Effect of Rounded Trailing Edge on Drag and Lift

Claes Johnson

March 16, 2012

Abstract

We study the effect of the radius of the trailing edge of a wing on lift and drag, as an aspect of a new theory of flight. We find based on mathematical analysis, computational solution of the Navier-Stokes equations and experimental observation, that lift and drag are essentially independent of the radius below a certain upper bound of about 1% of the chord length, with some increase of drag for 2%. We conclude that the new theory of flight comes together with construction practice in wing designs with trailing edge radius of about 1% of chord, without further need of sharpening neither in reality nor in computation.

1 Sharp or Rounded Trailing Edge

The New Theory of Flight presented in [1, 2] is based on an analysis of computational solutions of the Navier-Stokes equations with slip boundary condition, which shows that the rotational slip separation pattern at the trailing edge depicted in Fig. 1, has an important role for the generation of both lift and drag. To capture the crucial separation pattern it is necessary to resolve the flow at the trailing edge, which requires that the trailing edge is rounded with a certain positive radius.

On the other hand, the classical circulation theory of lift of Kutta-Zhukovsky requires the trailing edge to be sharp, and the practical necessity of constructing wings with somewhat rounded trailing edges is considered as an imperfection, which luckiliy in practice does not destroy the lift supposedy coming from the sharp edge.

Experiments were made early on to determine the dependence of lift and drag on the radius r of the trailing edge, with the principal finding [3, 4] that a rounded edge with $r \leq 1\%$ of the chord length showed essentially the same lift and drag as a maximally sharp edge, while a certain increase of drag was noted above 2%.

Does the New Theory predict anything concerning drag as the trailing edge radius is decreased starting with say 2% of chord length? Yes, it seems that the slip separation reduces a potential flow pressure singularity scaling with $\frac{1}{r}$ to a constant value in a zone of area scaling with r, resulting in a constant drag under decreasing radius.

It follows that even if the wing has a nearly sharp trailing edge, one may in computational simulations replace it with a rounded edge with $r \approx 1\%$ chord length allowing resolution of the crucial separation pattern without excessive number of finite elements.

There is neither any practical need to construct wings with very sharp trailing edges. In the New Theory thus practice with necessarily somewhat rounded trailing edges comes together with a theory also requiring rounded trailing edges.

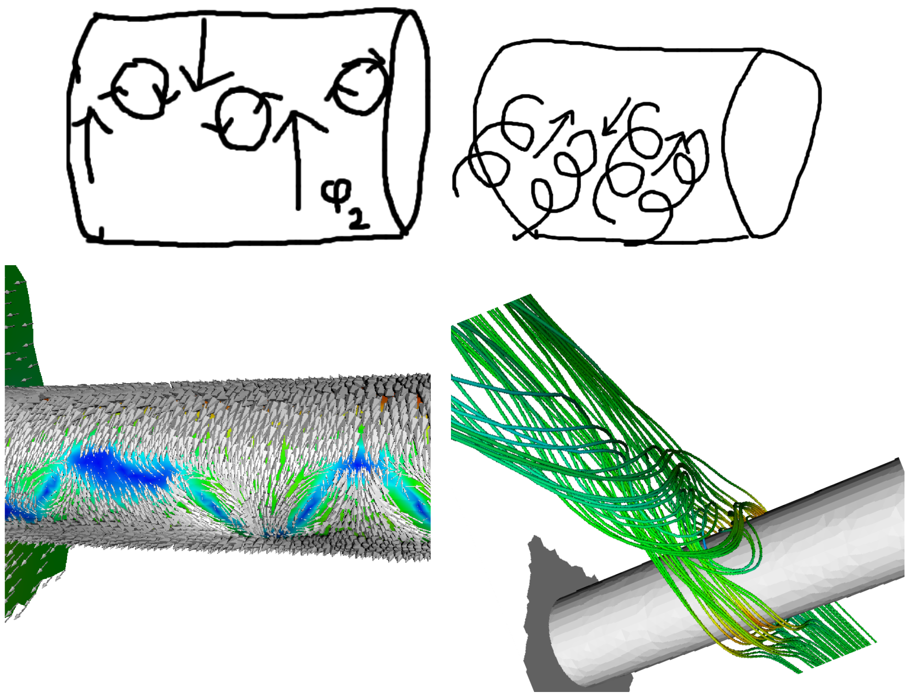

Figure 1: 3d separation in principle and computation

2 Mathematical Analysis

Potential flow has shows irrotational separation and zero drag with a velocity singularity at a rounded trailing edge of radius r of order $1/\sqrt{r}$. The corresponding pressure has a singularity of order $\frac{1}{r}$ by Bernoulli's principle.

On the other hand, rotational slip separation shows non-zero drag and by scale invariance from the slip boundary condition, has a pressure which is essentially independent of r.

It follows that the shift from potential flow separation with zero drag to rotational slip separation with non-zero drag, can be associated with an elimination of a pressure singularity of order $\frac{1}{r}$ in a zone of width r, resulting in a non-zero drag which is essentially independent of the radius of the trailing edge.

Lift is similarly generated by the elimination of the pressure singularity of potential flow through rotational slip separation.

3 Computation

4 Experimental Observation

The experimental observations reported in [3, 4] show that lift and drag are independent of the trailing edge radius below an upper limit of about 1% of the chord.

5 Conclusion

We conclude on the basis of mathematical analysis, computation and experimental observations that the radius of a trailing edge of a wing does not influence lift nor drag below an upper limit of about 1 of chord.

References

[1] New Theory of Flight, J. Hoffman, J. Jansson and C. Johnson, submitted to AIAA, March 8, 2012.

[2] Separation in Slightly Viscous Flow, J. Hoffman and C. Johnson, submitted to AIAA, March 8, 2012.

[3] NACA Report, 1938.

[4] NACA Memorandum, 1956.