Modeling Arbitrary NACA 4-Digit Airfoils with Kuethe Chow Vortex Panel Method

Patrick M. Kennedy
Embry-Riddle Aeronautical University, Daytona Beach FL, USA

This technical report presents a comprehensive numerical analysis of the aerodynamic characteristics of NACA 4-digit airfoils utilizing the Kuethe Chow vortex panel method. The airfoil surface is discretized into a series of panels, and the vortex panel strengths are computed to satisfy the imposed boundary conditions. The pressure distribution, lift, drag, and pitching moment coefficients around the airfoil are thoroughly examined and compared with experimental data obtained from wind tunnel tests. The results demonstrate a high degree of agreement with the experimental data, particularly when comparing the rate of change of coefficients. The Kuethe Chow method proves to be a valuable alternative to Computational Fluid Dynamics (CFD) for predicting the aerodynamic performance of airfoils.

Nomenclature

AoA	= *Angle of Attack*
CFD	= *Computation Fluid Dynamics*
Cp	= *Coefficient of Pressure*
Cmc/4	= *Coefficient of Moment about 25% chord point*
Cmac	= *Coefficient of Moment about aerodynamic center*
VPM	= *Vortex Panel Method*
MCL	= *Mean Camber Line*
x/c	= *x location in % chord*
y/c	= *y location in % chord*
LE	= *Leading Edge*
TE	= *Trailing Edge*
TODO	

I. Introduction

NACA airfoils have been widely used in the aerospace industry due to their superior aerodynamic performance. Various numerical methods have been developed to accurately predict their characteristics, including the source panel method. However, this method is limited in its lack of circulation, thus unable to predict lift. The Kuethe Chow vortex panel method addresses this limitation by considering vortex shedding and circulation around the airfoil. Moreover, its computation time is significantly shorter than that of CFD, making it a valuable alternative for practical engineering applications.

II. Problem Statement

The Kuethe Chow vortex panel method represents an airfoil body as an infinitesimal summation of vortices forming a vortex sheet. This vortex sheet induces a circulation around the airfoil, which can be integrated to determine the lift produced on the airfoil via the Kutta-Joukowski theorem. This process is known as the Vortex Panel Method (VPM). VPM can be applied to either the upper and lower surfaces of an airfoil or to the mean camber line (MCL) in conjunction with thin airfoil theory.

The accuracy of VPM is evaluated in this paper. Results are compared to experimental data referenced in the Perkins and Hage airfoil tables.

III. Program Structure

All code utilized for the analysis is implemented in MATLAB and referenced in the appendix.

Before defining the vortex, sheet and iterating across each panel, the geometry of the airfoil should be defined. The function "naca4digit" will accept a 4-character string and parse the digits into a struct containing all necessary parameters of the NACA 4-digit airfoil specified.

Once the geometry is defined, the program iterates over a list of angle of attack (AoA) values and executes the "vortex_panel_method" function for each airfoil orientation. Flow characteristics are computed within this function using VPM and returned as an output struct to the main scope.

The main scope iterates over all flow characteristics for each AoA and ultimately determines the aerodynamic center of the NACA 4-digit airfoil.

a. naca4digit

The function "naca4digit" accepts 2 parameters: *digits* and *n*. *digits* will specify the NACA 4-digit airfoil to be modeled. This parameter does not accept modified NACA 4-digits and only standard 4 number definitions. *n* is the reference for how many panels are to be used in the NACA 4-digit model. *n* must be an even number, if odd the program will round down to the nearest even number.

The *digits* parameter is parsed to get the max camber, distance of max camber, and max thickness of the airfoil. Equations defined in the NACA Technical Report 824 were utilized to define function handles for the upper and lower surface of the airfoil.

The airfoil vertices are defined by assessing the upper and lower body coordinates over a cosine spacing from 0 to 180 degrees about the midchord of the airfoil. The algorithm will produce *n+1* vertices, which amounts to *n* number of panels. The leading edge (LE) and trailing edge (TE) are fixed at *(0,0)* and *(1,0)* respectively. An example of this cosine spacing is done for a 12-panel cut in *Figure 1*.

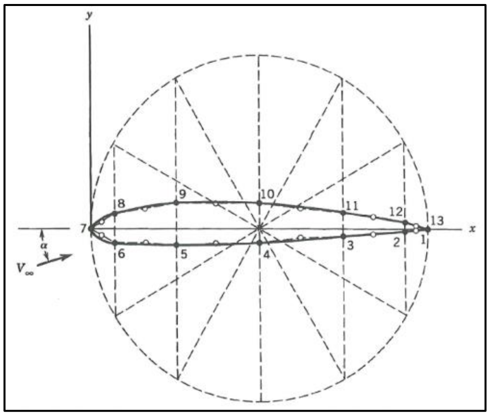

Figure 1: Cosine spacing on x-axis for 12-panel model.

b. vortext_panel_method

The function "vortext_panel_method" accepts three parameters: *naca4*, *aoa_deg*, and *fig*. The following is a brief description of each parameter and their use case.

naca4: A struct that represents the airfoil to be simulated. The output of "naca4digits" is a struct that contains all members required of the *naca4* parameter. The necessary members of the parameter are a body definition in (*x/c, y/c)* coordinates, the number of panels, and the x intercept from the cosine spacing.

aoa_deg: A double representing the angle of attack to be evaluated in degrees. AoA is converted into radians immediately after the function is run. All results from the VPM are unique to the specific *naca4* and *aoa_deg* definitions.

fig: An int representing which figure to plot the coefficient of pressure (Cp) vs AoA curve. If *fig* is -1 or undefined the function will not plot the curve.

IV. Kuethe Chow Implementation

V. Results

VI. Conclusions

VII. Appendix