Preliminary Analysis of Drag Reduction for The Boeing 747-400

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Potential for Airflow Separation That Can Be Reduced By Vortex Control Finlets™

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Summary

A preliminary technical analysis has been conducted to determine the potential for airflow separation from the aft fuselage of a Boeing 747-400. **Based on preliminary analysis, it is concluded that the B-747-400 is a very good candidate for drag reduction with the application of Vortex Control Finlets (VC Finlets).** To establish this conclusion an aerodynamic analysis using the CASSC software was conducted on the Boeing 747-400 aircraft for steady state flight conditions. A preliminary estimate of drag reduction is between 2% and 4% for cruise conditions. This is based on estimated area of flow separation and results from previous VC Finlet tests. To obtain these results significant geometric and aerodynamic factors have to be considered. Among these factors are:

- Shape of the fuselage cross sections
- Aerodynamic streamline angle or downwash approaching the separation location
- Upsweep angle of the after body
- Boundary layer thickness
- Area of flow separation relative to the wing area

Shape of Fuselage

The cross sectional shape is a very important factor for the creation of separated airflow on the fuselage after body. In reality most after body fuselage shapes are a combination of these three shapes; a vertical ellipse, a circle, and a horizontal ellipse. An example of the combination of the horizontal ellipse and a circle is the after body of the C-130. It begins with a circular shape at the trailing edge of the wing root and rapidly transitions to a horizontal ellipse. The Boeing 747 cross sections also begin as a circular shape, but it flattens out on the bottom progressively towards the end of the fuselage. The flattening becomes oval in the area under the horizontal tail. A side view of the 747-400 after body is shown in Figure 1. Figure 2 illustrates the area of the aft fuselage that has a flatter cross-section under the bottom of the aircraft. Figures 3 and 4 show just how flat the surface becomes aft of the landing gear pod to the horizontal stabilizer.

The shapes of the cross sections of fuselage have a strong propensity to cause flow separation and vortex formation. They will definitely have flow separation if they are immersed in a flow from the wing and tail that create downwash; that is a vertical component of the velocity that flows from the top of the fuselage to the bottom.

Figure 1: 747-400 After Body Side View

Figure 2: 747-400 After Body Looking Forward

Figure 3: 747-400 Flat Section of After Body

Figure 4 747-400 After Body Around Cargo Door

Downwash

In order to determine the potential for downwash over the fuselage, CASSC software was employed on the 747-400 model. CASSC is proven and unique software that can predict the pre and post-stall aerodynamics of almost any type of airplane. One of its attributes is predicting the downwash at prescribed locations. To develop the input for CASSC a good three-view drawing is required along with, the airfoil shapes for the wing and tail surfaces and the wing twist. The three-view drawing of the 747-400 is shown in Figure 5. The results from CASSC show that significant downwash occurs over the aft fuselage.

Figure 6 illustrates the downwash angle along the length of the aft fuselage. As illustrated the downwash is highest near the wing, and it decreases as it approaches the end of the fuselage. This downwash over the aft fuselage is a strong indicator that there will be significant flow separation. The combination of the downwash and the fuselage cross sections, which are prone to flow separation, on the 747-400 provide the opportunity to reduce drag with the application of VC Finlets.

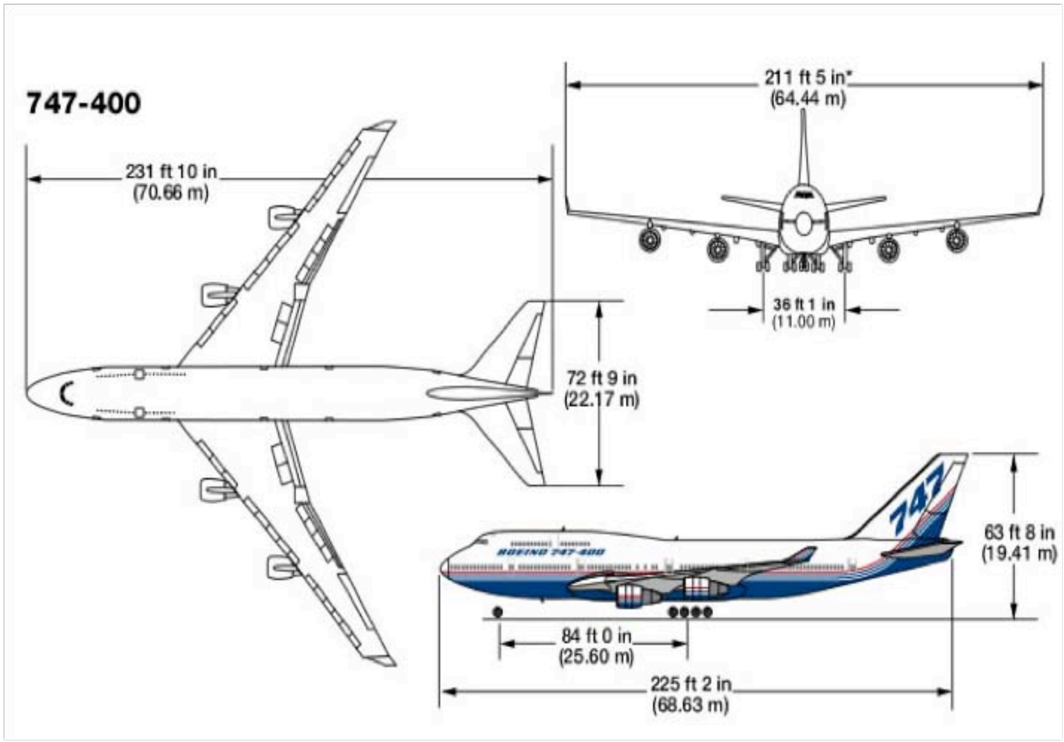

Figure 5: 747-400 Three-view

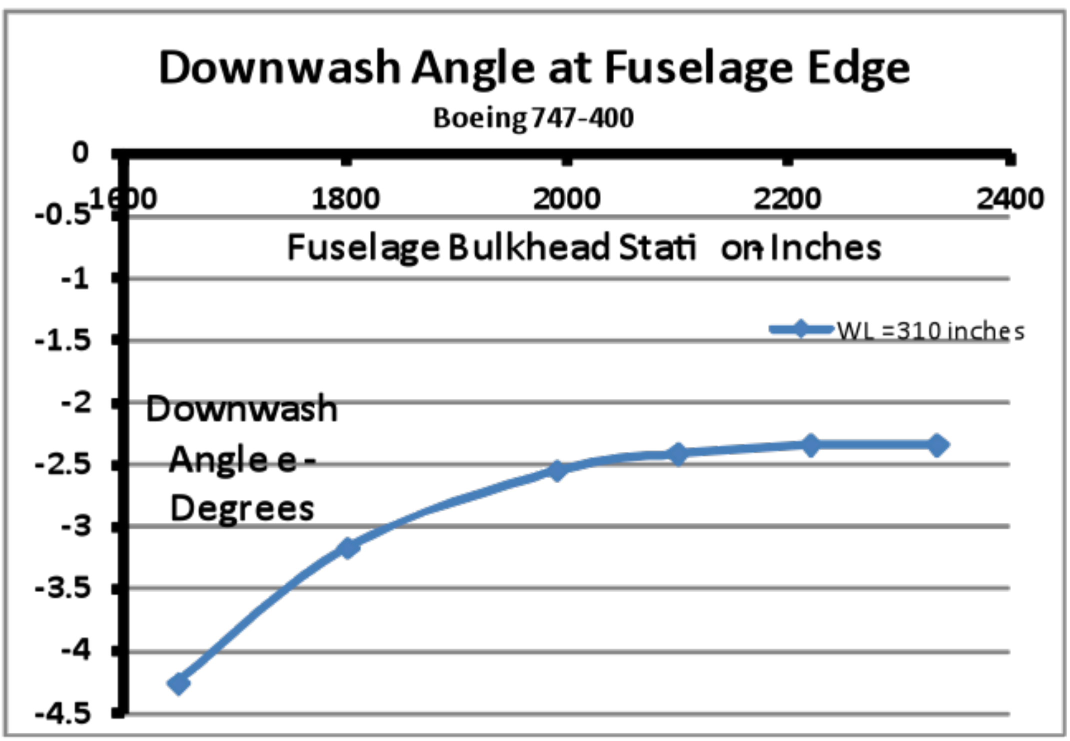

Figure 6: Downwash along Fuselage Edge

Computation of Drag Reduction

At this stage of the preliminary drag reduction analysis, past experience with both wind tunnel test and flight test data for the C-130 as well as Computational Fluid Dynamics (CFD) analysis of commercial aircraft were used in approximating the drag reduction for the 747 with VC Finlets.

Three important factors related to estimating the after body drags are:

- Upsweep angle of the after body
- Boundary layer thickness
- Area of flow separation relative to the wing area

Knowledge of these factors plus the downwash angle at the separation location is required to estimate the drag reduction. The first step is to obtain the strength of the vortex (circulation) that forms at the separation location. The normal force on the after body is a direct function of the product of the vortex strength of the vortex and the velocity normal to the vortex core. That velocity is obtained from the downwash angle at the separation. The average change in normal force due to VC Finlets is calculated for the 747-400. Preliminary estimates indicate that the ratio of flow separation area to wing area is about the same as that for the C-130.

The largest source of error at this time is the flow separation area. Using the currently estimated area, the drag reduction is 4%. Allowing for errors in the separated area and other factors should not reduce the drag reduction to less than 2%. The limit of 2% is based on the previous experience with the problem of flow separation on the after body of other military and commercial aircraft.

Conclusions

1. Preliminary analysis of the Boeing 747-400 aircraft indicates a high potential of flow separation from the aft fuselage that can be controlled with Vortex Control Finlets.
2. An estimate of 2% to 4% drag reduction with VC Finlets is highly probable.
3. The next steps to confirm the drag reduction estimates are to develop an accurate CAD model, perform CFD analysis, and design the VC Finlets for the 747-400.


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