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Aerodynamic Analysis of Flow Characteristics over Rotors Using CFD Methods

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Abstract: Near future goals of the national aerospace industry for producing rotorcraft systems is boosting academic and industrial interest. In order to validate and accelerate design processes, computational methods are largely used. In this study, an open-source CFD (Computational Fluid Dynamics) code, SU2 is used for analyses of 2D and 3D cases which includes different airfoils, wings and a rotor geometry. The results were compared with the experimental results and shown on graphics.

Keywords: Rotor, Computational Fluid Dynamics, Aerodynamics.

1 Introduction

Computational fluid analysis of rotorcraft has been widely discussed in the literature. Although experimentation with suitably scaled models would lead to more accurate results, computational methods used today can provide quite dependable results. Use of open source codes, beside the commercial codes in the computational fluid dynamics studies has been on the rise as a recent trend. This provides numerous advantages for the researchers, such as being free of charge and letting users to directly interact with the software problems are most common benefits of open-sourced codes. In this study, SU2 [1] CFD code will be used in the simulation processes of selected cases.

The study starts with 2D test problems. First of all, a flat plate experiment of Wieghart [2] was analyzed with SU2. After that NACA 4412 airfoil case was implemented and the results were compared with the Coles & Wadcock's study [3]. Then another airfoil, SC1095 airfoil cases were practiced and the results were compared with Flemming's experimental data [4]. 2D analyses were finalized at this point.

First 3D study is Schmitt & Charpin's ONERAM6 case [5]. Final study is Caradonna-Tung Rotor [6] verification case. The goal of this study is to check the capabilities of an open source computational fluid dynamics code for simple and complex geometries and turbulent flows. During these studies, Spalart Allmaras turbulence model [7] was used. Primarily a grid structure was generated for each geometry. Pointwise [8] mesh generation tool was used. For post-processing, Tecplot [9] and Paraview [10] tools were used to examine and verify the results.

2 Problem Statements

2.1 Two-Dimensional Cases

2.1.1 Flat Plate

The problem set starts with a flat plate case for some basic validation goals. The case examines a flow over a flat plate. The flat plate has 5 meters length. H-type grid structure for SU2 simulation is shown at Figure 1.

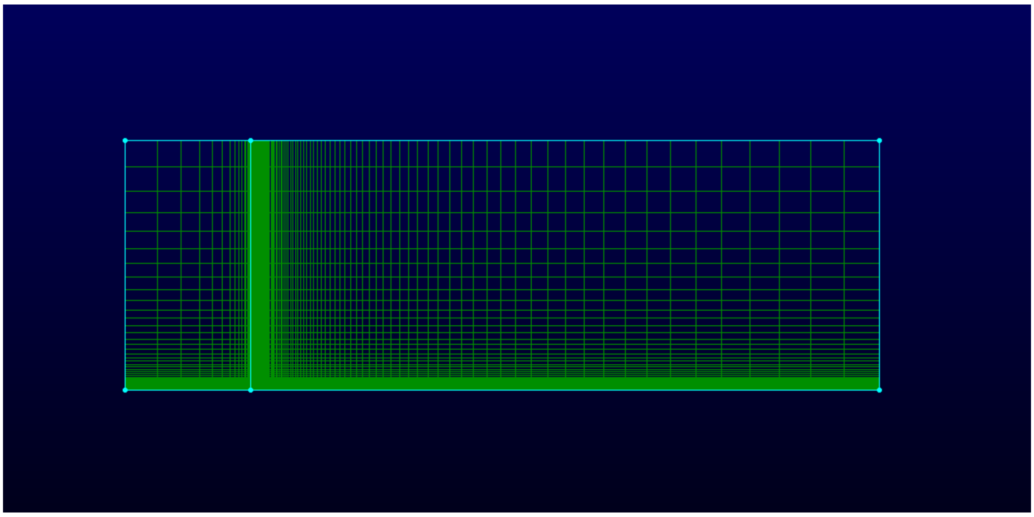

Figure 1: Flat Plate Grid Structure

Grid structure contains 23400 cells and has 200 nodes on x-axis and 117 nodes on y-axis. Height of the first cell on the surface is set to meet y+≤ 1 condition. Freestream conditions are shown at Table 1.

Mach	Pressure (Pa)	Temperature (K)	Angle of Attack (˚)
0.2	101353	294	0

Table 1: Flat Plate Freestream Conditions

2.1.2 NACA 4412

1 meter chord length of NACA 4412 airfoil was simulated. O-Grid structure was used to form the domain.

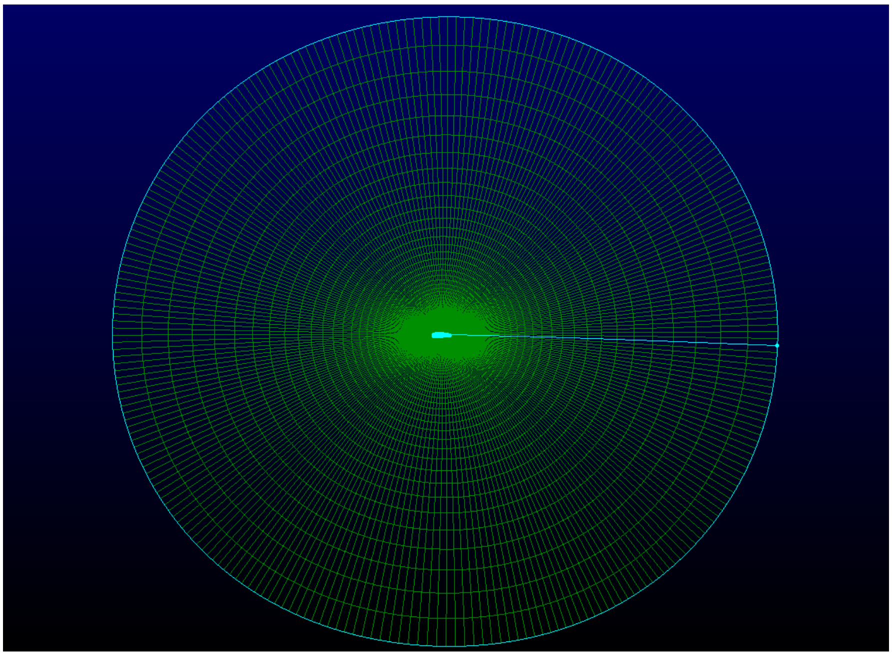

Figure 2: Grid Structure for NACA 4412 Airfoil

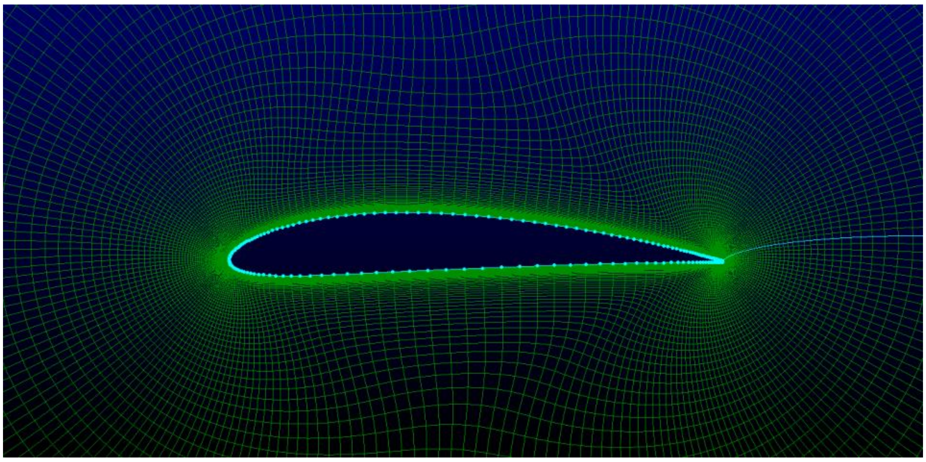

Figure 3: Near surface grid structure for NACA 4412

The domain consists of 34250 cells. There are 150 nodes on the upper surface of the airfoil, 100 on the lower surface of the airfoil. 137 nodes are set perpendicular to the wall. Freestream conditions;

Mach	Re_c (c=1m)	Temperature (K)	Angle of Attack (˚)
0.09	1.52E6	313	13.87

Table 2: Freestream conditions for NACA 4412

2.1.3 SC1095

C-shaped structured (Figure 4. and Figure 5.) grid was used for SC1095 airfoil study. The airfoil has 0.4082 meters chord length.

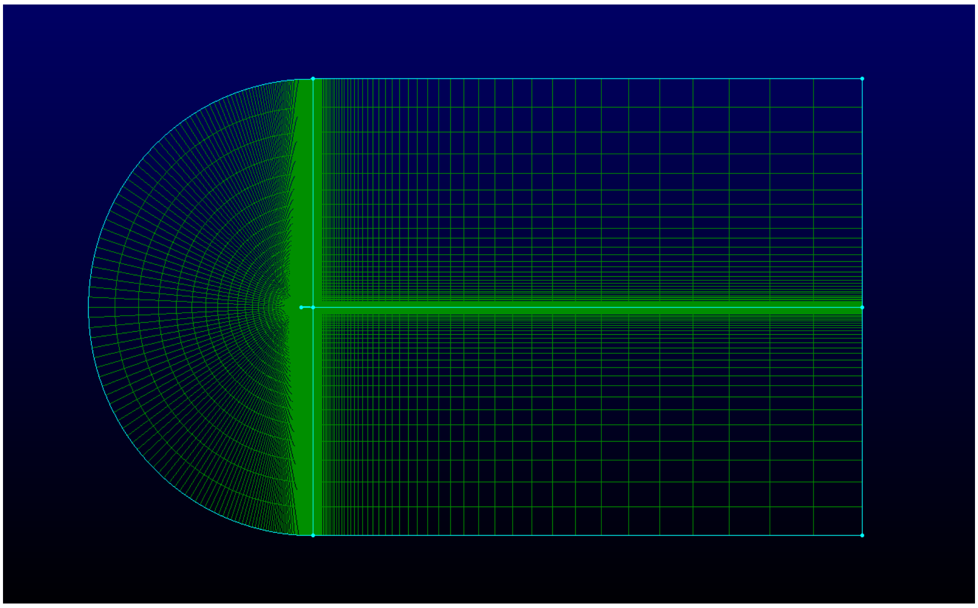

Figure 4: SC1095 Grid Structure

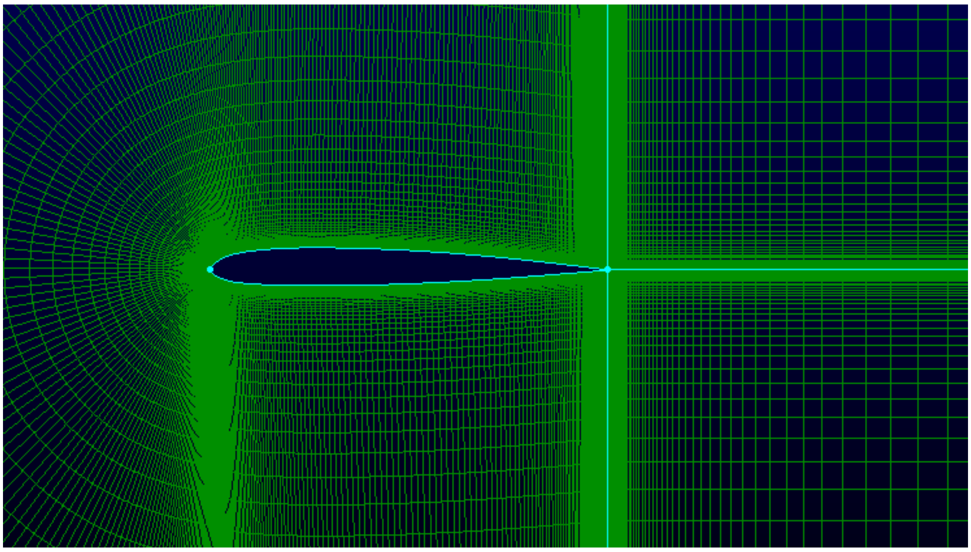

Figure 5: Near Surface Grid Structure for SC1095

The structure has 74354 cells. There are 250 nodes on the upper surface and 200 nodes on the lower surface of airfoil. Four different cases based on Flemming's experiment were studied. The cases are named as Run14, Run24, Run30 and Run52 and setup conditions are shown in Table 3.

	Temperature (K)	Mach Number	Re_c (x10^6)	Angle of Attack (˚)					
				α_1	α_2	α_3	α_4	α_5	α_6
Run14	294	0.401	8.97	-1.24	2.98	9.09	12.06	13.94	16.13
Run24	294	0.601	13.44	-1.42	3.14	9.17	11.23	13.15	16.15
Run30	294	0.806	18.03	-1.20	2.21	4.20	5.29	6.30	7.26
Run52	294	0.925	20.69	-1.03	1.01	2.08	3.10	4.09	5.18

Table 3: SC1095 Setup Conditions

2.2 Three-Dimensional Cases

2.2.1 ONERAM6

The first three-dimensional study is OneraM6. To compare the results, Schmitt & Charpin's data was used.

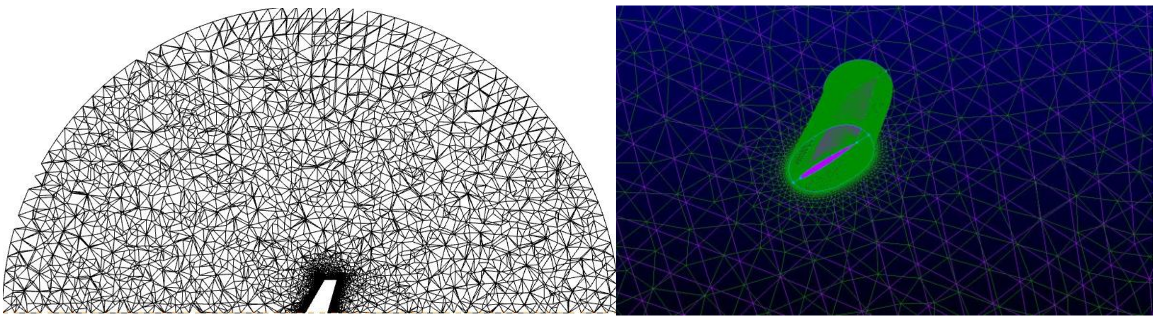

Figure 6: ONERAM6 Grid Structure

There are 2600090 cells in the domain. The setup conditions are given in Table 4.

Mach	Temperature (K)	$Re_{ort,c}(x10^6)$	Angle of Attack (˚)
0.8395	288.13	11.72	3.06

Tablo 4: Freestream Conditions for ONERAM6

2.2.2 Caradonna-Tung Rotor

For 3D rotor analyses, Caradonna-Tung's experiment conditions were used. Rotating frame dynamic mesh model was used to simulate the motion. Both structured and unstructured grid were used for domain. The hybrid structure is shown in Figure 7 and Figure 8.

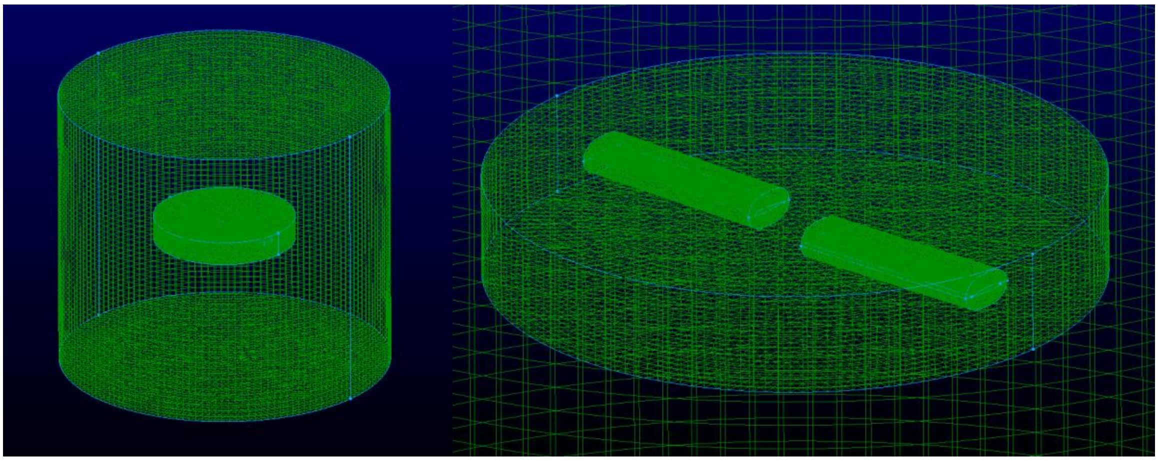

Figure 7: Caradonna-Tung Rotor Grid Structure

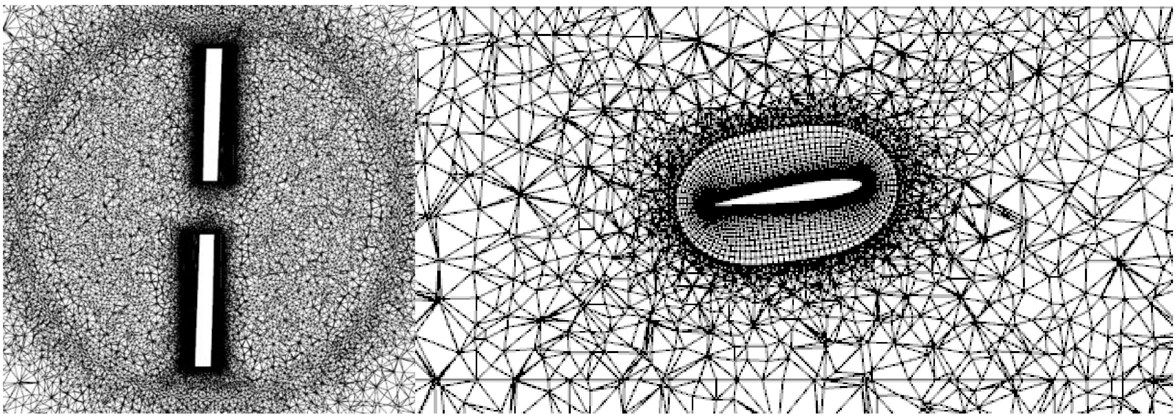

Figure 8: Caradonna-Tung Rotor Grid Structure

The model shown in Figure 7 and Figure 8 has 8° collective pitch angle. The analyses were done also for a model which has 0° collective pitch angle. 0° collective pitch angle model has 2577469 cells and 8° model has 2675138 cells.

θ=0˚	Ma_{tip}(Mach at tip) = 0.520	ω = 157.1 rad/sec
θ=8˚	Ma_{tip}(Mach at tip) = 0.439	ω = 130.9 rad/sec

Table 5: Caradonna-Tung Rotor Setup Conditions

3 Results

3.1 Two-Dimensional Cases

3.1.1 Flat Plate

Flat Plate analyses was converged in 36326 iterations for 6 order residual in density. The results were compared with the experiments done by Wieghardt in 1951.

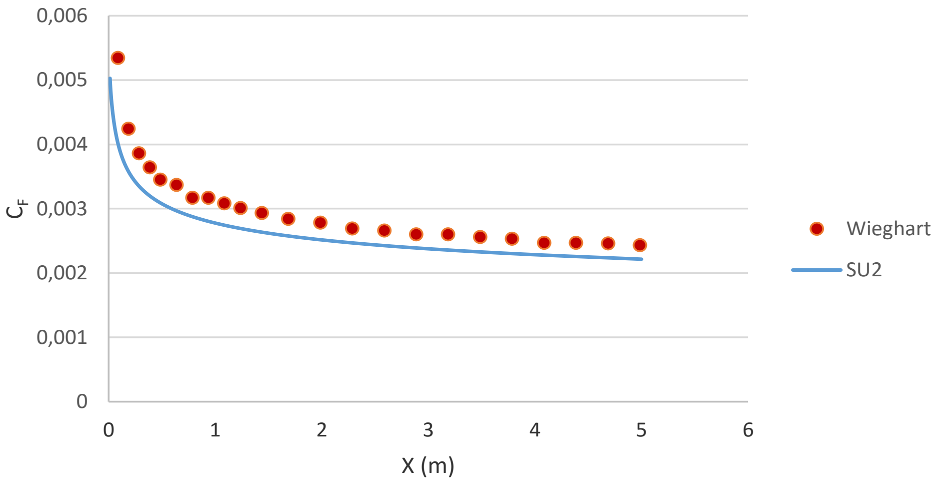

Figure 9: C_f Distribution on Flat Plate

3.1.2 NACA 4412

NACA 4412 airfoil analyses was completed in 32548 iterations for 3 order residual in density. The pressure coefficient distribution along the airfoil surface is given in Figure 10.

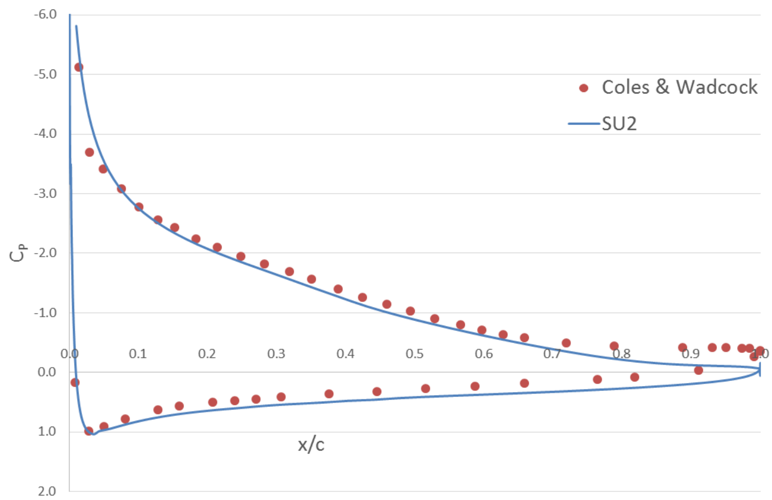

Figure 10: NACA 4412 Cp Distribution

3.1.3 SC1095

Iteration numbers and angle of attack are given in Table 6. The residual reduction is order of 3.

	α_1	α_2	α_3	α_4	α_5	α_6
Run14	-1.24	2.98	9.09	12.06	13.94	16.13
CI*	15364	15479	31546	69423	65123	67950
Run24	-1.42	3.14	9.17	11.23	13.15	16.15
CI	15547	42259	32548	64547	62548	66984
Run30	-1.26	2.21	4.20	5.29	6.30	7.26
CI	22568	26548	31569	45698	45694	54316
Run52	-1.03	1.01	2.08	3.10	4.09	5.18
CI	14779	15478	15568	46792	45216	31461

*CI: Converged Iteration

Table 6: Iteration Numbers of Analyses

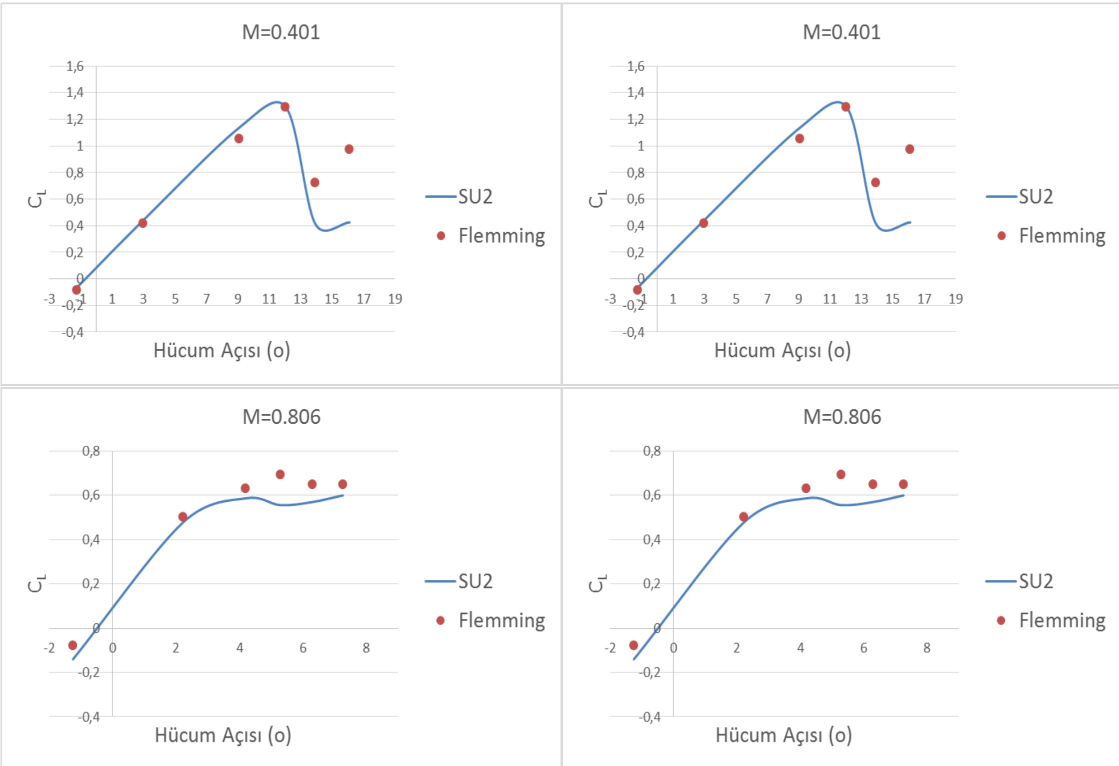

Figure 11: Lift Coefficient vs. Angle of Attack

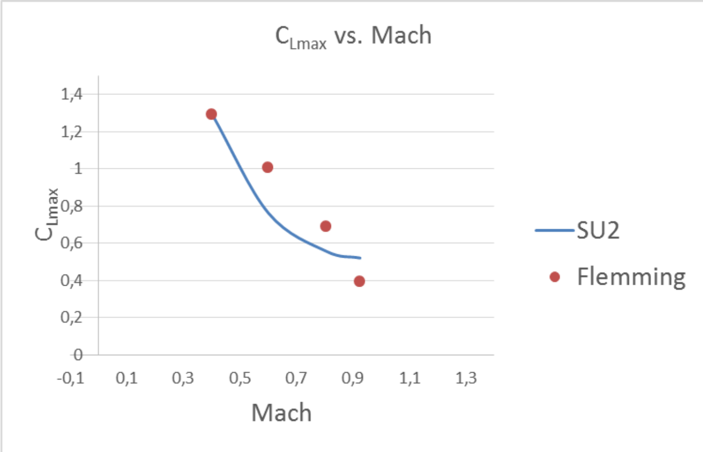

Figure 12: C_{Lmax} vs. Mach Number

3.2 Three-Dimensional Cases

3.2.1 ONERAM6

OneraM6 simulations were converged in 12322 iterations, for 3 order residual in density. SU2 solutions and experimental data were compared at the 4 stations along the wingspan. It is observable that simulations are quite accurate. Single shocks at the stations y/b=0.2 and y/b=0.90 and double shocks at the stations y/b=0.65 and y/b=0.80 are well placed. ONERAM6 wing is quite popular among CFD society. Therefore, it can be inferred that SU2 provides reliable solutions for 3 dimensional, static, viscous and turbulent flows.

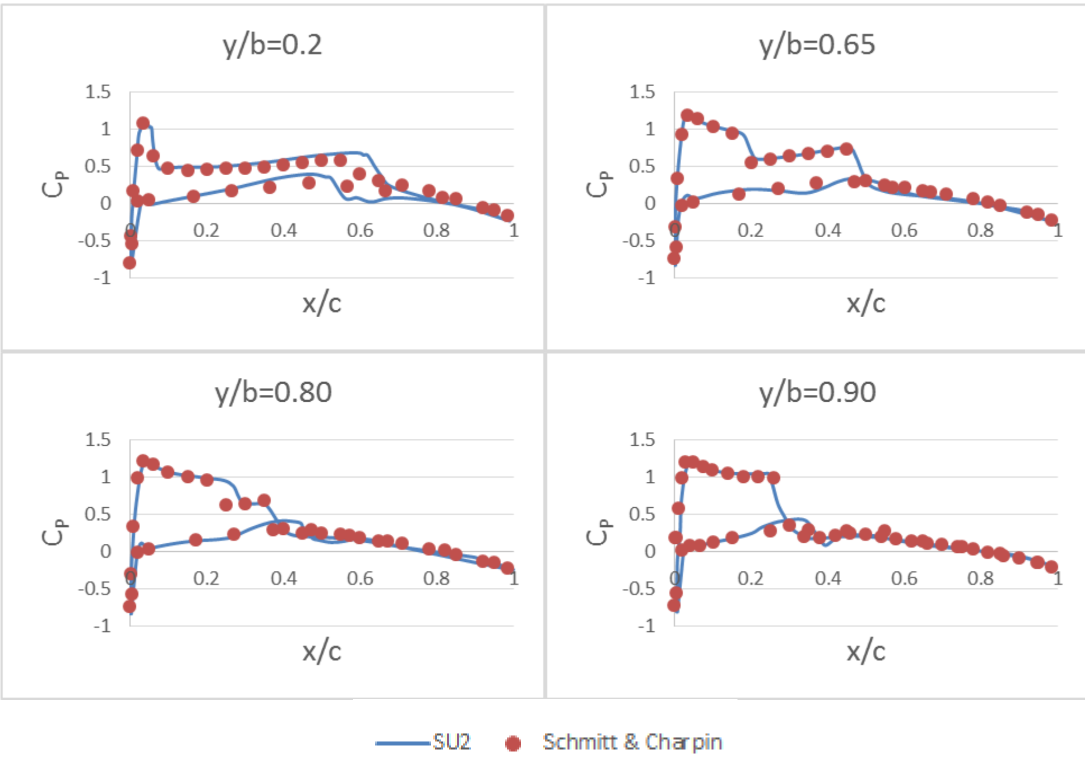

Figure 13. ONERAM6 Pressure Coefficient Distributions on Different Wingspan Stations
(M=0.84, Re=11.7 M, alfa=3.06°)

3.2.2 Caradonna-Tung Rotor

Caradonna-Tung Rotor simulation at θ=0˚ was converged in 1361 iterations for 3 order residual in density. SU2 solutions and Caradonna-Tung's experimental data were compared at 2 stations along the wingspan. The results are shown in Figure 14.

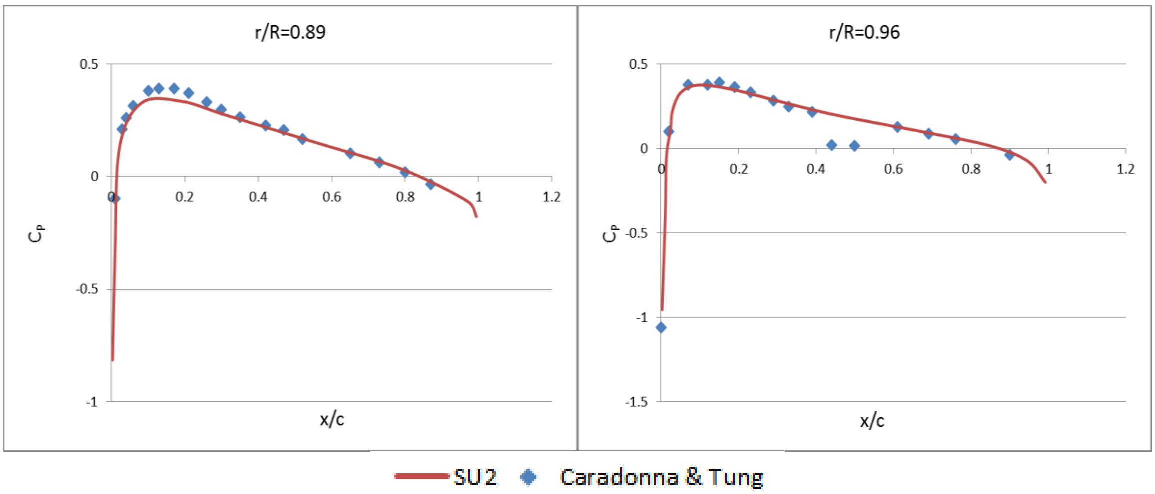

Figure 14: Caradonna-Tung Rotor C_p Distributions for θ=0˚

Simulation at θ=8˚ was converged in 8248 iterations for 3 order residual in density. SU2 solutions and Caradonna&Tung's experimental data were compared at 2 stations along the wingspan. The results are shown in Figure 15.

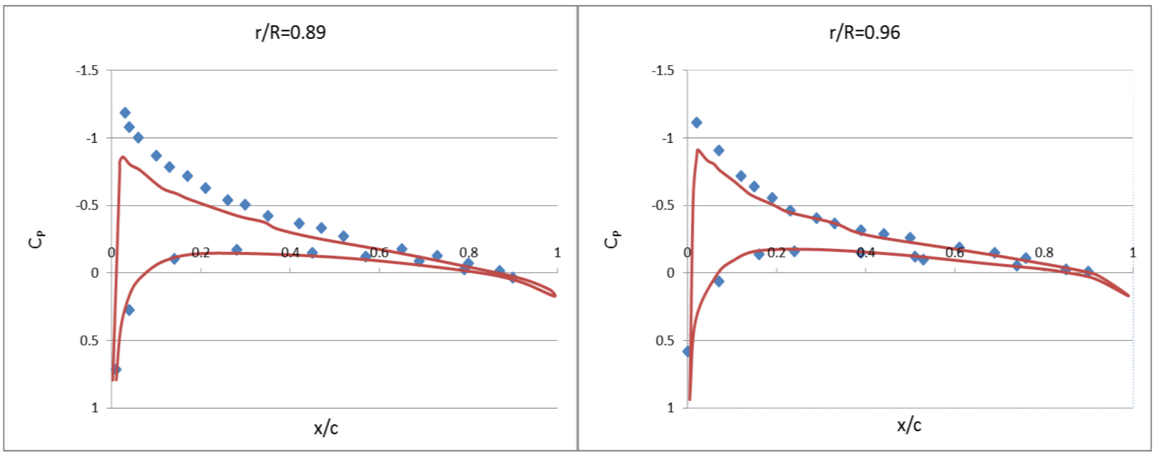

Figure 15: Caradonna-Tung Rotor C_p Distributions for θ=8˚

It is observable that simulations are quite accurate for θ=0˚ case. On the other hand, SU2 solution shows some differences with the experiment results around the leading edge for the case with θ=8˚.

3 Conclusion

This study proves that SU2 gives usually reliable solutions for two dimensional cases. On some cases with high angle of attack, the code gives bad results at leading edge comparing to cases with zero angle of attack. Moreover, SU2 can be used to solve compressible flow with shocks. 3D Wing case is solved nearly perfect with SU2, which is a promising advantage for users. Although better results can be expected for flat plate and rotor cases, the solutions shown in this study are still acceptable. SU2 is rather a new code and has plenty of area to improve.

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