Comparison of wind tunnel test results on the Eppler 387 airfoil with XFOIL Computations

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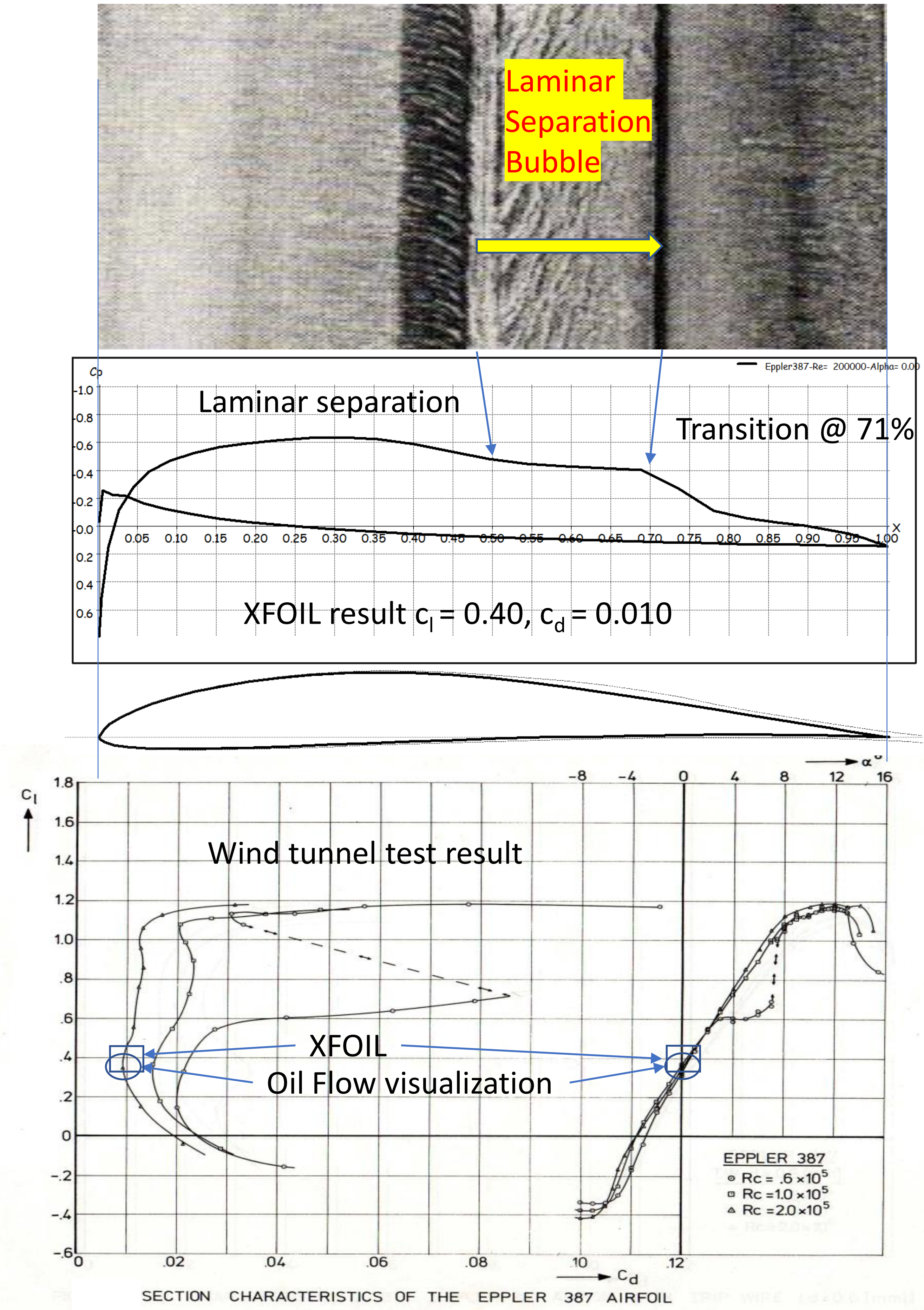
January 2021

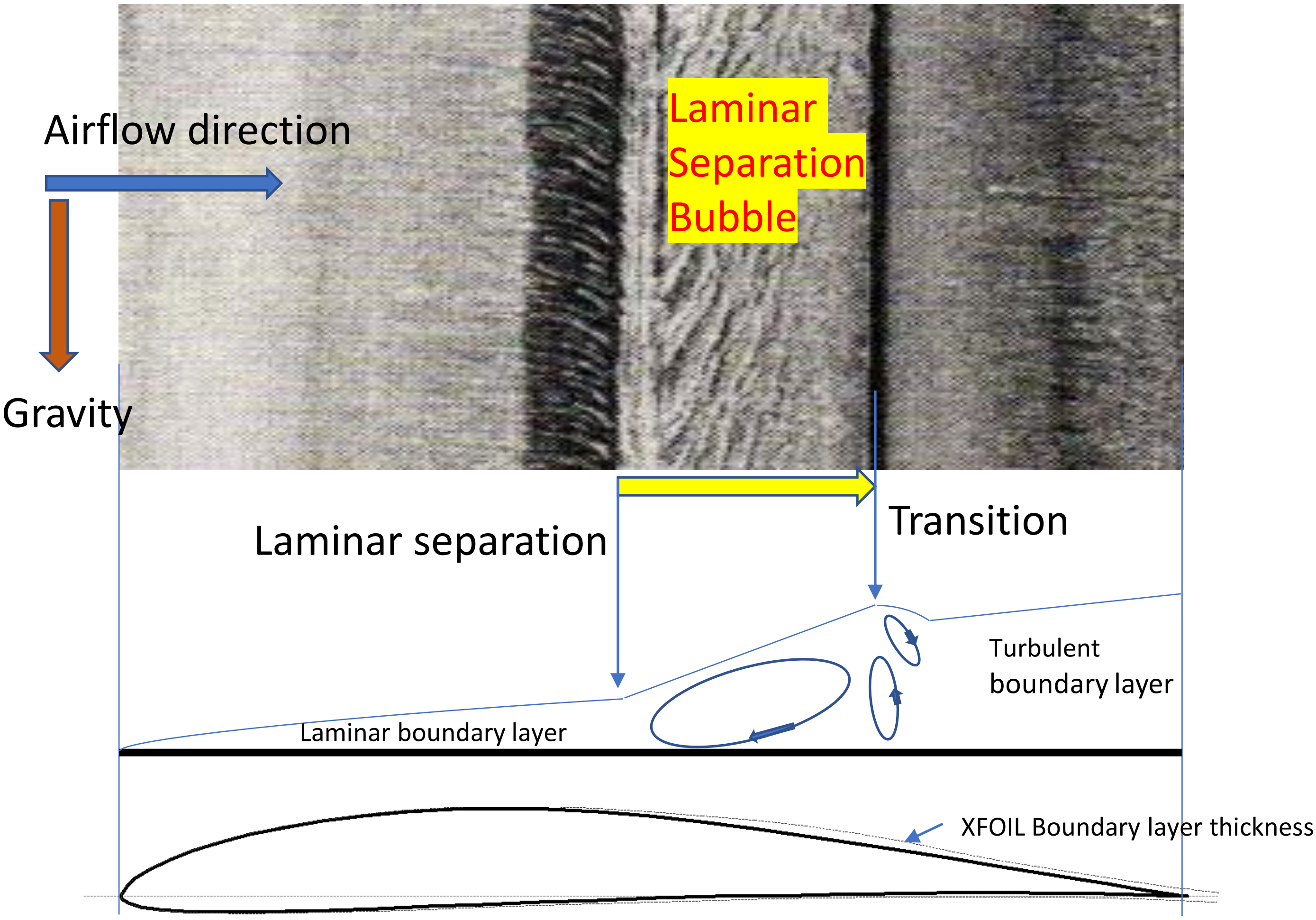
Based on a wind tunnel study done in the scope of my education as aeronautical engineer in 1977 and the nowadays available accurate computational tool XFOIL.

Oil Flow Visualization Eppler 387 upper surface

Alpha = 0 deg, $Re_C = 2.0 \times 10^5$



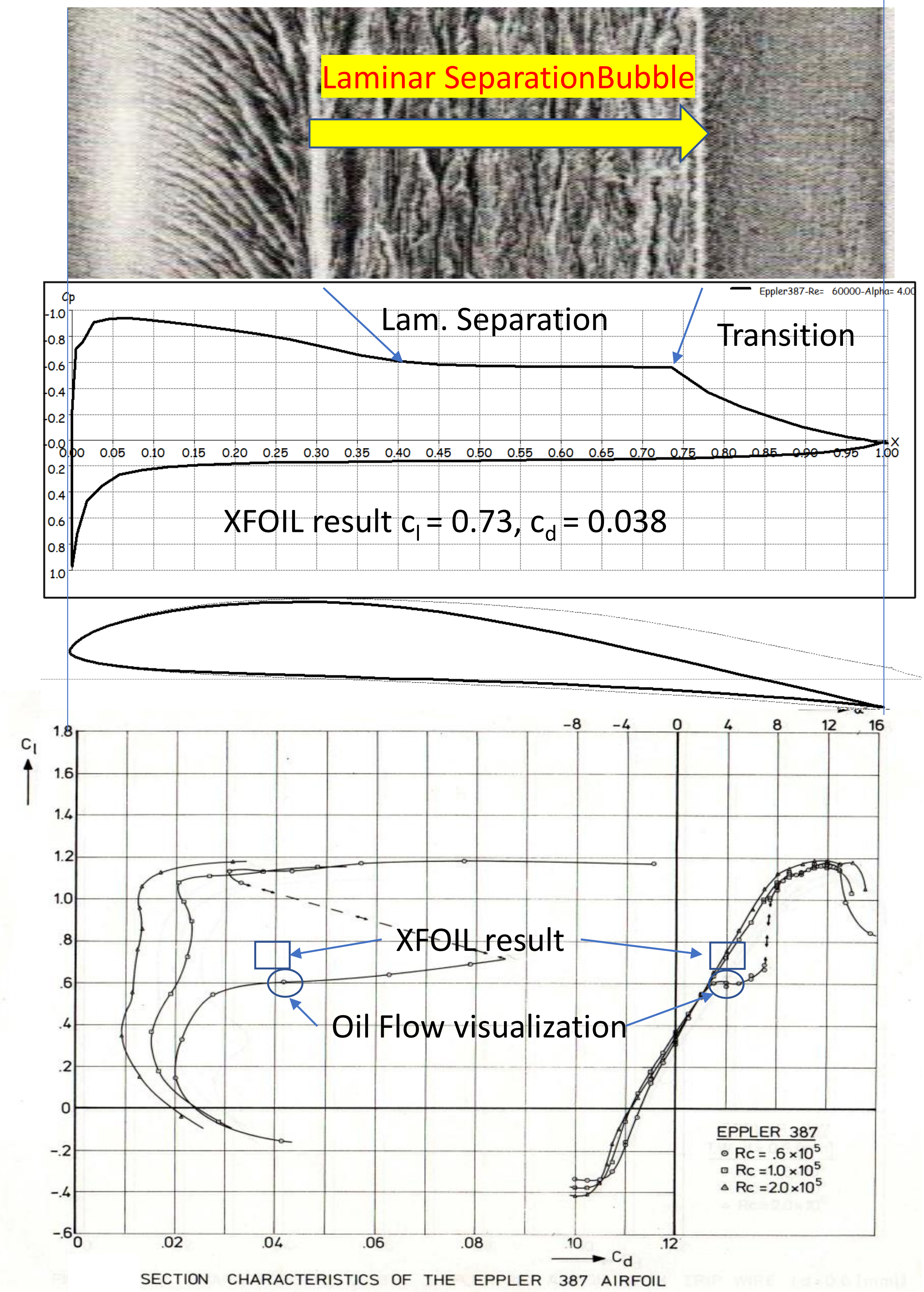
Oil Flow Visualization Eppler 387 upper surface Alpha = 0 deg, $Re_C = 2.0x10^5$



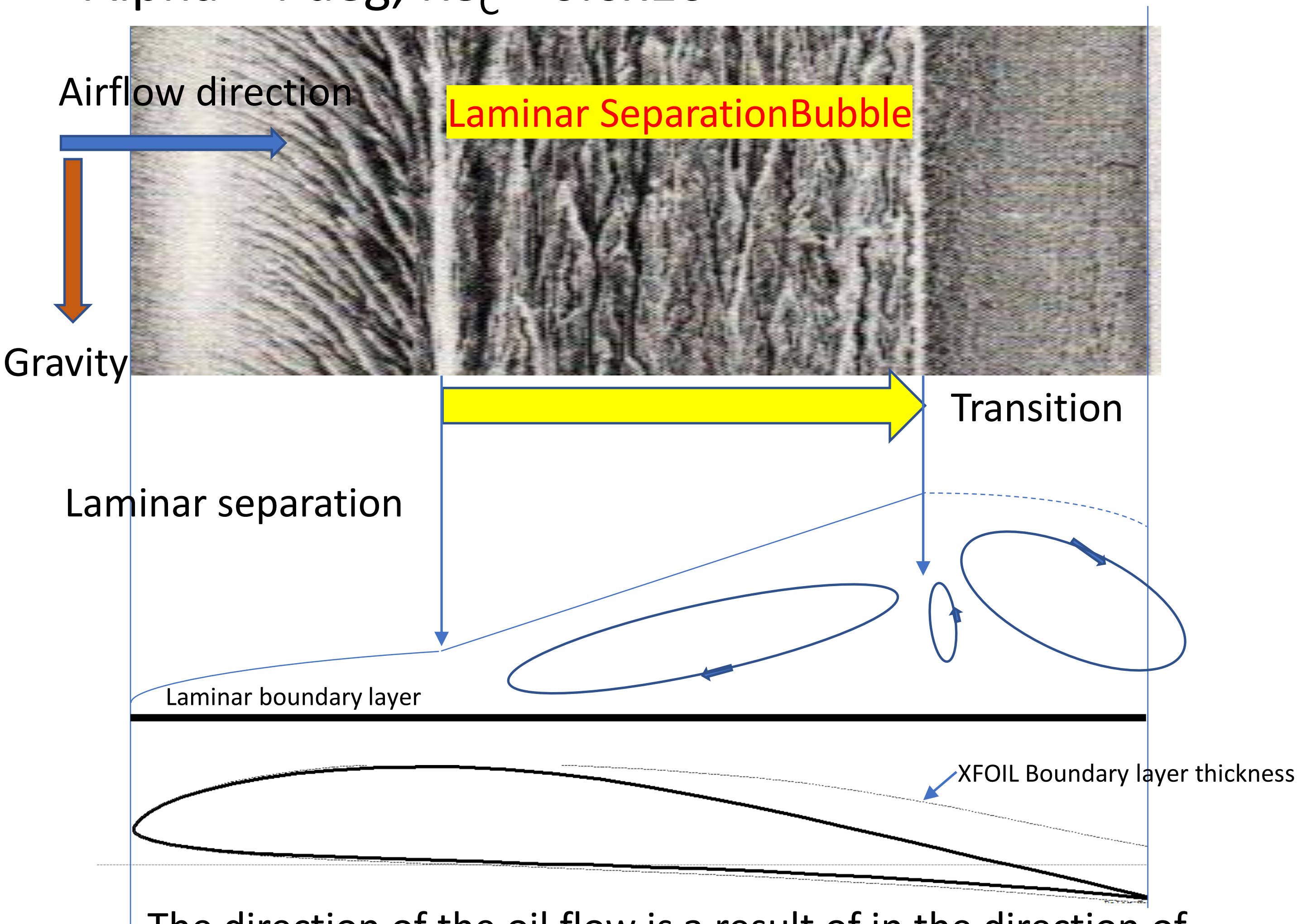
The direction of the oil flow is a result of in the direction of the friction of the air flow AND of the effect of gravity.

- At the laminar separation location, the friction of the airflow is zero. The oil flows vertical in the direction of the gravity.
- In the laminar separation bubble the first vortex yields a friction on the oil in direction against the flow direction.
- The combination of the first and second vortices clean the surface locally. This is the location of the transition of laminar into turbulent boundary layer according to the sound listening by a microphone probe.
- The reattachment of the flow is not clearly indicated. Therefor the total length of the bubble is not clear. It is expected to occur just downstream of the transition location.
- Note: In a number of articles only one vortex is shown in the bubble. With three vortices the oil flow pattern is easier to explain. With two vortices it is not possible to explain the reattachment.

Oil Flow Visualization Eppler 387 upper surface
Alpha= 4 deg, $Re_C = 0.6 \times 10^5$

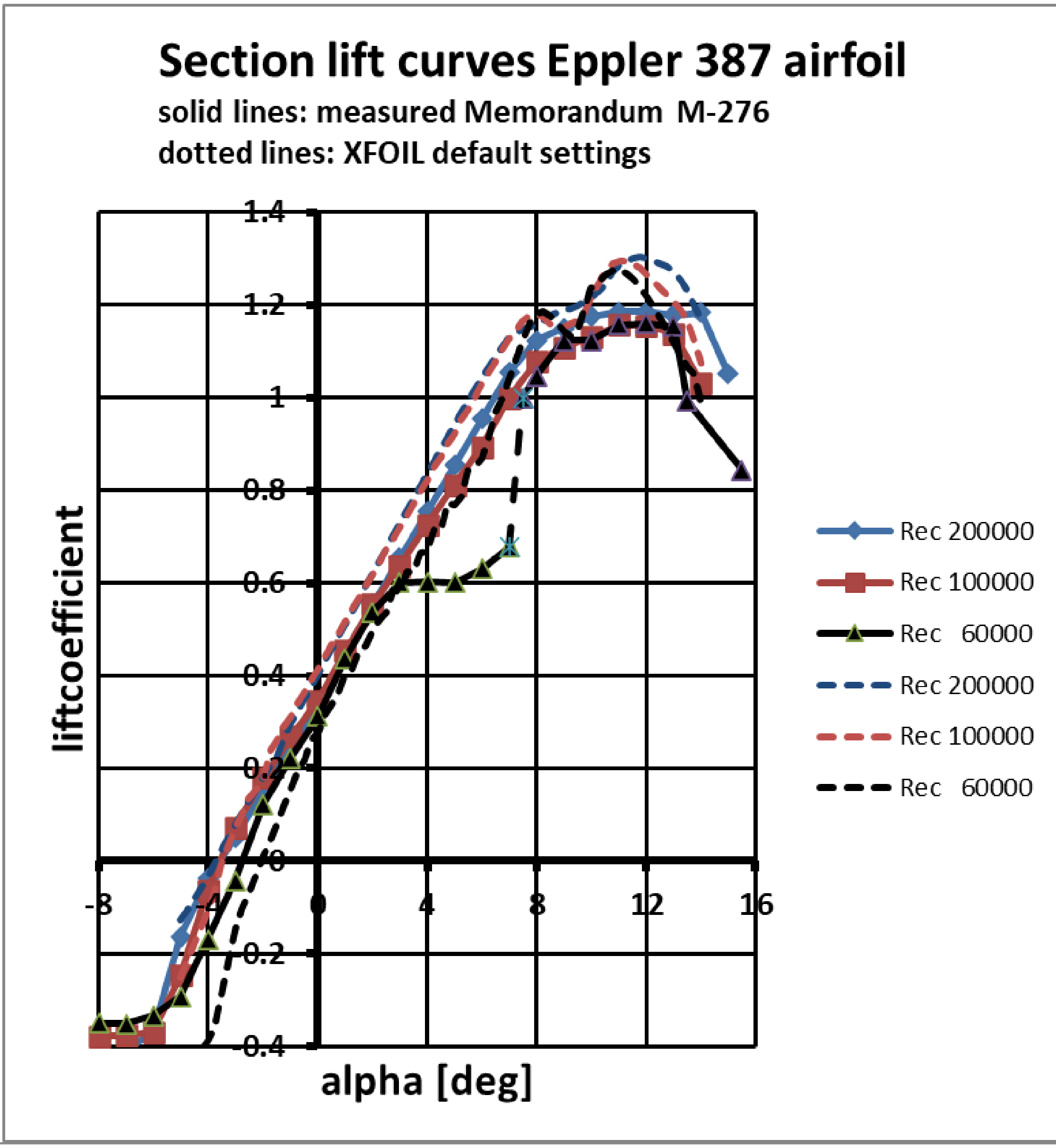


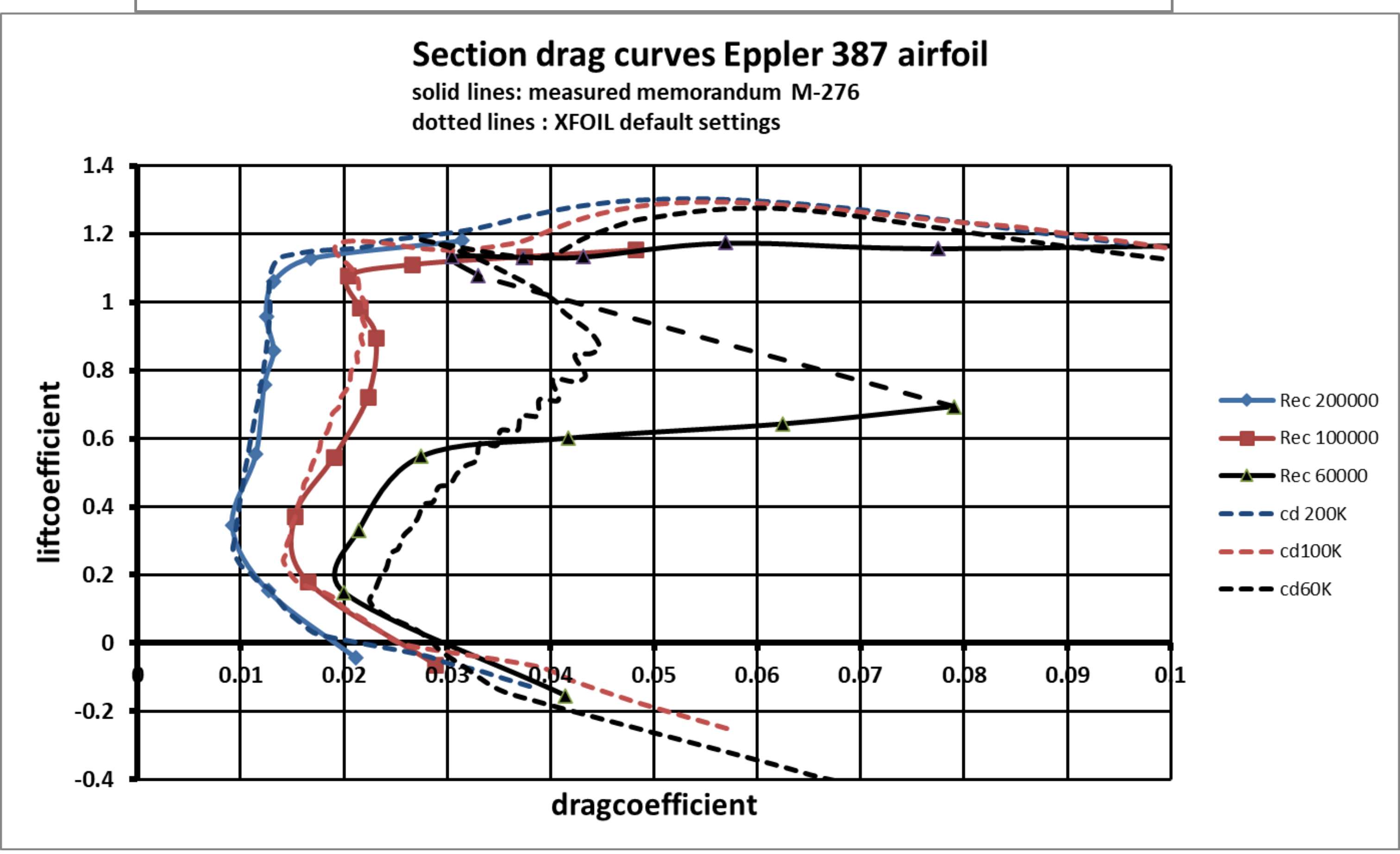
Oil Flow Visualization Eppler 387 upper surface Alpha= 4 deg, $Re_C = 0.6x10^5$



The direction of the oil flow is a result of in the direction of the friction of the air flow AND of the effect of gravity.

- At the laminar separation location, the friction of the airflow is zero. The oil flows vertical in the direction of the gravity.
- In the laminar separation bubble the first vortex yields a very low friction on the oil in direction against the flow direction.
- The combination of the first and second vortices are not able to clean the surface locally. In this case oil is concentrated. This is the (approximate) location of the transition of laminar into turbulent boundary layer according to sound listening by a microphone probe.
- The reattachment of the flow is not clearly indicated. Therefor the total length of the bubble is not clear. It is expected to occur far downstream of the transition location, probably in the wake. In the measured section lift- and drag curves indicate a separated flow (with no reattachment of the turbulent boundary layer on the airfoil surface). The XFOIL computations indicate a very thick boundary layer and transition @74%chord.


Section lift curves Eppler 387 airfoil
solid lines: measured Memorandum M-276
dotted lines: XFOIL default settings
liftcoefficient
alpha [deg]
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-8
-4
0
4
8
12
16
Rec 200000
Rec 100000
Rec 60000
Rec 200000
Rec 100000
Rec 60000


Section drag curves Eppler 387 airfoil
solid lines: measured memorandum M-276
dotted lines : XFOIL default settings
liftcoefficient
dragcoefficient
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
Rec 200000
Rec 100000
Rec 60000
cd 200K
cd100K
cd60K

Observations and comment

- At Alpha = 0 deg, $Re_C = 2.0x\ 10^5$ the XFOIL results are in good agreement with the wind tunnel results.
  - The computed laminar separation bubble is slightly smaller than indicated by the oil flow visualization
  - the section lift and drag coefficients almost the same as in the wind tunnel test

- At Alpha=4.0 deg, $Re_C = 0.6x\ 10^5$ the XFOIL results are too optimistic.
  - The computed laminar separation bubble is considerably smaller than indicated by the oil flow visualization
  - The section lift coefficient is overestimated
  - The section drag coefficient is underestimated

- In general the XFOIL computations are underestimating the the size of the laminar separation bubble. The results improve with increasing Reynoldsnumber.

The wind tunnel setup is described in memorandum M-276.

- The two dimensionality of the flow can be seen in the oil flow patterns shown in figure 5 of said memorandum. A slight tip effect might have a small effect on the slope of the section liftcurve, resulting in a too low liftcoefficient at a given angle of attack.
- The liftcoefficient is measured with a very sensitive balance.
- The section drag coefficient is measured with a wake rake with a highly sensitive pressure transducer and a scanivalve. Its presence might cause some (local) blockage effects, resulting in an unknown error in the drag coefficient. The rake was not present during the oil flow visualization tests.

The XFOIL computations were done with version XFLR5_v319 with default settings.