Adam Causse

RANS Analysis of Transonic Wing Flow

Faculty of Engineering and Applied Sciences
Modelling Approaches for Aerospace Application

MSc
Academic Year: 2025–2026

Supervisors: Dr. László Könözsy
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This thesis is submitted in partial fulfilment of the requirements for the degree of MSc.

Academic Integrity Declaration

I declare that:

- the thesis submitted has been written by me alone.
- the thesis submitted has not been previously submitted to this university or any other.
- that all content, including primary and/or secondary data, is true to the best of my knowledge.
- that all quotations and references have been duly acknowledged according to the requirements of academic research.

I understand that to knowingly submit work in violation of the above statement will be considered by examiners as academic misconduct.

Abstract

This study presents a comparison of several RANS models applied to a transonic flow around an ONERA M6 wing[1]. The obtained results appear to be limited in terms of accuracy and reliability due to issues related to the simulation parameters. Nevertheless, the k–ω SST model stands out compared to the other models considered.

Keywords:
CFD simulation, RANS Model, ONERA M6 Wing

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Dr. László Könözsy

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List of Abbreviations

RANS	Reynolds-averaged Navier–Stokes
l	local chord
Cp	Coefficient Pressure

Chapter 1

Introduction

Modern transport aircraft typically cruise at transonic speeds, making this flight regime of paramount importance in contemporary aeronautics. Accurately capturing the associated flow physics remains a significant challenge due to the presence of strong shock waves, boundary-layer interactions, and three-dimensional effects. As a result, a solid understanding of transonic aerodynamics is essential for aerospace engineers relying on computational methods.

In this context, the ONERA M6 wing has become a well-established benchmark for the validation of numerical approaches. The experimental study conducted in 1972 by V. Schmitt and F. Charpin[2] investigated the flow around the ONERA M6 wing at various transonic Mach numbers and angles of attack, providing a comprehensive reference database. Owing to its fully three-dimensional, external, and transonic nature, this configuration is widely used to assess the performance of CFD models, particularly those based on the Reynolds-Averaged Navier–Stokes (RANS) approach. In the present work, numerical results are compared with available experimental and reference numerical data in order to evaluate the capabilities and limitations of different turbulence models.

Chapter 2

Literature review

A large number of studies have investigated the performance of RANS turbulence models for wing flow simulations. Most of this research focuses on comparisons between the Spalart–Allmaras model and the k–ω SST model. In particular, the study conducted by Jakirlić, Eisfeld, Jester-Zürker, and Kroll[3] in 2007 highlighted a strong similarity in the results produced by these two models, notably for simulations of the ONERA M6 wing.

Mazumder[4] proposed a comprehensive comparison involving two k–ε models, two k–ω models, and the Spalart–Allmaras model applied to the ONERA M6 wing. The results indicated that all these models provide sufficiently accurate predictions for many engineering applications.

Additional studies have extended such comparisons to other wing configurations. Ahmad, McEwan, Watterson, and Cole[5] investigated the flow around a NACA 0012 airfoil by comparing various k–ε and k–ω models, concluding that the k–ω SST model yielded the best overall performance.

Finally, the performance of these turbulence models has also been assessed at lower Reynolds numbers. Shahjahan, Emmerson, and Verstraete[6] conducted a study at Reynolds numbers below 2×10^5, where both the Spalart–Allmaras and k–ω SST models showed reduced accuracy but remained sufficiently reliable for engineering-level predictions.

Chapter 3

Methodology

3.1 Boundaries Conditions

3.1.1 Pressure Calculation

The pressure prescribed at the pressure far-field boundary is determined from the freestream temperature and the Reynolds number.

The freestream speed of sound a_∞ is first computed from the temperature as

$$a_\infty = \sqrt{\gamma R T}. \tag{3.1}$$

In the present case, the temperature is set to $T = 300$ K, which yields a speed of sound of $a_\infty = 347.19\ \mathrm{m\,s^{-1}}$. The freestream velocity is therefore $U_\infty = 291.57\ \mathrm{m\,s^{-1}}$.

Using the freestream velocity U_∞ and the Reynolds number Re, the freestream density ρ_∞ can be determined as

$$\rho_\infty = \frac{\mathrm{Re}\,\mu_\infty}{U_\infty\, c}, \tag{3.2}$$

where μ_∞ denotes the dynamic viscosity and c the reference chord length. For $U_\infty = 291.57\ \mathrm{m\,s^{-1}}$ and $\mathrm{Re} = 11.72 \times 10^6$, the resulting freestream density is $\rho_\infty = 1.11\ \mathrm{kg\,m^{-3}}$.

Finally, the freestream pressure p_∞ is obtained using the ideal gas law,

$$p_\infty = \rho_\infty R T. \tag{3.3}$$

For a temperature of 300 K, this results in a freestream pressure of $p_\infty = 95\,571$ Pa.

3.1.2 Reference values

To initiate the computation, it is necessary to define the reference values. These are directly taken from the pressure far-field conditions. The reference surface area and the mean aerodynamic chord are specified manually based on the geometric data of the ONERA M6 wing[2]. The mean chord length is $c = 0.64607$ m, and the reference surface area is $S_{\mathrm{ref}} = 0.7532\ \mathrm{m}^2$.

3.2 Calculation Strategy

3.2.1 Calculation Setup

Since the freestream velocity U_∞ exceeds 0.3 Mach, the flow is considered compressible. Consequently, the fluid is modeled as an ideal gas. The experiment is conducted at an angle of attack of 1.07°, and the x- and y-components of the pressure far-field velocity are therefore defined accordingly.

3.2.2 calculation convergence

The number of iterations for each calculation is 200 to allow the simulation to converge.

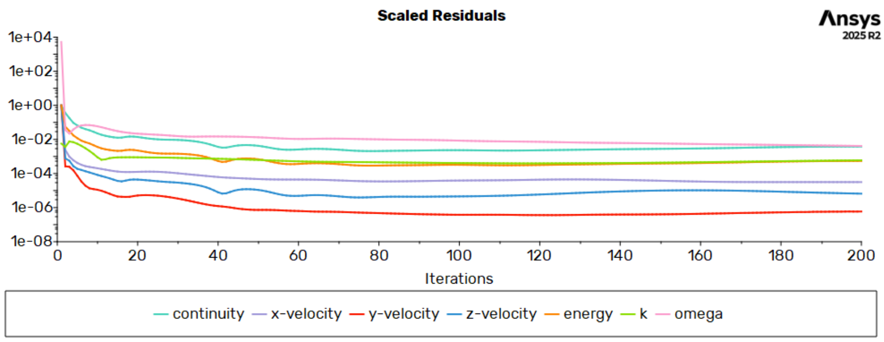

Figure 3.1: K-omega sst convergence

3.3 Data Analyse with CFD Post

Post-processing of the numerical results is performed using *CFD-Post*. In order to comply with the seven spanwise sections defined in the ONERA experimental study, the *Polyline* tool is employed to extract data only at the intersection between a cutting plane and the wing surface. The following table lists the positions of the cutting planes along the Z-axis as a function of the percentage of the wing span considered.

Wing span percentage (%)	Z-coordinate (mm)
20	239.26
44	526.372
65	777.595
80	957.04
90	1076.67
96	1148.448
99	1184.337

Table 3.1: Spanwise locations of the extraction planes used for data analysis.

The extracted dataset provides the pressure coefficient as a function of the streamwise coordinate x. Consequently, an additional post-processing step is required to compute the non-dimensional coordinate x/l, enabling direct comparison with the experimental ONERA results.

Chapter 4

Result and Discussion

4.1 Results

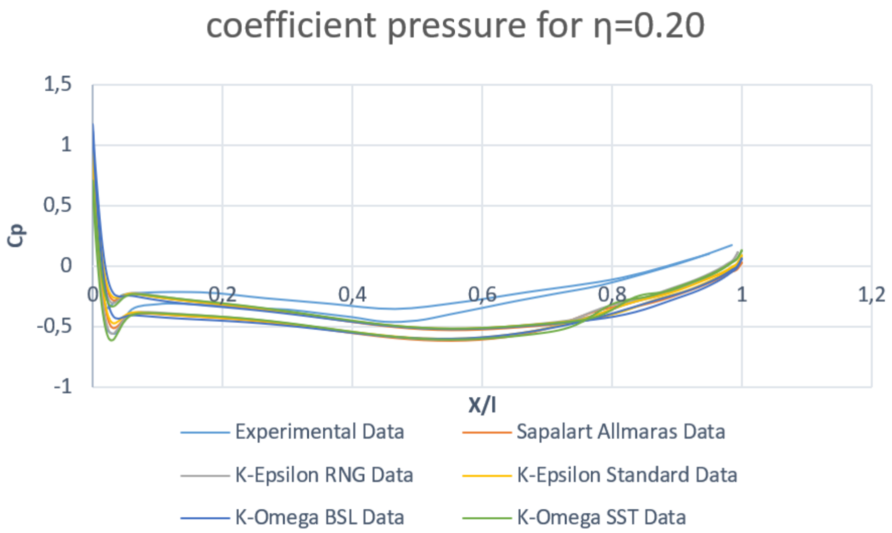

Figure 4.1: Coefficient Pressure at 20% of the wing span

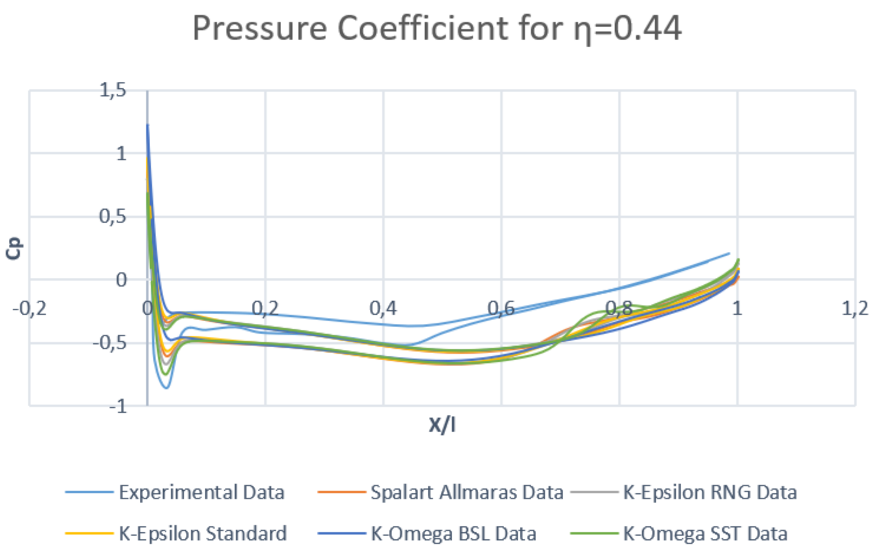

Figure 4.2: Coefficient Pressure at 44% of the wing span

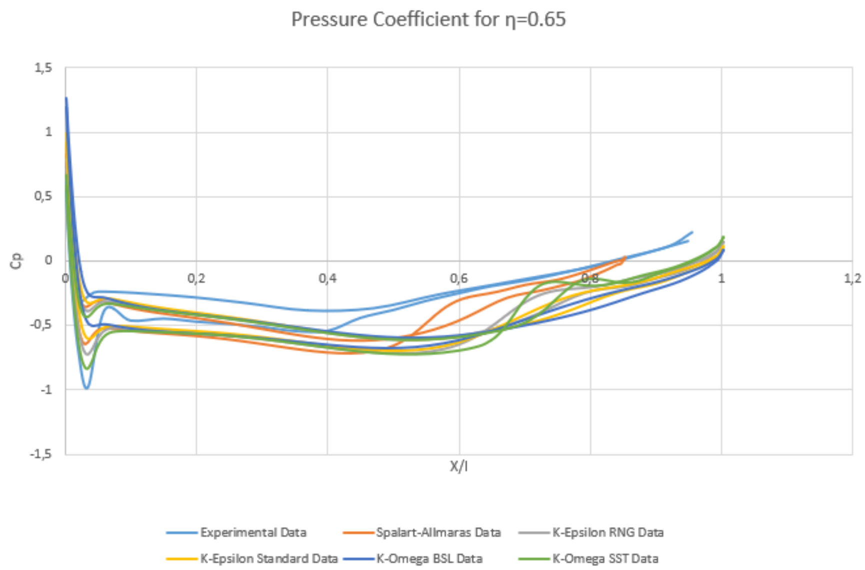

Figure 4.3: Coefficient Pressure at 65% of the wing span

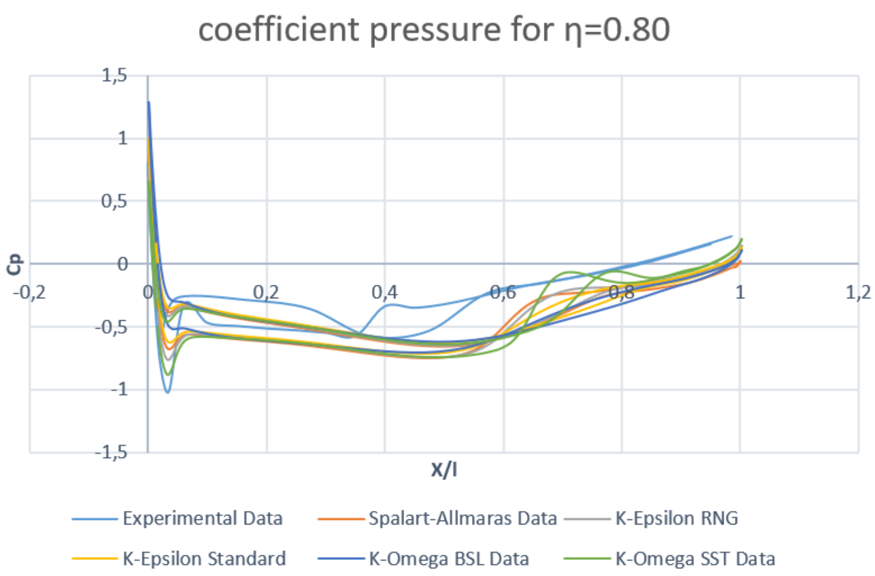

Figure 4.4: Coefficient Pressure at 80% of the wing span

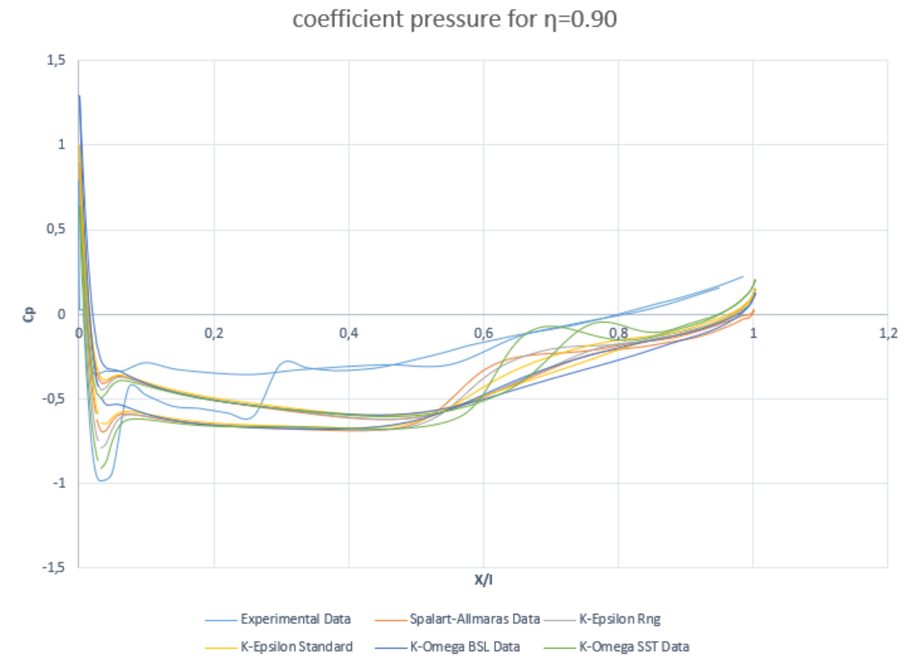

Figure 4.5: Coefficient Pressure at 90% of the wing span

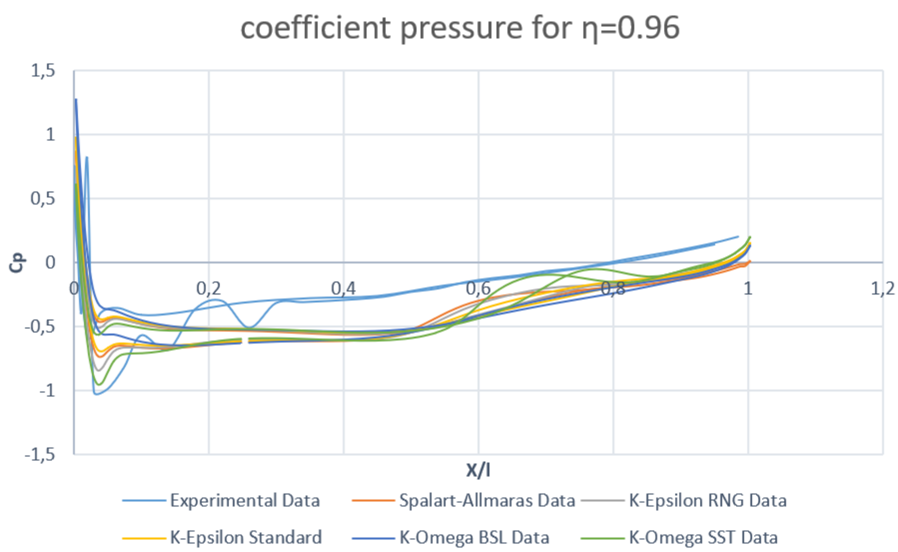

Figure 4.6: Coefficient Pressure at 96% of the wing span

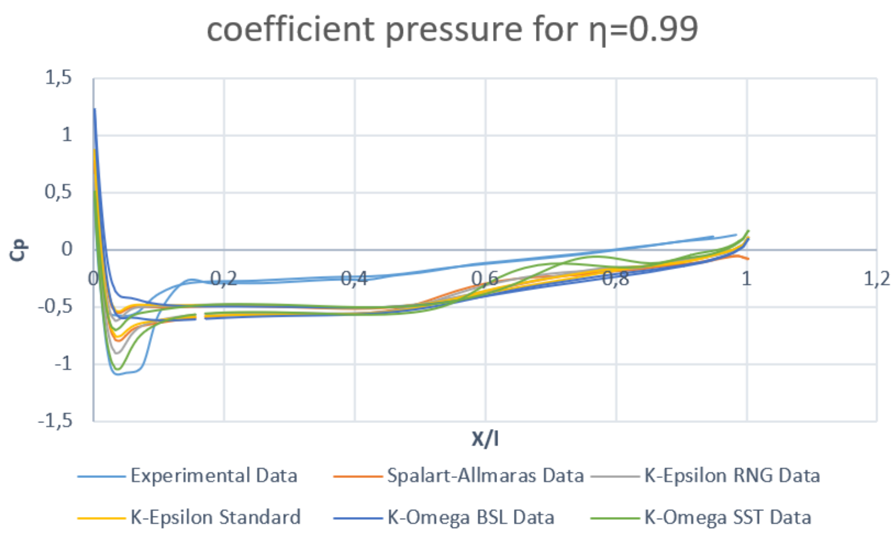

Figure 4.7: Coefficient Pressure at 99% of the wing span

4.2 Discussion and Limitations

The setup of these simulations encountered several difficulties. Initial results yielded pressure coefficient distributions that were even further from the experimental data than those presented in this study. One approach adopted to improve the relevance of the results was to modify the turbulence specification by switching to a formulation based on *length scale and intensity*. These parameters were left at the default values provided by the solver. No investigation was conducted regarding mesh quality or potential grid refinement, which could have led to further improvements in the results.

Despite the significant discrepancies attributed to inaccuracies in the simulation setup, the k–ω SST model appears to provide a closer agreement with the experimental pressure distributions over the different wing sections. This observation is consistent with trends reported in the literature. It is also noteworthy that the various turbulence models yield relatively similar results overall, highlighting comparable predictive capabilities under the present simulation conditions.

Chapter 5

Conclusion

This study focused on the comparison of several RANS turbulence models against experimental reference data. The obtained results suggest that inaccuracies were introduced in the selection of the simulation parameters, which likely affected the overall level of agreement with the experimental measurements. Nevertheless, among the models investigated, the k–ω SST model consistently provided the best agreement across the different simulations. This outcome is in line with conclusions reported in the existing literature.

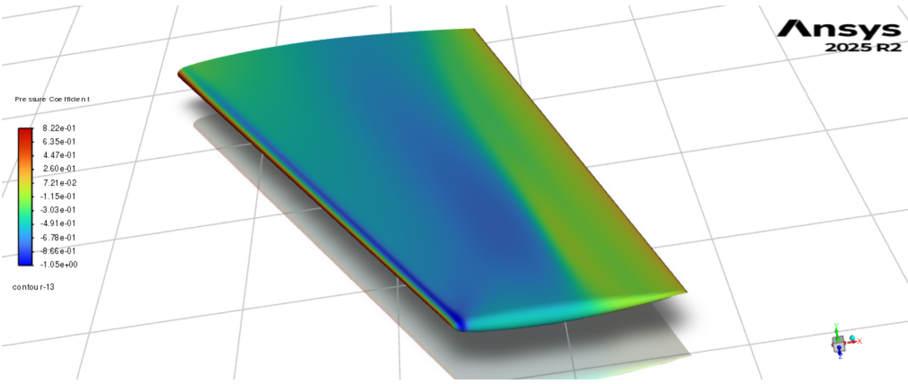

Figure 5.1: Coefficient Pressure calculated with K-Omega SST Model

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