A NEW DIRECT VISCIOUS-INVISCID INTERACTION METHOD FOR AERODYNAMICS ANALYSIS

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In the name of Allah, the Most Merciful, and the Most Beneficent, I am grateful to Allah who gave me the strength to finish this thesis and granted me success in this long-time effort.

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Lastly, I offer my regards and blessings to all of those who supported me in all the way during the completion of this thesis.
ABSTRACT

In manner the way how to solve the flow problem past through a streamlined body such as airfoil, the present work introduce the combination of the method for solving the Euler equation and the method for solving the boundary layers equation. Such approach is known as the direct viscous–inviscid interaction (DVII) method. The Euler equation is solved by use of finite volume method based on Roe’s cell center Scheme while the Boundary layer equation is solved by use of the Keller Box method. Firstly the flow problem is solved which the whole flow domain is governed by the Euler equation. As the pressure distribution as the result of Euler solver obtained, then, it used as input for solving boundary layer equation according the Keller Box Scheme. The boundary layer solution beside provide the skin friction distribution along the body surface is also providing the boundary layer displacement thickness $\delta^*$. This quantity describes the displacement of stream line due to the viscous effects. Through displacement thickness, modifying geometry is carried out, to allow recalculation by using Euler solver can be done. As the pressure distribution based on new geometry is obtained, and then it is used for solving the boundary layer equation. This calculation is carried out for several times until a prescribed convergence criterion is fulfilled. The computer code based on these two approaches are developed and used for airfoil aerodynamics analysis. Comparison result between the developed computer code with the available experimental result and Xfoil software for the case of flow past through airfoil NACA 0012 and RAE 2822 at various flow condition confirm that the present computer code had been developed successfully. Finally, present study found that the DVII method is only compatible for low and medium Mach number, $M \leq 0.8$, where at higher Mach number, DVII method is breakdown due to solution not converge in inviscid solution. However, the convergence determination of global iteration should be included in current study in order to systemize entire computation and it is highly recommended for future.
Dalam rangka untuk menyelesaikan masalah aliran yang melalui sebuah badan aliran seperti aerofoil, kajian ini mempergunakan gabungan kaedah untuk menyelesaikan persamaan Euler dan kaedah untuk menyelesaikan persamaan lapisan sempadan. Pendekatan ini dikenali sebagai kaedah hubungan aliran likat dan tidak likat. Persamaan Euler diselesaikan dengan menggunakan kaedah isipadu terhingga berdasarkan skim titik tengah sel Roe manakala persamaan lapisan sempadan diselesaikan dengan menggunakan kaedah Keller Box. Pertamanya masalah aliran itu diselesaikan yang domain aliran keseluruhan oleh persamaan Euler. Setelah taburan tekanan diperolehi, maka, ia digunakan sebagai input untuk menyelesaikan persamaan lapisan sempadan mengikut skim Keller Box. Penyelesaian lapisan sempadan memberikan pengagihan geseran permukaan sepanjang permukaan badan juga menyediakan sempadan lapisan anjakan ketebalan δ*. Kuantiti ini menerangkan anjakan garis arus kerana kesan likat. Melalui ketedahan anjakan ini pengubahana geometri adalah menjalankan, untuk membolehkan pengiraan semula dengan menggunakan Euler. Setelah taburan tekanan berdasarkan geometri baru diperolehi, maka ia digunakan untuk menyelesaikan persamaan lapisan sempadan. Pengiraan ini dijalankan untuk beberapa kali sehingga mencapai kriteria yang ditetapkan Kod komputer yang berdasarkan dua pendekatan dibangunkan dan digunakan untuk analisis aerodinamik aerofoil. hasil perbandingan antara kod yang dibangunkan komputer dengan keputusan eksperimen yang ada dan juga perisian Xfoil bagi kes aliran melalui aerofoil NACA 0012 dan RAE 2822 dalam pelbagai keadaan aliran telah mengesahkan kod komputer ini telah dibangunkan dengan jayanya. keputusan umum analisis menunjukkan kebolehan yang besar dalam menyediakan ketepatan walaupun dalam had yang tertentu. Akhirnya, kajian mendapati kaedah ini hanya sesuai digunakan untuk kes Mach number rendah iaitu M ≤ 0.8, di mana pada Mach number yang lebih tinggi kaedah DVII mengalami kegagalan disebabkan penyelesaian yang tidak jitu oleh penyelesaian aliran tidak likat. Walaubagaimanapun, penentuan bagi kejituan lelaran bagi keseluruhan pengiraan sepatutnya digunakan didalam kajian ini bagi menjadikan kajian ini lebih sistematik, dan ini amatlah ditekan untuk kajian-kajian yang mendatang.
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<td>DVII</td>
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</tr>
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<td>MUSCL</td>
<td>Monotone Upstream Centred-Schemes</td>
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<td>KBM</td>
<td>Keller Box Method</td>
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<td>SBLI</td>
<td>Shock Boundary Layer Interaction</td>
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<td>TVD</td>
<td>Total Variation Deminishing</td>
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<td>IBL</td>
<td>Integral Boundary Layer</td>
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<tr>
<td>$D, d$</td>
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<tr>
<td>$c_f$</td>
<td>Friction coefficient</td>
</tr>
<tr>
<td>$\rho$</td>
<td>Density [kg/m$^3$]</td>
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<tr>
<td>$T$</td>
<td>Temperature [$^\circ$C]</td>
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\(u,v,w\) - Cartesian velocity component [m/s]

\(\psi\) - Stream function [m\(^2\)/s]

\(\Phi\) - Potential flow [m\(^2\)/s]

\(\Gamma\) - Shear stress [Pa]

\(\alpha\) - Angle of attack [°]

\(\Omega\) - Circulation [m\(^2\)/s]

\(H\) - Shape factor

\(Re\) - Reynolds number

\(\delta^*\) - Displacement thickness [m]

\(\delta\) - Boundary layer thickness [m]

\(\theta\) - Momentum Thickness [m]

\(K\) - Von Karman constant

\(\varepsilon\) - Eddy viscosity [m\(^2\)/s]

\(c\) - Speed of Sound [m/s]

\((O)^t\) - Order of magnitude

\(M\) - Mach number

\(C_p\) - Pressure coefficient

\(C_L\) - Lift coefficient

\(C_D\) - Drag coefficient

\(C_M\) - Moment coefficient

\(X_s\) - Incipient separation
$X_i$ - Transition location

\[ \frac{\partial}{\partial x} , \frac{\partial}{\partial y} , \frac{\partial}{\partial z} \] - Differential operator

\[ \int, \iint, \iiint \] - Integral operator

\[ \nabla \] - Laplace operator

\[ \Gamma \] - Transition coefficient

\[ \chi/c \] - Length in chordwise

\[ \xi \] - Horizontal in panel plane

\[ \eta \] - Vertical in panel plane

\[ \mu \] - Kinematic viscosity

\[ \nu \] - Viscosity

\[ \Omega \] - Finite spatial volume
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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Aerodynamic is a branch of Fluid dynamics study which is primarily focussed on designing of vehicle moving through air. Generally, in manner aerodynamic problems are solved one can use one of three following approaches, they are namely: (1) experimental aerodynamics, (2) Analytical/theoretical aerodynamics and (3) computational aerodynamics/ fluid dynamics. The governing equation of fluid (air) motion was well established since in the early 1800's when G.G. Stokes, in England, and M. Navier, in France, were derived independently that equations. To honour their works, the governing equation of fluid motion was named as the Navier Stokes equations. These equations describe how the velocity, pressure, p, temperature, T, and density, ρ of a moving fluid are related and represent the extensions of the Euler Equations in year 1757 by Leonhard Euler (Anderson and Wendt, 1995).

The Navier Stokes equations are included the viscosity in their mathematical model, meanwhile the Euler Equation as well as the Navier Stokes equation represent a set of coupled differential equations and could, in theory, be solved for a given flow problem by using methods from calculus. But, in practice, these equations are too difficult to solve analytically. The difference between these two types of governing equation of fluid motion is on the effects of viscosity.
Hirsch (2007) indicated if the Navier Stokes equations supplemented by empirical laws for the dependence of viscosity and thermal conductivity with other flow variables and by a constitutive law defining the nature of the fluid, it made the Navier Stokes equation represented the governing equation of fluid which able to capture whatever flow phenomena may appear in the flow field. Hence in solving flow problem, if it is possible ideally, through solve the Navier Stokes equations directly, since theoretical approach is basically solve the flow problem through a simplifying to the Navier Stokes equation for producing a simple flow model. As results the theoretical approach is used just to provide insights in which aerodynamicists can use it as a basis in developing aerodynamic concepts and understanding experimental results. Such conditions made at the early time of the aircraft industries solved their aerodynamics problems met in their aircraft design program carried out experimentally by use of wind tunnel.

However as the era of computer begun, especially when computer manufacture IBM introduced IBM system 360 in the year of 1964 which allowing customers to consolidate all of their data and applications onto a single system, had given a significant change in the way of aerodynamicists solved the aerodynamics problems. Before that year, the way how the aerodynamics problems were solved through further approximations and simplifications to the governing equations of motion until these equations had a group of equations which could be solved, or through the use of a “thin” boundary condition assumption as well as body geometry resulted the manner how to solve the flow problems developed based on a thin airfoil theory, lifting line theory, lifting surface theory and small-disturbance theory or boundary layer concepts (Mason, 2009). For the case of external flow problems, the availability computing machine, had made the flow problem in hand belong to the class of inviscid and irrotational flow problem which allowing the Panel method can be applied to solve it with no limitation to the geometry of the body immersed in the flow field. Smith and Hess, (1962) may represent the first person in this work. The beauty of the Panel is in the way how to solve the flow problem through transforming from the flow field solution to the body surface solution.

Strictly speaking, Panel methods are numerical schemes for solving (the Prandtl-Glauert equation) for linear, inviscid, irrotational flow about aircraft flying at subsonic or supersonic speeds. According to Ballman, Eppler, and Hackbush, (1987), there are fundamental analytic solutions to the Prandtl-Glauert equation known as
source, doublet, and vorticity singularities. Panel methods are based on the principle of superimposing surface distributions of these singularities over small quadrilateral portions, called panels, of the body surface, or to some approximation to the body surface. The resulting distribution of superimposed singularities automatically satisfies the Prandtl-Glauert equation. To make the solution correspond to the desired geometry, boundary conditions are imposed at discrete points of the panels. In this respect, one can develop various numerical scheme applied to the Panel method. The panel method which may apply only source, doublet, vortex or combination among of them are distributed over a flat or curvature panel. Since Hess Smith panel method which use a varying strength of source between panel and a constant vortex over the whole panel, there are other panel method had been developed such as Macaero by MacDouglas Aircraft Company, Pmarch by NASA, and Panair by Boeing Aircraft Industry.

The success of Panel Method in solving the Aerodynamic problems especially in subsonic flow problem and in line with powerful computing machine becoming more available, had driven researchers around world to develop other method in solving the flow problem were not rely on Prandtl–Glauert equation but at higher level of that. A variety of techniques like finite difference, finite volume, finite element, and spectral methods are used for solving the governing equations of fluid motion. This area of study creates a new branch of science is called Computational Fluid Dynamics or CFD. The governing equation of fluid motion can be set a hierarchal with the three dimensional unsteady of full Navier Stokes which represents the highest level of governing equation of fluid motion, in which all flow phenomena may exist in the flow field can be captured by this equation. Unfortunately to solve this equation require a formidable computing power and only possible for solving the flow problem over a complete aircraft configuration based on technology computing machine in very long period (Anderson and Wendt, 1995).

The second level of the governing equation of fluid motion is called the Reynolds-averaged Navier–Stokes equations. Here turbulent flows may be simulated by the Reynolds equations, in which statistical averages are used to describe details of the turbulence. Closure requires the development of turbulence models, which tend to be adequate for the particular and rather restrictive classes of flow for which empirical correlations are available, but which may not be currently capable of reliably predicting behaviour of the more complex flows that are generally of interest.
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