Labor Windkanal/Strömungsmesstechnik

HOCHSCHULE REGENSBURG UNIVERSITY OF APPLIED SCIENCES

Various Methods for Airfoil Polar Determinations: Pressure Measurement, Force Measurement, Numerical Simulation

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1. Introduction

Airfoil polars constitute diagrams with drag coefficient c_D and lift coefficient c_L axes (Fig. 1). The aim of this project is to create these polars of wing sections with pressure measurement, force measurement as well as numerical simulation. The measurements of the polars are carried out in the so called "Regensburg Wind Tunnel" (RWT) (Fig. 2).
The results produced thereby are to be compared subsequently with measurement data cited in relevant literature. In addition it is important to have a closer look on the physical background in order to evaluate the generated measurements and computations.

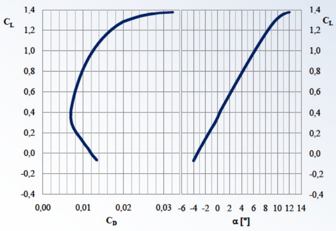


Fig. 1: Airfoil polars, in principle

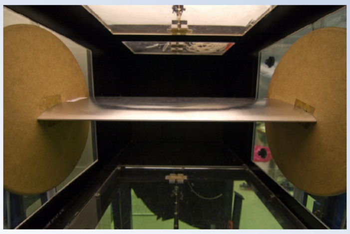


Fig. 2: Installed airfoil wing in test section

2. Physical Background

The main objective is to compare Regensburg measurement results with results of other wind tunnels. So there is a need for introducing standard wind tunnel corrections as well as some local adaption to make c_L and c_D comparable in a two dimensional sense. There are corrections concerning the dimension (finiteness of the length of pressure scan), the geometry (endplates, blockage) as well as the flow quality (turbulence, homogeneity). Also the geometrical properties of the wing as well as the interference of wing tips with the wind tunnel side wall have to be considered. Here, an effective aspect ratio of the test wing is established. The effective aspect ratio of the wings is now set to Λ = 30 in correlation to reference airfoils measured in renowned wind tunnels. This correction makes possible a sound comparison of future measurements in the RWT with measurements from other laboratories where results are presented pure two dimensional.

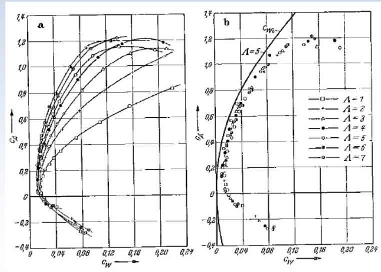


Fig. 3: Inclusion of the effective aspect ratio

3. Pressure Measurement

One method to determine c_D and c_L values in a wind tunnel is the so called "pressure measurement". The principle of lift coefficient detection is based on measuring mean pressure differences between the lower and upper wall of the test section (Fig. 4). The drag coefficient may be obtained by measuring the momentum deficit with a wake-rake (Fig. 5). It also deserves mentioning that the determination by pressure is a very precise way to gain airfoil-polars. But there is a high risk of measurement uncertainties because even small pressure differences may have a significant effect on c_D and c_L values. Therefore the main part of this project was to increase the quality of c_D and c_L detection results by valid and suitable improvements in measuring technique and measuring configuration.

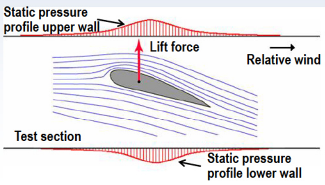


Fig. 4: Static wall pressure

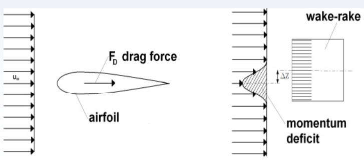


Fig. 5: Illustration of momentum deficit measuring

4. Force Measurement

Force measurement is another experimental method. In contrast to the pressure method lift and drag forces are collected directly. The concept is based on so called platform load cells. Details of the load cells are strain gages, producing electrical signal outputs. In the RWT this principle is implemented by using four load cells. One load cell respectively on each side of the breadboard for the drag and lift direction.

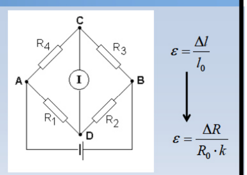


Fig. 6: Deformation of resistive wire strain

The subsequent insertion of the calculated forces into formulas of the coefficients deliver the values for the drag and lift direction.

As far as formulas are concerned the drag coefficient c_D and lift coefficient c_L are defined as follows:

Drag: $$c_D = \frac{F_D}{\frac{\rho}{2} \cdot u^2 \cdot A}$$

Lift: $$c_L = \frac{F_L}{\frac{\rho}{2} \cdot u^2 \cdot A}$$

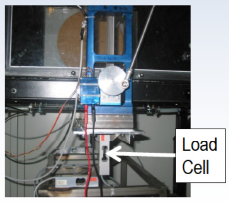
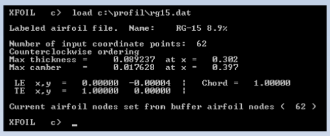


Fig. 7: Force measurement breadboard

5. Numerical Simulation

Numerical simulations are performed with the 2D subsonic airfoil code 'XFOIL'. This open source computer program is a text based interactive software for the design and analysis of subsonic isolated airfoils and consists of a collection of different function levels like geometry design, calculation and plotting polars.



```
XFOIL   c>  load c:\profil\rg15.dat

Labeled airfoil file.  Name:    RG-15 8.9%

Number of input coordinate points:  62
Counterclockwise ordering
Max thickness =     0.089237  at x =   0.302
Max camber    =     0.017628  at x =   0.397

 LE  x,y  =   0.00000  -0.00004  |   Chord =   1.00000
 TE  x,y  =   1.00000   0.00000  |

Current airfoil nodes set from buffer airfoil nodes (  62 )

XFOIL   c> _
```

Fig. 8: Text based XFOIL input mask

In a first step reference airfoil polars are computed for preceding measurement methods. In a second step the contours of the real airfoils are determined geometrically and also calculated. Therefore the influences of the contour accuracy on the drag and lift coefficients are identified depending on the angle of attack.

The results show, that for example the actual RWT-Model of the airfoil SD7037 is not able to gain the maximum c_L according to literature. This information is important for the evaluation of the measurement results described before.

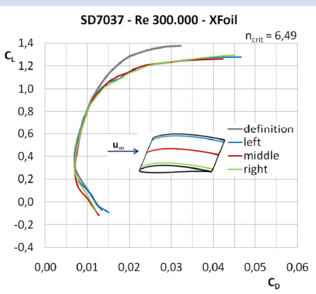


Fig. 9: Polars of the airfoil SD7037

6. Conclusion

After compilation of the several measurement methods a wide range of new information can be obtained. While the values of the pressure measurement method (c_L und c_D) are close to the Illinois reference data, the numerical simulation results deliver a slightly increased c_L value. The values of the force measurement method is characterised by a higher drag coefficient and an even more increased lift coefficient compared to the numerical simulation.

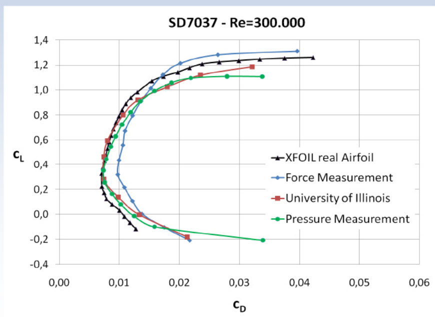


Fig. 10: Comparison of results of the several measurement methods

It can be stated that the pressure measurement method at the RWT matches the reference data far better than the force measurement method.
For gaining a quick overview of the polars the force measurement is advantageous with a measuring time per Reynolds number of 15 minutes compared to 60 minutes with pressure measurement.
The numerical simulation may be classified as a useful tool for comparison. It reproduces the most measurements in a close approximation.

Literature: SELIG, M: Summary of Low-Speed Airfoil Data – Vol. 3. Virginia: SoarTech Publications 1997
DRELA, M: XFOIL 6.9 User Primer. Massachusetts Institute of Technology 2001

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