Go4Hybrid

Definition for Test Case I.3
3-element airfoil

TC co-ordinator: DLR

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Table of Contents

1 Introduction

The present test case F15 three-element airfoil has been investigated in the DLR project LEISA (Low noise exposing integrated design for start and approach, 2005-2008), which combined and focused activities in the research areas of high lift system design, flow control and aero-acoustic design methods.

The underlying contour is the F15 three-element airfoil by Airbus, denoted F15 3eRef, where "3e" stands for "three-element" airfoil and "Ref" denotes "reference position of slat and flap". The considered geometry is a modified position of slat and flap developed by DLR and is denoted by F15 3eOpt, where "Opt" is the abbreviation for "optimized". The terms "reference" and "optimized" characterize the flow conditions on the flap. For the reference position of slat and flap, flow separation is observed on the flap for high Reynolds numbers close to flight conditions. For the optimized position, flow remains attached on the flap. However, for the low Reynolds number considered here due to the too large computational costs of the high Re conditions, the situation is opposite. Flow separation on the flap is observed for 3eOpt at around 45% flap chord, but the flow remains attached for 3eRef.

For the present test case, the full test case ID is F15 3eOptV2 NWB TN2297 VN1103 MP11, where TN (German: Testnummer) specifies the test case number being the ID of the measurement campain in the wind tunnel, VN (German: Versuchsnummer) specifies the number of the experiment, i.e., the configuration, Reynolds number and Mach number, and MP (German: Messpunkt) is the measurement point specifying the incidence angle. Measurements were performed in the low-speed wind-tunnel Braunschweig (NWB). The wind tunnel model has chord length c=0.6m, span 2.8m, and thus the aspect ratio span to chord is 4.66. Note that experiments have also been performed in other windtunnels like the acoustic wind tunnel Braunschweig (AWB) and the cryogenic wind tunnel Cologne (KKK), but the NWB data are considered to have the highest quality for validation purposes.

3 Geometric description

The geometry of the airfoil consists of three elements, i.e. slat, main wing and flap (see Figure 1). The inclination angles are 28,814° for the slat and 38,296° for the flap. The trailing edges of all three elements of the wind tunnel model are blunt and given by straight lines. The lower edge of the slat is sharp. An ASCII file of the geometry (exported from CENTAUR after reading the original IGES CAD file) is provided on the Go4Hybrid website. The deviation between the CAD data and the geometry of the manufactured wind tunnel model is estimated to be smaller than 0.01mm (private communication with LEISA project leader Jochen Wild).

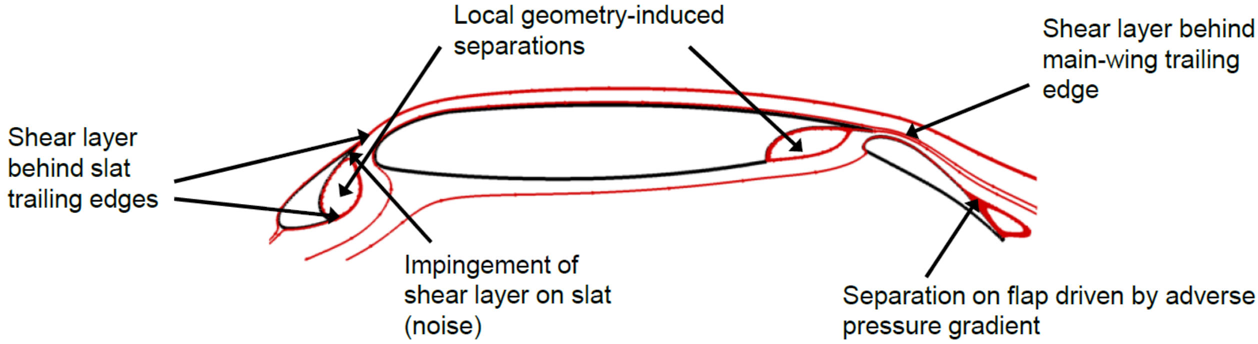


Figure 1 Geometry and basic flow features of the considered LEISA configuration.

4 Description of available reference data

NOTE: Based on experience from the ATAAC project, the experimental uncertainties in the different wind-tunnel campaigns (w.r.t. 3D- and side-wall effects, laminar/turbulent transition, necessary angle-of-attack corrections etc.) are considered too numerous to use this flow as a full validation test case. Thus, instead of spending huge effort on trying to approach the (assumed) experimental flow conditions, it was decided to keep the simulation setup rather simple (see below) and to focus the assessment on model-to-model and code-to-code comparisons.
Nevertheless, measurement data is provided for flow conditions similar to the simulation setup which should, however, be mainly used for plausibility checks and NOT taken as fully-reliable validation data (especially when considered for publication).

Experimental data cover mean pressure coefficient c_p in three span-wise sections at positions $\eta=y/s=0.5$ (mid span), $\eta=0.1071$, and $\eta=0.8928$, where s=2.8m denotes the model span and y is the coordinate in span-wise direction. In the mid section the model is equipped with a full row of pressure probes whereas the two side sections at 0.03m wall distance only have half the number of probes. Moreover there are profiles for the total pressure at around 80mm downstream of the flap trailing edge. Additionally there are acoustic data using microphone wall array for frequencies ranging from 1kHz to 0.5MHz. However, there are no experimental data available for mean velocity or Reynolds stresses.

5 Design and assessment parameters

The use of integral parameters such as lift or drag coefficient cannot be recommended by the experimenters (private communication with LEISA project leader Jochen Wild). Firstly, as the lift coefficient was not measured directly but was only obtained through integration of the pressure distribution. Secondly, due to spreading of the lift value resulting from one or two pressure probes, which may have randomly failed when repeating the measurement. Thirdly, it was noticed that even for small incidence angles the wind tunnel side walls cause a change in the effective angle of attack. However, for code-to-code and model-to-model comparisons the lift and drag coefficients may be useful.

6 Description of errors and known uncertainties

For incidence angles α smaller or equal 9°, the flow on the wind tunnel side walls remains attached until the position on the flap where separation occurs. Therefore, the angle-of-attack (AOA) correction to account for the effects of the wind tunnel side walls for numerical simulations of the 2D airfoil section is only around 1°. A series of steady state SA-RANS simulations and time accurate SST-URANS simulations was conducted, which yielded a corrected AOA of about 6° for the considered experimental AOA of 7,05°. However, due to limitations of the RANS approach for such a complex flow, this AOA correction can only be considered a rough approximation.

Moreover, laminar-turbulent transition in the wind tunnel experiments was free, i.e., no tripping was used. There are no infrared data measurements for laminar-turbulent transition for the present case F15 3eOptV2 NWB TN2297 VN1103 MP11, but only for two similar cases. Firstly, for the same onflow conditions (Re, Ma, α), but for a different flap position (3eRef). Secondly, for the same geometry 3eOpt and for the same values Re and Ma, but for different α.
Due to these uncertainties, it was decided to neglect the effects of laminar-turbulent transition, and instead apply fully-turbulent modelling in the mandatory numerical setup.

7 Physical phenomena and modelling challenges

For the considered flow configuration, the main physical phenomena are flow separations on the flap at around 45% flap chord at the considered Reynolds number and flow-generated airframe acoustic noise generated at the slat trailing edge due to the slat position. Moreover, the developing boundary layer on the main wing, the free shear layers behind the two (geometry-induced) separations in the slat and main-wing coves, as well as the pressure-induced separation on the flap yield complex “elliptic” interactions which altogether determine the global flow pattern (i.e. lift and drag).

8 Relevant modelling techniques

Due to the complex interaction of rather different flow phenomena involved in this test case, both non-zonal and embedded approaches may be applicable, possibly even in combined form (e.g. non-zonal methods in the free shear layers behind the slat and/or the main wing + embedded methods in the flap region, see Figure 2).

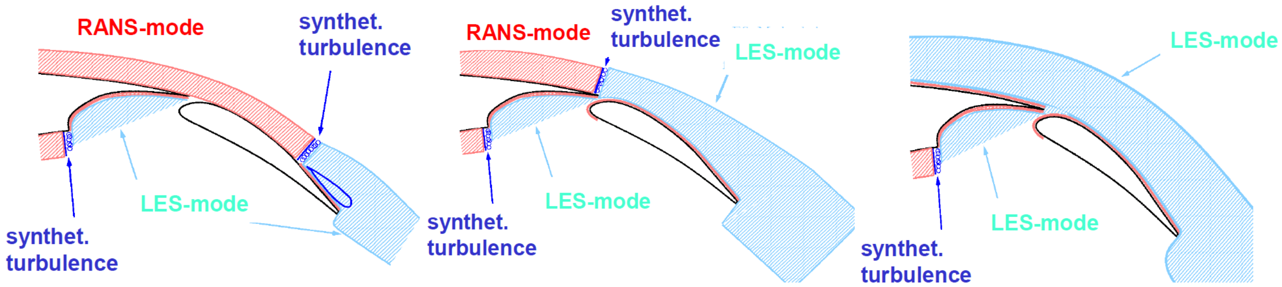


Figure 2 Possible Embedded-LES configurations for the flap region of the LEISA airfoil flow.

9 Flow and boundary conditions

Onflow conditions for the considered LEISA case are Ma=0.15 and Re=2.094Mio, where Re is based on the retracted chord length c (= 0.6 m in the experiment). The mandatory (corrected) angle of attack is α=6°.
Although Ma and Re (along with α) are sufficient to exactly determine the basic flow conditions, possible values for the primary flow quantities in SI-units (as used by DLR) are given here for reference: U_∞ = 51.48 m/s, p_∞ = 103471 Pa, ρ_∞ = 1.229 kg/m^3, T_∞ = 293.15 K.

In the mandatory setup, fully-turbulent modelling on all viscous airfoil surfaces is applied, i.e., no laminar regions are specified.

Mandatory turbulent onflow conditions are not given, as suited values may depend on the freely chosen modelling approach. Reasonable values for SST-based approaches are e.g.: $(\nu_t/\nu)_\infty$=0.1, $Tu_\infty = (2/3\ k_\infty)^{1/2}/U_\infty = 1\cdot 10^{-3}$. However, for most common RANS models used within HRLM (e.g. SA and SST), the onflow values of the turbulent variables should play no significant role, anyway.

10. Non-dimensional quantities

Pressure coefficient:	$c_p = 2 \cdot (p - p_\infty) / (\rho_\infty \cdot U_\infty^2)$
Skin-friction coefficient:	$c_f = 2 \cdot \lvert\tau_w\rvert / (\rho_\infty \cdot U_\infty^2)$
Normalized velocity:	u_i / U_∞
Normalized Reynolds stress:	$\langle u'_i u'_j \rangle / U_\infty^2$

Normalized λ_2-criterion: $\lambda_2 \cdot (c / U_\infty)^2$

11 Grids

For partners who are able to run computations on hexahedral grids, a fully block-structured mesh (created by NTS using Pointwise) is provided as mandatory grid (see Figure 3). The 2D (x-y) plane of the grid contains about 270,000 points, which is to be extruded in spanwise direction in n_z = 100 layers over an extend of L_z = 0.08 c. Thus, the mandatory 3D grid contains about 27 million points in total.
With normalized spacings (in wall units) of $\Delta x+ \approx 350$, $\Delta y+(1) \approx 1$, $\Delta z+ \approx 100$ (exemplarily taken at x/c = 0.5 on the upper wing surface), the grid should be suited for wall-modelled LES on the upper sides of the main-wing and the flap element.
Note, that in the provided grid file, the chord length is c = 1 (m), whereas for the wind-tunnel model, c = 0.6 m.

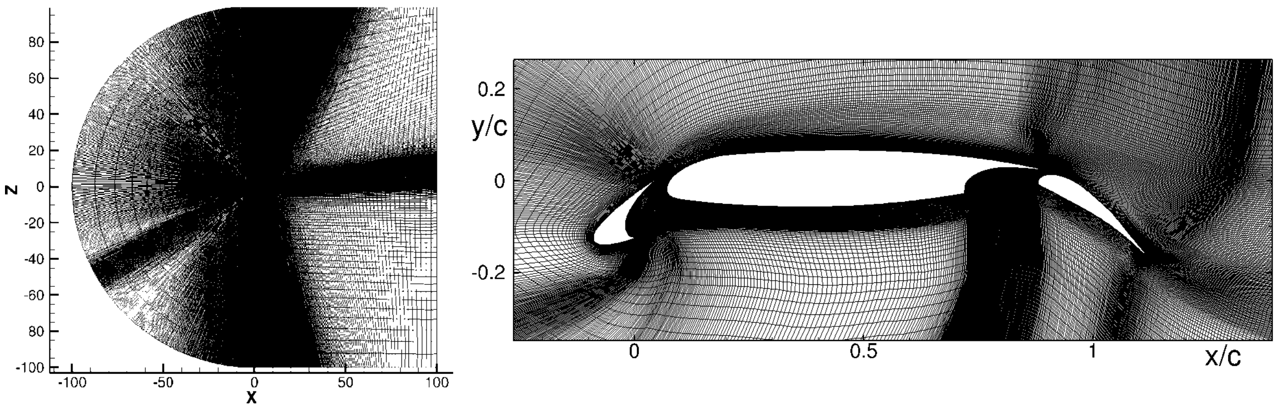


Figure 3 Global view (left) and close-up (right) of the mandatory LEISA airfoil mesh.

12 Computational guidelines

For the unsteady simulations, a physical time step of $\Delta t = 2 \cdot 10^{-4}\ c/U_\infty$ (based on chord length c and freestream velocity U_∞) is suggested for a 2nd-order time-stepping scheme.
Depending on the chosen HRLM approach, using a RANS/URANS solution as initial solution may be advisable (e.g. for IDDES-based methods).
Based on experience from SST-IDDES simulations (starting with an SST-URANS solution), the initial transient phase before starting averaging should be $t_{init} = 4\ c/U_\infty$ (i.e. 4 CTU) at least. Another 2-3 CTU for statistical averaging appears to be sufficient to obtain meaningful mean values and power spectra. For 2nd-order statistics (e.g. Reynolds stresses) a longer averaging period may be necessary.

13 Pre- and post-processing tools

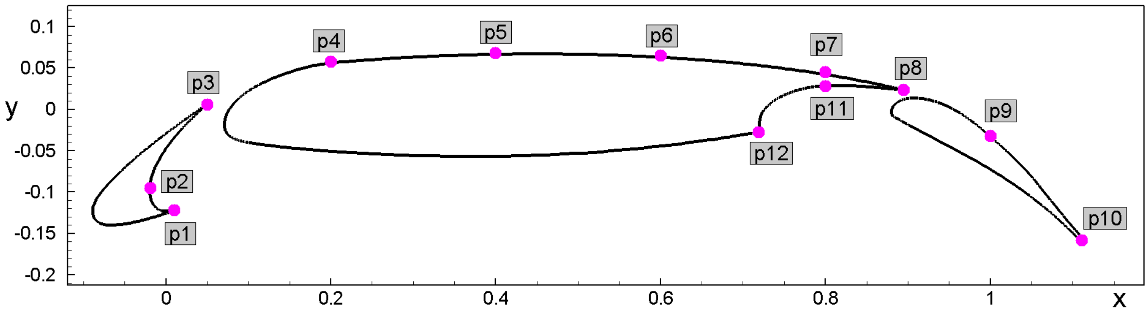
N/A.

14 Mandatory and optional results

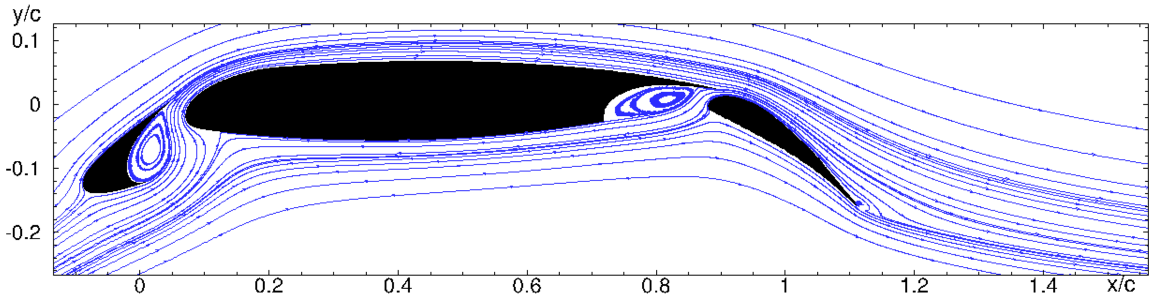
Mandatory results:

1) Span-averaged distributions of mean pressure **($\langle c_p \rangle$)** and skin-friction coefficients **($\langle c_f \rangle$)** along x/c on slat, wing, and flap.

2) Span-averaged profiles of normalized mean velocities **($<u>/U_\infty$, $<v>/U_\infty$)** in the following streamwise positions: **x/c = 0.1, 0.3, 0.5, 0.8, 1, 1.1**
3) Normalized time series of pressure (**c_p over $t \cdot (U_\infty / c)$**) in the coordinates provided in the file **“LEISA_additional_surf-probe_pos.dat”** on the test-case website (to be used for PSD and 2-point correlations). The 2D-coordinate positions are:



4) Visualization of mean 2D flow via time-averaged streamlines, e.g. as:



5) Qualitative visualizations of turbulent structures via iso-surfaces of instantaneous normalized λ_2-criterion **($\lambda_2 \cdot (c / U_\infty)^2$)** (iso-values and views to be provided on website)

Optional results:

a) Span-averaged profiles of normalized modelled & resolved Reynolds shear stress **($<u'v'>_{mod} / U_\infty^2$, $<u'v'>_{res} / U_\infty^2$)** in the streamwise positions defined in 2)
b) Span-averaged distributions of RMS-value of pressure coefficient **(RMS(c_p))** along x/c on slat, wing, and flap
c) Normalized time series of pressure (i.e. c_p over $t \cdot (U_\infty / c)$) in the coordinates provided in the file **“LEISA_AWB_Kulite_positions.dat”** on the test-case website

Example of data files (Tecplot-readable format):

<u>Profiles data file:</u>

```
variables = x/c, y/c, u/U0, v/U0, uv_mod/U0^2, uv_res/U0^2
ZONE T="x/c=0.1"
0.1 0.0 0.0 0.0 0.0 0.0
................................
ZONE T="x/c=0.3"
0.3 0.0 0.0 0.0 0.0 0.0
................................
```

Cp, Cf data file:

variables = x/c, Cp, Cf
ZONE
-2.140000E+00 5.6520E-02 2.9134E-03
....

15 Others

N/A.

16. References

Wild, J., Pott-Pollenske, M., “An Integrated Design Approach for low Noise exposing high-lift devices”, AIAA 2006-2843, 2006