www.compassis.com

Tdyn-CFD+HT - Validation Case 3

Incompressible flow over a NACA 0012 airfoil profile

Tdyn

Version
15.1.0

Compass Ingeniería y Sistemas http://www.compassis.com
Tel.: +34 932 181 989 - Fax.: +34 933 969 746 - E: info@compassis.com - C/ Tuset 8, 7o 2a, Barcelona 08006 (Spain)

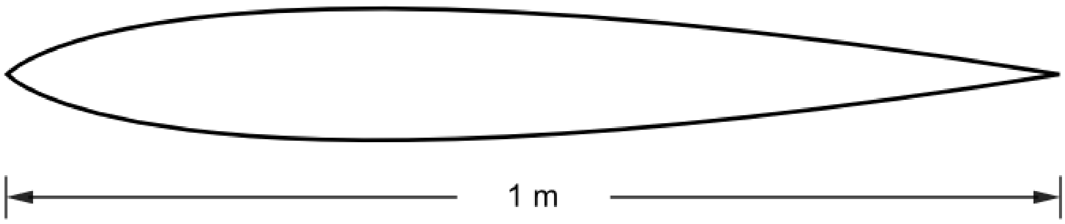
http://www.compassis.com
info@compassis.com
November 2018

Table of Contents

1 Validation Case 3 - Incompressible Flow over a NACA 0012 Airfoil Profile

This case studies the flow over a NACA 0012 airfoil profile. Numerical calculations of the 2-D flow over the airfoil are presented, and results are compared against the experimental results of two-dimensional wind tunnel tests of the symmetrical NACA 0012 airfoil reported in reference [1].

The incompressible flow over the airfoil is performed in a 2D analysis domain Ω. Several configurations have been studied by varying the angle of attack, alpha (α), in the range 0º < α < 16º. In addition, pressure distribution over the airfoil, and lift coefficient are evaluated as a function of the angle of attack. Solutions are obtained for Re = $3.0 \cdot 10^6$.



NACA 0012 airfoil profile. Chord length is 1.0 m.

The flow velocity is taken as 10m/s, resulting in a Mach number well below 0.3, and therefore the fluid model is assumed to be incompressible. Detailed experimental results concerning the Mach number can also be found in reference [1]. The boundary conditions used in the problem are the following:

-Null normal velocity (free-slip condition) is applied at both upper and lower boundaries $\Gamma_{Velocity}$of the domain. The vertical component of the velocity has been fixed to null value (Fix Y velocity is marked).

-Null velocity ('V FixWall' condition) is applied at the contour of the airfoil $\Gamma_{Wall/Bodies}$.

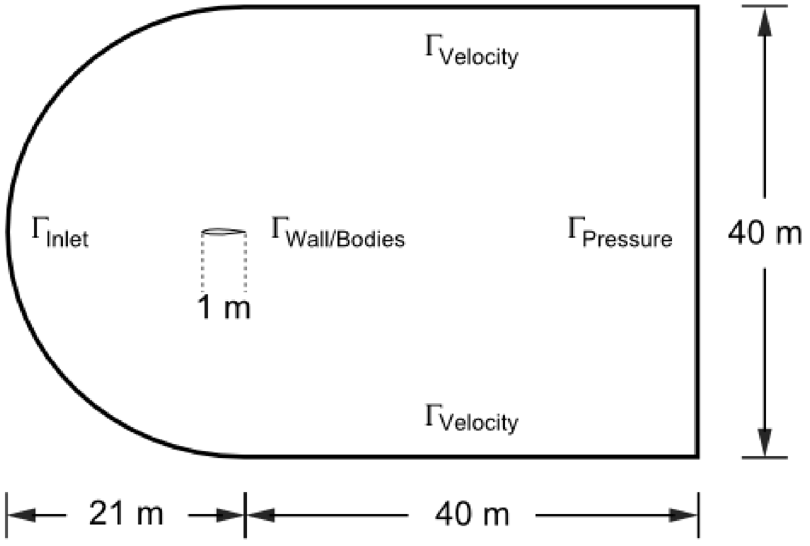
-The Inlet velocity is assigned at the left boundary Γ^{Inlet}.

-Null pressure is applied at the right boundary $\Gamma^{Pressure}$.

A brief summary of the boundary conditions that have been applied on the space domain is given as follows:

Condition	Boundary
V FixWall	$\Gamma_{Wall/Bodies}$
Fix X velocity field	Γ_{Inlet}
Fix pressure	$\Gamma_{Pressure}$

Fix Y velocity	$\Gamma_{Velocity}$



Schematic diagram of applied boundary conditions in the domain

Problem description

The problem definition is common to all simulations performed in this test case.

- Geometry

NACA 0012 airfoil profile.

- Domain

Steady-state.

- Fluid properties

Incompressible fluid. Fluid parameters were adjusted in order to match the required Reynolds number.

Re = $(\rho \cdot v \cdot c)/\mu$ = 3.0E+06

Simulation parameters		
Density	ρ [Kg/m^3]	1.0
Inlet velocity	v [m/s]	10.0

Airfoil chord length	c [m]	1.0
Viscosity	μ [Kg/m·s]	3.33333 E-06

- Fluid Models

Spallart-Allmaras turbulence model.

- Boundary Conditions

Inlet: fix velocity condition is especified at the left side of the control volume which has been discretized by using a C-grid.

Outlet: fix pressure is especified at the right side of the control volume.

Wall/Body: V FixWall condition has been used in order to enforce the no-slip condition at the surface of the airfoil.

Other: null normal velocity (free-slip) has been enforced at the top and bottom edges of the control volume.

- Initial conditions

Velocity: was initialized within the entire domain to the value specified at the inlet boundary.

Pressure: automatically initialized to 0.0

Turbulence model: the Spallart-Allmaras turbulence model was initialized by using a value of the turbulent kinetic energy K_t = 0.00135 m^2/s^2 and a characteristic turbulent length L_t = 0.01 m. No particular adjustment of the turbulence model was undertaken in the present analysis.

- Solver parameters

All simulations were run using the implicit fractional step solver.

Assembling type: mixed.

Time step: from 0.005 up to 0.01 seconds depending on the angle of attack (smaller time steps for larger angles of attack).

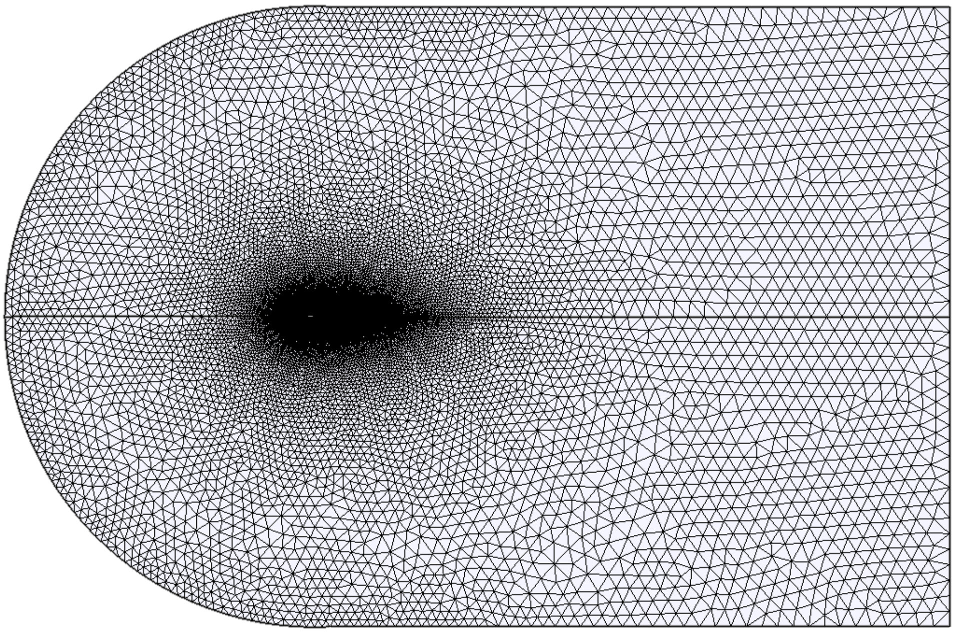
Non-symmetric solver: Bi-Conjugate Gradient (tolerance = 1.0E-07) with ILU preconditioner.

Symmetric solver: Conjugate Gradient (tolerance = 1.0E-07) with ILU preconditioner.

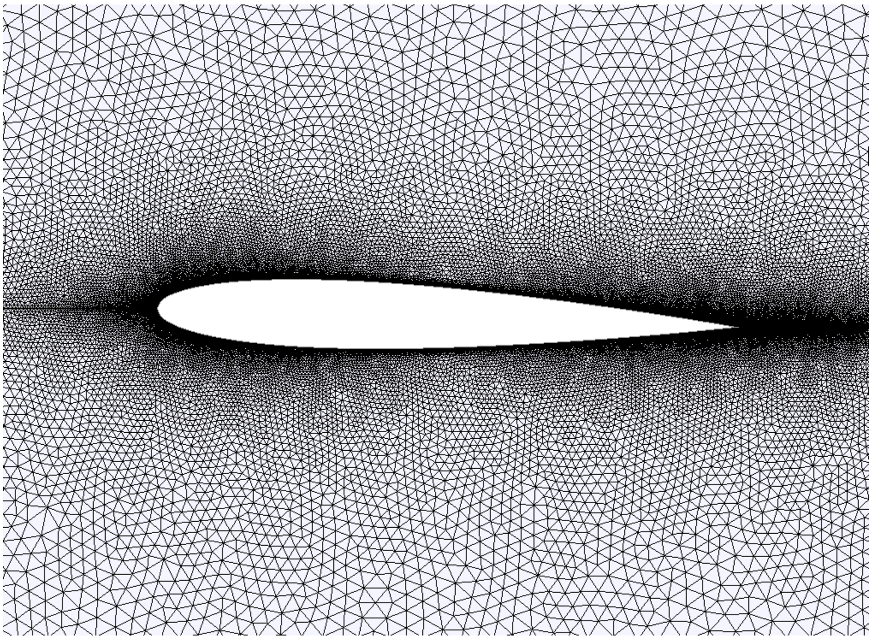
Mesh

All the simulations has been performed with the same geometry. It was necessary some structured subdivisions of the analysis domain Ω to generate the mesh. The domain is discretized by a structured grid of linear triangles. The finite elements mesh has 54698 nodes, and 110224 elements (triangles).

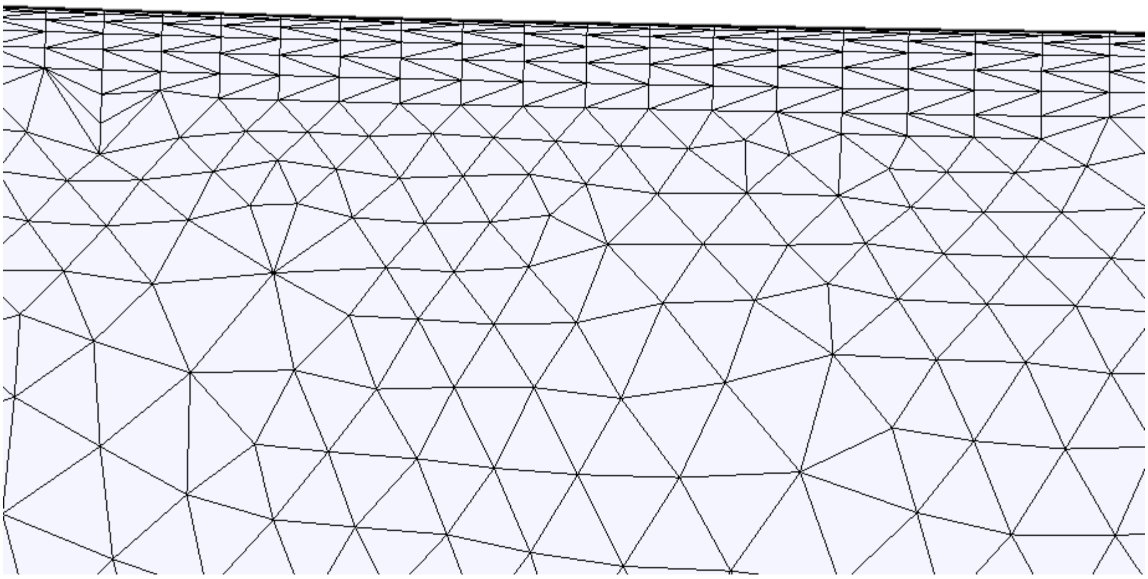
Sizes of elements vary just slightly close to the airfoil due to the different angle of attack. Anyway, the resulting meshes are roughly similar and have exactly the same characteristics.



General view of the C-grid used in all the calculations of the incompressible flow over the NACA 0012 airfoil.



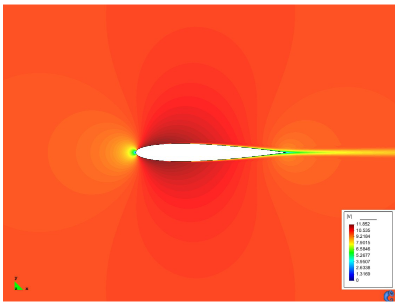
Detail of the mesh-size transition close to the airfoil profile.



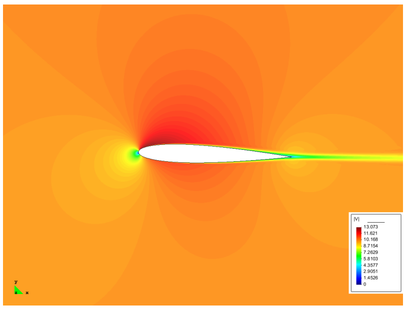
Detail of the mesh at the lower boundary of the airfoil profile.

Results

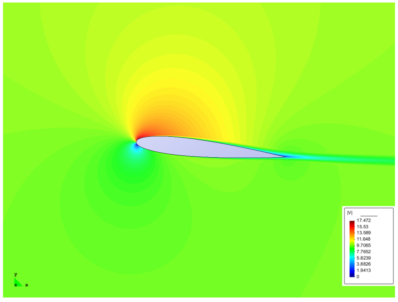
The figures below show the velocity field, for the given mesh and for a range of angles of attack at the last time step (t = 1 s) of the simulation.



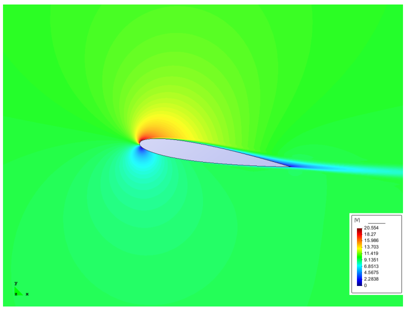
α=0º



α=1.86º

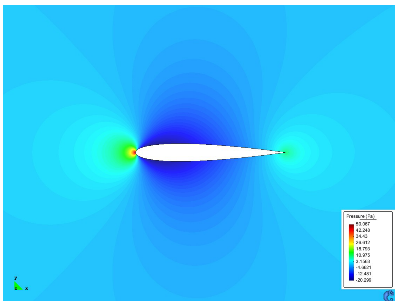


α=5.86º

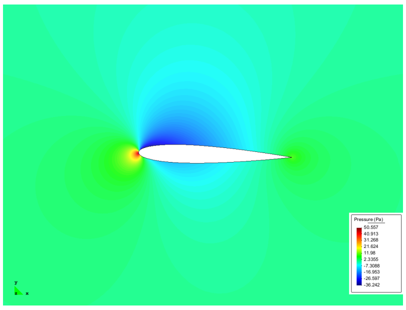


α=8.86º

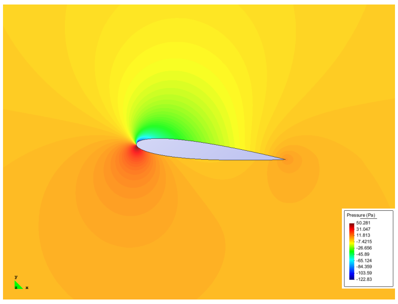
The figures below show the pressure field, for the given mesh and for a range of angles of attack at the last time step (t = 1 s) of the simulation.



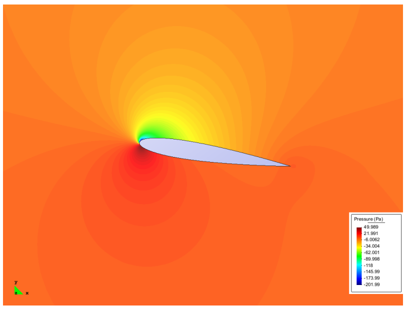
α=0º



α=1.86º



α=5.86º



α=8.86º

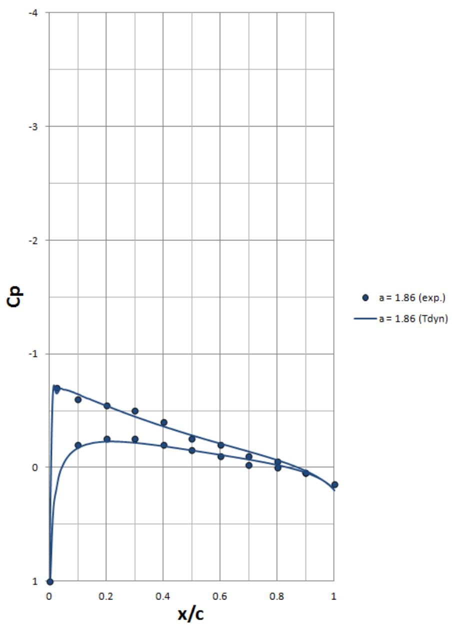
Verification

Pressure coefficient

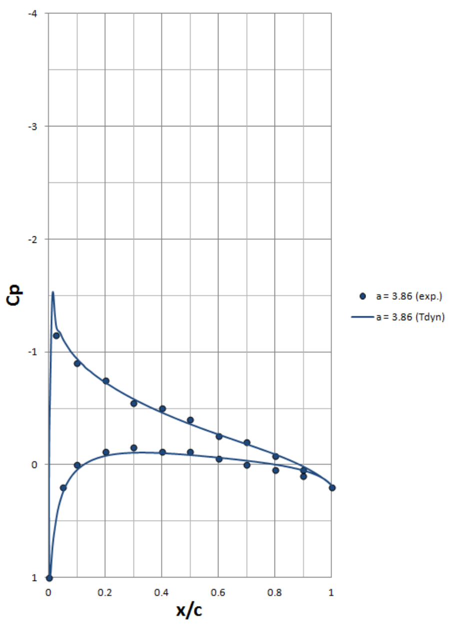
The pressure distribution on the upper and lower boundaries of the airfoil can be obtained from the simulations, and can be compared against the experiments given in reference [1]. Usually, not the pressure but the ratio of the local pressure to the stagnation pressure is plotted, known as pressure Coefficient (C_p), as follows,

$$C_p = \frac{p - p_{\text{inf}}}{0.5 \cdot \rho \cdot v^2}$$

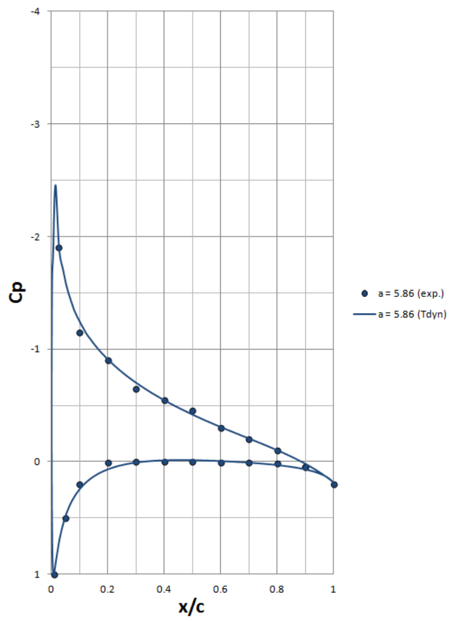
The figures below show the pressure coefficient distributions along the normalized airfoil profile, for various angles of attack. Simulation results (solid lines) are compared to the experimental results (solid dots) reported in reference [1].



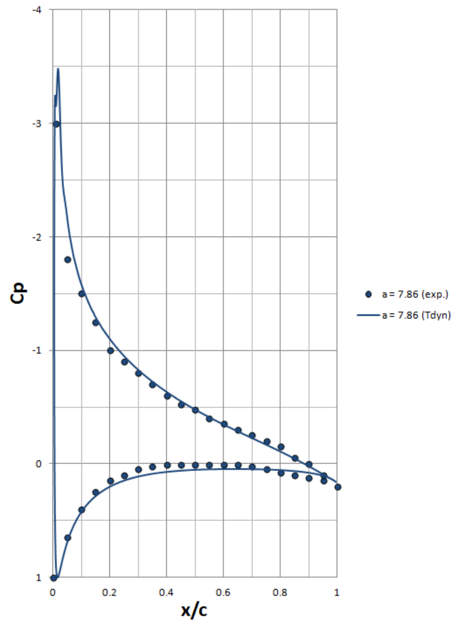
α=1.86º



α=3.86º



α=5.86



α=7.86

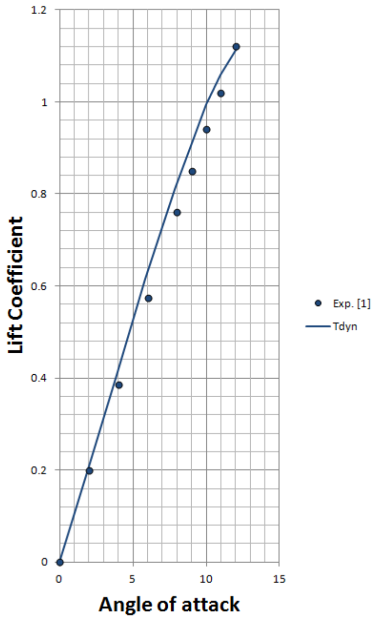
Overall results are in good agreement with experiments in the entire range of angles of attack under analysis.

Lift coefficient

Another important aerodynamic property is the lift coefficient (C_l), which depends on the angle of attack for a given inflow velocity and airfoil profile, as follows,

$$C_l = \frac{L}{0.5 \cdot \rho \cdot v^2 \cdot S}$$

where L is the lift force that depends on the angle of attack, and S is the profile area. The figure below shows the lift coefficient as a function of the angle of attack. Simulation results (solid lines) are compared against experimental results (solid dots) reported in reference [1].



Lift coefficient against angle of
attack over the airfoil.

Tdyn results are in good agreement with the lift values obtained in the experiments, in the range below the critical angle of attach $0 < \alpha < 12$.

Pressure verification

The following table shows the pressure values associated with the numerical solution for the given mesh, of the current Tdyn solver version versus the reference result of Tdyn, by varying the angle of attack.

Angle α	Point coordinates	Pressure (Pa) Ref. Value	Pressure (Pa) Curr. Value	Error (%)
0º	(-0.5,0.0,0.0)	50.067	50.067	0.0
1.86º	(-0.49974, 0.01623, 0.0)	42.593	42.593	0.0
5.86º	(-0.4974, 0.05105, 0.0)	-27.06	-27.06	0.0
8.86º	(-0.49403, 0.07701, 0.0)	-113.69	-113.69	0.0
12º	(-0.48907, 0.10396, 0.0)	-208.45	-208.45	0.0

It also shows the percent error, the difference between the current Tdyn value and the reference result, for each angle of attack. It must be noted that Tdyn result for the current version is exactly equal to the reference result.

References

[1] Two-dimensional aerodynamic characteristics of the NACA 0012 airfoil in the Langley 8-foot transonic pressure tunnel. NASA Technical Memorandum 81927. 1981.

Validation Summary

CompassFEM version	15.1.0
Tdyn solver version	15.1.0
RamSeries solver version	15.1.0
Benchmark status	Successfull
Last validation date	27/11/2018