Abstract

In engineering education, presentations based on visual object are very important as well as audio presentations. Therefore, one of the ways to teach the quantity and the quality of and physical phenomena is demonstrations through experiments. However, experimental methods need always expensive devices and use of them is not so easy. Furthermore, a class often has to be taken into the laboratory, since the experimental devices are generally difficult to transport into the class. Since sixties, by the development of the numerical methods and also the computers, several numerical analysis methods have been developed in aerodynamics as well as many disciplines of physics. Due to developing computer programming languages high speed solutions are possible by programming these methods. Also, it is easily possible to conduct pre-process and post-process stage of the numerical methods by using interfaces, to create graphics and other visual object from the numerical results, and to make animations. Due to developed projection systems and powerful personnel computers it is possible to do all the calculations, pre- and post-process in the class. In the recent years, we developed several Visual Basic programs in the frame of aerodynamics and related courses and used in the education. In this paper some of these programs will be presented briefly.

1. Introduction

Experimental techniques have been used widely in aircraft developments and also in aerodynamics education since the beginning of the modern aeronautics. For the educational purposes many experimental devices have been planted in the laboratories at the universities. These experimental setups have been used sometimes in the courses particularly designed for the aerodynamic experiments, or, sometimes demonstrational experiments are done when needed during the aerodynamics courses. Detailed information about typical aerodynamic experiments, experimental devices and techniques can be found in valuable text books [1-4].

In the course of time the films taken during experiments were used for demonstrational purposes instead to do directly the experiments in the classes, since they are expensive and difficult to operate generally. Nowadays, these types of images are easily used as video clips through a PC-projection system in a class during an aerodynamic course.

Many demonstrational experiments in aerodynamics use flow visualization techniques to make the flow field visible. In the low speed regimes, tuft, smoke, and oil methods are used for flow visualizations. In high speed regimes optical techniques and heat sensitive paints are preferred. [5-6] Today, it is easily possible to edit the images taken from the demonstrational experiments by using any photo shop software, and use them any time during an aerodynamic course.

During a century of aeronautics, theoretical methods in aerodynamics have been also developed in parallel to the experimental techniques. With the advent of the powerful computers in nineteen sixties numerical simulation
techniques for fluid flows have been developed quickly. Today, by using several numerical techniques to resolve the mathematical models at different levels of aerodynamic flows in powerful PCs, it is possible to simulate most of the airflows quickly in the class and to show the results to the students immediately with graphical outputs, or animations.

The author of this paper have been witnessed all the experience mentioned above in the last four decades during the aerodynamic courses. He followed the experiments in a separate course as a student; he conducted experiments in a unique course and also inside of his aerodynamic courses. He used aerodynamic demonstration films with projection devices, and video clips in PCs. In the last decade he has begun to develop codes to simulate several aerodynamic flows. In this paper some examples of them are presented.

2. Aims of the Basic Aerodynamics Education

The basic problems of aerodynamics can be described generally as (i) to analyze the aerodynamic performance (such as lift and drag forces, pitching moment, etc.) of an aircraft (or any aircraft component) through air in the atmosphere, and/or, (ii) to design an aircraft (or its component) to give desired performances.

In the past, the aerodynamic analysis and design works were usually based on experiments conducted on the small models of the aircraft or component in a wind tunnel or a prototype of the airplane in flight. Nowadays, however, mostly theoretical and numerical techniques are preferred at the beginning of the aircraft designs and developments then the experimental works are done when it is necessary.

In this perspective, the aims of the basic aerodynamics education are threefold: (i) to make understand the students the physics of several types of aerodynamic flows, (ii) to present the mathematical models of different levels for different flow types obtained from the basic governing equations, and, (iii) to show the available analytical solutions for special cases and also numerical solution techniques for low level mathematical models to be used conceptual and initial design stages of the aircraft design.

For these purposes it is common to divide the basic aerodynamics education into two or three parts as: (i) non-viscous incompressible (low speed) aerodynamics, (ii) non-viscous compressible (high speed) aerodynamics, and, (iii) boundary layer theory. Each of them is educated generally in a one-semester course.

Any aircraft or its component commonly forwards with a high speed (with respect to other vehicles such as car, train, ship etc.) in the air. If any aerodynamic investigation is conducted in a frame fixed to earth, this phenomena is time-dependent, making the mathematical model difficult to resolve. Therefore, the aerodynamic investigations are generally done in an aircraft fixed frame to make the phenomena time-independent. In the aircraft axes, a uniform parallel flow oriented to the aircraft exists in the infinity, and this flow is disturbed near the aircraft.

One of the basic subjects have to be understood clearly by the students is the flow regime; say, subsonic, transonic or supersonic. The flow regime is characterized by Mach number, the ratio between the flight speed of the aircraft (or component) and the ambient speed of sound. This problem will be investigated as a first example in the following section.

Another subject is the viscosity of the air. Where and which extend this effect is important, and also, what would be occurred when the viscosity was not existed? The answers of these questions may be given by describing quickly the real flow around a flat plate, around an airfoil then comparing the results obtained by a non-viscous mathematical model with experimental results. This comparison shows that the viscosity has usually a secondary effect on the flow and the primary effects are due to the existence of the airfoil in the flow.

The next subject is to understand the effects of the existence of any body in a uniform-parallel flow. In order to make clear this subject the flow is generally assumed non-viscous, i.e. potential. For this type of flows in low speed regime the mathematical model is rather simple one, the Laplace equation. The second example of the following section about simulations is based on the solution of this equation around an analytical airfoil, Joukowsky airfoil.

For the classical wings with large aspect ratios, the main difference from the infinite wing (airfoil) is the trailing vortices and wing tip vortices. To show these vortices to the students, some pictures and/or video clips obtained through flow visualization experiments in wind tunnel or in flight may be useful. Or, some simulations can be developed based on Prandtl’s lifting line model or vortex lattice methods. With this type of codes quick calculation of the pressure distribution around any wing having an arbitrary planform and airfoil shape, in the frame of the potential flow theory is possible, and the results can be shown by the graphic interfaces.
Compressible aerodynamics deal with the high speed subsonic, transonic and supersonic flows. Compressibility effects for high speed subsonic flows can be shown simply by applying well-known compressibility correction methods to the flows around airfoils and by comparing the results with incompressible ones.

Among the several flow regimes, transonic flow is the most difficult case to resolve mathematically, since the flow field contains both the subsonic and supersonic flow regions. Quick analytical solutions are very rare, while the numerical solutions are time-consuming. Therefore some pictures and/or video clips obtained flow visualization experiments around airfoils and/or animations created with the numerical solutions can be used to present the transonic flows to the students.

Supersonic flows are generally interested in for the flows around aircraft bodies, wings and airfoils and for the flows in channels such as turbine motors and wind tunnels. In these flows the most important phenomena are shock and expansion waves. The last examples of simulation are given in this flow.

3. Example Simulations for Aerodynamics Education

Although many simulation codes are developed by the author in the recent years, only a few of them are presented here as examples.

3.1. Simulation for Flow Regimes

An aircraft in flight disturbs the air particles around it. These disturbances emanating from all surface points of the aircraft are spherical weak pressure waves and propagate with the speed of sound. To understand the effect of the flight speed on this propagation phenomenon it is better to investigate the propagation of pressure waves generating from a singular point source of disturbance. If ambient air is immobile the pressure waves are all concentric as shown in Fig. 1a and propagate with same speed in all directions. If the air is flowing from left to right with a uniform subsonic speed, the pressure waves are forced to propagate to the left direction then right as shown in Fig. 1b. If the air speed is equal to the speed of sound the pressure waves propagating normally with the speed of sound are not able to advance in the left direction as in Fig. 1c. In this case the point source of distribution and all the pressure wave fronts are coincide and combining weak pressure waves create a strong pressure wave in the ahead of source point. Finally, if the ambient air speed is higher then the speed of sound, all the pressure waves are stand inside a conical region behind of the point source of distribution as shown in Fig. 1d. To simulate this phenomenon a vBasic program, MacReg, is developed. Number of waves, speed of frames and Mach number can be changed continuously through the interface of the code shown in Fig. 1 e.
3.2. Two-Dimensional Potential Flow Simulations

The effect of any body in low speed air flow is primarily due to the existence of the body, as mentioned above. This effect can be understood easily through the potential flow simulations. The Laplace equation, mathematical model for low speed potential flows, is a linear partial differential equation and its several solutions can be obtained by superposing its simple solutions. IdealFlow program developed for this purpose calculates the value of stream function at all the flow field points by superposing the uniform flow, sources, vortices and doublets with given locations, directions and strengths by the user, then paints with assigned colors depending on the value of stream function at each point. In Fig. 2, superposition of 9 sources (and sinks) with a uniform flow to simulate the symmetrical flow around an airfoil is shown, as an example.

![Fig. 2. Superposition of basic solutions of Laplace equation](image)

In order to show the effects of an airfoil in a uniform flow, and also importance of its geometrical parameters such as thickness, camber and angle of attack, an easy way is to utilize the analytical solutions obtained by conformal mapping techniques. The present author developed an iterative method to design Karman-Trefftz and Joukowsy airfoils of desired geometrical characteristics. [7] He developed also several codes based on this method to illustrate the typical pressure (and velocity) distributions, lift and pitching moment characteristics of airfoils, change of these characteristics with thickness, camber and angle of attack, and to show streamlines around them. One of these codes given in Fig. 3 shows all the aerodynamic characteristic of a Joukowsky airfoil. The airfoil can be changed easily and continuously through the scroll bars on the interface to see the changes in the characteristics.

Another example of these codes animating the streamlines around Joukowsky airfoils is given in Fig. 4. Again, the airfoil is changed by the scroll bars to see also the well-known Kutta condition.

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3.3. Simulations for Subsonic Compressibility Effects

Compressibility effects on pressure distribution around an airfoil simulated by Prandtl-Glauert correction method can be shown through the interface given in Fig. 3, by changing the Mach number.

![Fig. 3. Interface of IdealFlow program](image)
3.3. High Speed Flow Simulations

For the high speed regimes two examples are given here: the one is for internal flow in a convergent-divergent channel and the other is external supersonic flow around an airfoil.

Fig. 3. Characteristics of a Joukowsky airfoil

Fig. 4. Streamlines around Joukowsky airfoils
In the first example shown in Fig. 5a, the flow in a convergent-divergent channel is simulated for any chosen exit Mach number, and the ratio between the pressures in the entrance and exit sections can be changed continuously. Thus, the changes in the distributions of Mach number and the pressure ratio along the channel axis due to the changes in exit pressure can be illustrated. After a certain value of the exit pressure, a normal shock wave occurs at the throat section, and this wave moves towards the exit section with decreasing exit pressures. After a certain values of the exit pressure, at the corners of the exit section, an oblique shock wave takes the normal shock’s place, and then this also disappears and expansion waves occur at the same point.

The last example given in Fig. 5b simulates the supersonic flow around a diamond type airfoil of given thickness ratio \( \frac{t}{c} \), corner point location \( \frac{a}{c} \), and for a Mach number \( M \), and angle of attack \( \alpha \). The code predicts first which kind of waves (oblique shock or expansion wave) occur at the upper and lower sides of the leading and trailing edges and the upper and lower corner points then calculates all the flow parameters behind these waves, finally drag and lift coefficients of the airfoil. The results are given in the list. This code calculates and draws also the drag and lift coefficients for changing angle of attack, for changing Mach number, for changing corner point location or for changing thickness ratio.

4. Conclusion

Aerodynamic flow simulation codes are developed by the author in recent years and used extensively in the aerodynamic courses to teach the students the physical mechanisms in different flow regimes. Some of these codes can also be used for the quick calculations in aerodynamic analysis and design problems. Only a few specific examples of these simulation codes are given in this paper.
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