuel but can also be designed to be expendable.

Learjet 35A aircraft which has an external tank mounted on the wing tip is considered to perform calculations. This article intends to show that the use of fins on external tanks can considerably reduce the drag. Three CAD models are created ; Learjet 35A wing with a tip tank; tip tank with a trapezoidal fin; tip tank with delta fin. A comparative flow analysis is then carried out for these three scenarios and the difference in lift and drag coefficients are studied. All the models are created using Unigraphics(NX) CAD software and flow analysis was carried out using ANSYS Fluent software. It can be concluded from the analysis that the addition of fins to any external fuel tanks improved the performance and showed promising results and there is a room for further optimization in design, in-depth analysis and live testing.

Index Terms – Tip tank, tip vortices, coefficient of lift, coefficient of drag, trapezoidal fin, delta fin.

1. INTRODUCTION

Aerodynamic drag has always been an undesirable and unavoidable aspect of fluid flows and methods or ways to reduce this drag has called in for extensive research for decades together and even today the research continues to find best possible ways to minimize drag to the least possible extent. There had been extensive research done to reduce drag for wing since it's a major contributor to lift, but there has been considerably very less research done on methods to reduce drag for external fuel tanks.

In this article the flow over the three wing models designated as Model A, B, C is being analyzed using ANSYS 14.5 Fluent software and a comparative study is being done for the lift and drag forces.

Flow over the wing is considered as Ideal gas conditions, so as to apply pressure far field for the inlet and outlet. There is no wing twist, with all chords being in the same plane. Therefore, the angle of attack is simply the angle between the free stream and the chord line. There is no side-slip in the simulation. The flow conditions are similar for all the three wing models. The flow conditions are calculated at aircraft cruise speed at an altitude of 45000 ft. All units are specified in SI system.

- Wing Tip-Tank (Designated as "Model A")
- Wing Tip-Tank with Trapezoidal Fin (Designated as "Model B")
- Wing Tip-Tank with Delta Fin (Designated as "Model C")

2. RELATED WORK

The article cited in [1], describes the use of wingtip sails to reduce drag similar to the sails at the end of a bird's wing. The article broadly presents the results of flight experiments carried out to evaluate the effect of wing-tip sails on fuel consumption and handling characteristics.

Various methods of reducing skin friction drag [2], including suggestions for future studies [5] are presented in the cited articles that gives a overall view of possible ideas that can be further developed for desirable results.

The latest addition to the set of ideas on reducing skin friction drag is the use of riblets [3], and the use of thin films on the wind turbine blades [4].

The use of fins for external tanks [6] has been exploited further in this article by presenting 3D models and evaluating the flow field using virtual models to calculate lift and drag for various fin configurations.

3. PORPOSED MODELLING

The Learjet 35A aircraft wings use a NACA 6A series airfoil for both the wing root and wing tip. The NACA 6-series airfoil sections were developed in the early 1940's. The NACA 6A-series airfoil sections were designed to eliminate the trailing-edge cusp which is characteristic of the NACA 6-series sections. The 6A-series cambered airfoils are derived by using a special form of the 6-series camber-line equation. This special form is designated as "the A = 0.8 modified mean line."

All the CAD models were generated from a Learjet 35A aircraft parasolid geometry. The models were edited and drawing created using Unigraphics (NX 9.0) CAD software. Figure 1 gives a overall picture of the tank dimensions along with the trapezoidal, delta fin and wing dimensions. The wing geometry remains the same in all the case studies except that a trapezoidal or delta fin is used additionally.

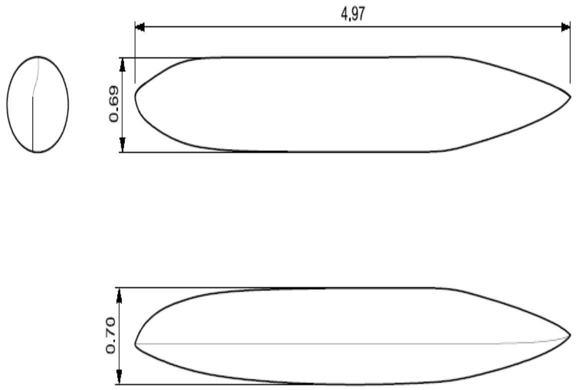

Figure 1 External Tank Drawing (Dimensions in meters)

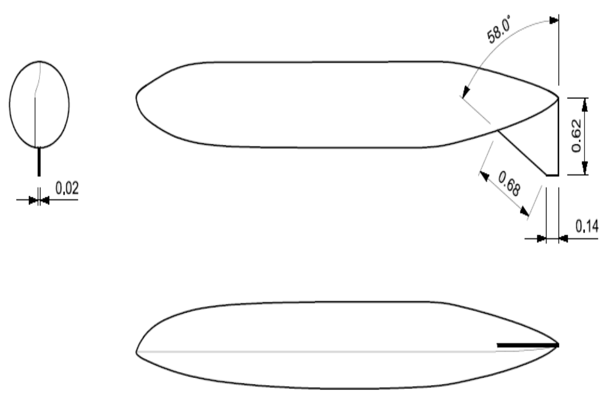

Figure 2 External Tank with Trapezoidal Fin Drawing (Dimensions in meters)

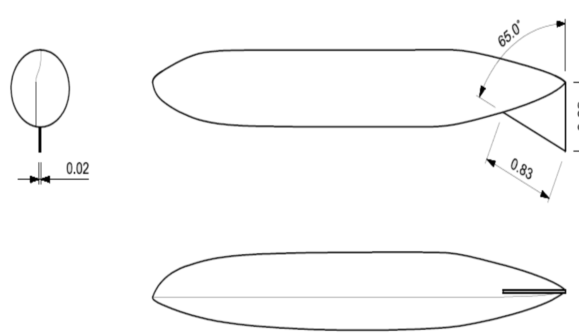

Figure 3 External Tank with Delta Fin Drawing (Dimensions in meters)

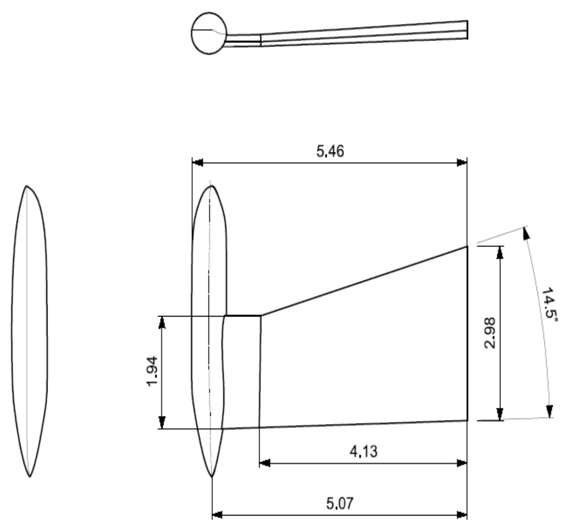

Figure 4 Wing Tip-Tank Drawing (Dimensions in meters)

The boundary conditions are considered at the cruise speed at an altitude of 45000 ft i.e. 13716 meters and the parameters are as specified below. All units are in SI system.

Parameters	**Values**
Flow velocity:	0.6318 M
Pressure:	14747.7 Pa
Temperature:	-56.5 degrees Celsius
Density of air:	Ideal Gas
Dynamic Viscosity:	1.43226e-5 N/m^2
Angle of attack:	3 degrees
X velocity vector:	0.9986
Y velocity vector:	0.0523

Table 1 Boundary Conditions

The enclosed body element size is 0.2 and the wing surface element size is 0.1, so we get finer results across the wing surface. The set up is chosen as double precision with parallel processing using a pressure based solver with the Energy Equation and the Spalart Allmaras Equation.

The inlet, outlet and surrounding enclosed surfaces are chosen as pressure far-fields, with flow along the +ve X direction, and the wing surface chosen as wall with zero pressure with number of iterations as 150.

The reference values given in Table 2 are used in flow analysis for the three models A, B, C.

Model Type	**Reference Area (m^2)**	**Reference Length(m)**
Model A	14.22	5.47
Model B	14.45	5.68
Model C	14.43	5.68

Table 2 Reference Areas and Lengths

4. RESULTS

The lift and drag curves are shown in the following figures for models A, B, C as obtained from the flow analysis. In all cases the drag decreases with the number of iterations and converges to a constant value and the lift increases with the number of iterations and converges to a constant value. The final values are shown in Table 3

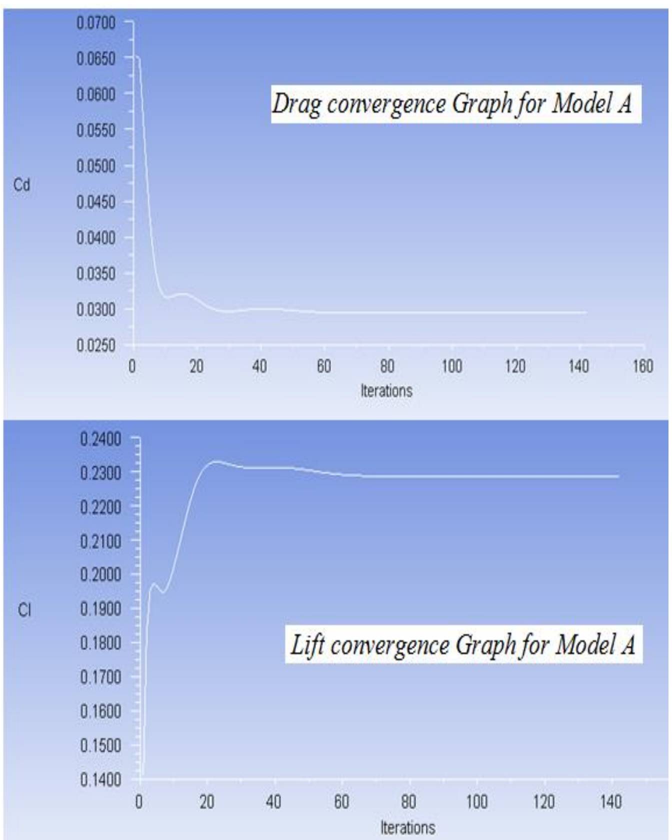

Figure 5 Drag and Lift convergence Graph for Model A

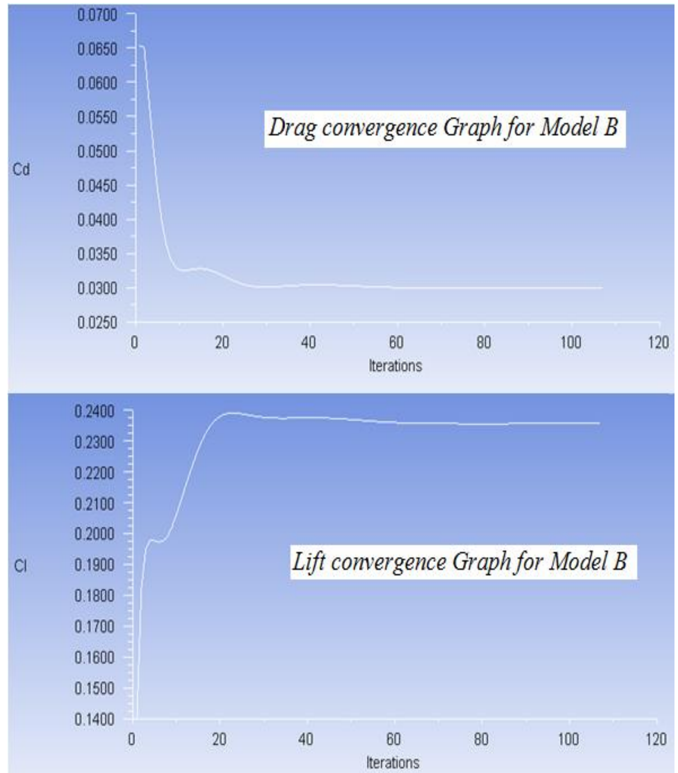

Figure 6 Drag and Lift convergence Graph for Model B

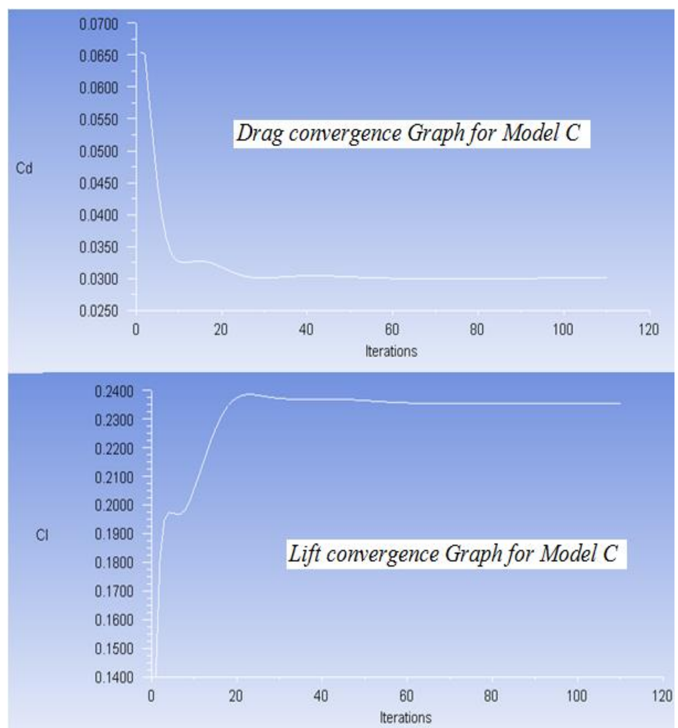

Figure 7 Drag and Lift convergence Graph for Model C

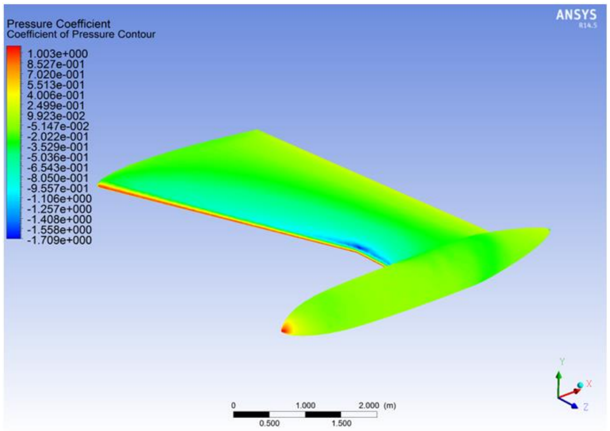

Figure 8 Pressure Coefficient Contour for Model A

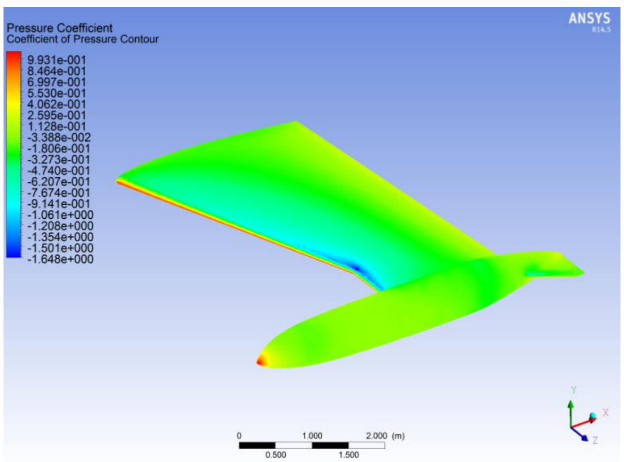

Figure 9 Pressure Coefficient Contour for Model B

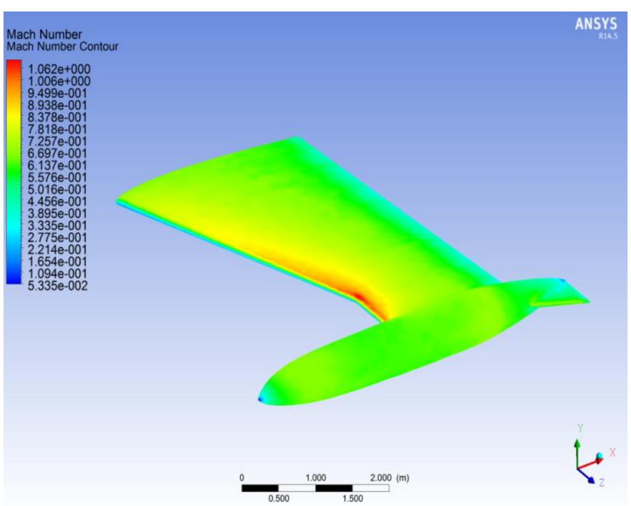

Figure 10 Pressure Coefficient Contour for Model B

Model Type	Lift Coefficient	Drag Coefficient
Model A	0.228	0.029
Model B	0.245	0.031
Model C	0.251	0.032

Table 3 Lift and Drag Coefficients

5. CONCLUSION

The lift and drag forces acting on a wing-tank configuration, with or without fins, have been measured for the boundary conditions given in Table 1. Comparisons with similar data obtained in a previous investigation as well cited in reference [6] with similar wing tank configuration indicate the following conclusions:

1. The total lifts and drag forces of the wing- tank with trapezoidal and delta fin combination were greater than those for the wing-tank alone.
2. The addition of a delta - or trapezoidal-shaped fin on the tip tank caused a increase in wet area, so there was a considerable increase in drag as well, along with the lift.
3. The tank lift increased with the addition of either fin.

Therefore it can be concluded from the lift and drag values in Table 3 that the addition of fins to any external fuel tanks improved the performance. Though the efficiency improvement is shown in the cruise conditions, consideration has to be given to many other aspects, such as non-cruise flight segments, stability and control, wing structure (including its weight and stiffness), etc.

There are also economic aspects associated with costs of production and maintenance that need to be taken into account. Retrofitting existing external tanks might be undertaken as well as the changes can be incorporated for future designs. In either situation addition of fins may be considered as possible features to include in the design process. These might serve the best purpose in case of expendable external fuel tanks. Finally it the choice of the particular configuration and the respective design trade-off for a particular aircraft has to be weighed before incorporating and bringing it into service.

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