White Paper

Easy Access to Validated Aerospace Estimation Methods

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VGK: an Example from Transonic Aerodynamics

Abstract

A transonic-aerofoil prediction code (VGK) is chosen as an example of a fully validated engineering design method, enhanced by the provision of user-friendly interfaces. Developments of the basic code allow direct application to a variety of engineering problems. These include its use to estimate the effect of simple flaps, to estimate separation boundaries, to design an aerofoil profile for a specified pressure distribution and to estimate additional drag due to excrescences. Versions of the program are also being developed to allow rapid specification of the surface finish of wind-tunnel models and optimum transition-band roughness height for wind-tunnel testing.

Introduction

Most large aerospace manufacturers employ sophisticated, in house, computer-based estimation methods for critical engineering design disciplines such as structures, aerodynamics, stability and control etc. Such methods are invaluable but their use must be tempered with a sound understanding of their limits of applicability and their precise role in the design process. This understanding is often founded on corporate experience, which must be imparted to new practitioners. It is also necessary for such practitioners to appreciate that the choice of a suitable tool at a particular point in the design cycle is constrained by economic as well as purely technical considerations.

In the aerodynamic design of an aircraft, for example, theoretically based computational fluid dynamics (CFD) methods may not provide sufficiently accurate prediction of absolute drag values, or may fail when extensive separations are present. Recourse must then be made to wind-tunnel testing. Such testing is extremely costly if carried out in a large scale tunnel, such as the European Transonic Wind Tunnel[1], which is capable of reproducing flows at something approaching full-scale conditions. Thus, in order to avoid undue economic risk, a design must be at a mature stage before such testing is undertaken.

Very sophisticated estimation methods are inappropriate for preliminary design and for minor modifications to existing designs. In such cases quick estimation methods are required, which are easily used and well calibrated. In most aerodynamics offices, the ubiquitous "Hoerner"[2, 3] volumes on aerodynamic drag and lift and databases of aerofoil and body aerodynamic characteristics are still the sources most often used for quick estimation at the lowest level. At a higher level, two dimensional aerofoil estimation programs, of the type discussed here, are more economical to run than three-dimensional CFD codes with turbulence modelling and, for flows near the operating point, where there are no significant areas of flow separation, will provide better accuracy. This makes them particularly useful in the design of aerofoil sections suitable for use in a wing of high aspect ratio, such as those employed on transport aircraft.

The Engineering Sciences Data Unit (ESDU) was founded in the United Kingdom in 1940 to cater for a rapidly expanding aircraft industry by collating design methods and data used in industry in a form which would be readily accessible and which would be both validated by specialist technical committees and frequently updated. Since that time 1350 Data Item have been published. These Data Items encapsulate design methods and experience from a wide variety of sources and many include fully developed and calibrated computer-based prediction methods.
One of these is a two-dimensional aerofoil prediction method of the type referred to above. This code, the Viscous Garabedian and Korn method (VGK) is a widely used program and has been developed by ESDU into a user friendly aerofoil design tool. The development of the latest user interface is described here, together with other developments, undertaken at ESDU, to enhance the versatility of the method when applied to a variety of problems. VGK is taken as a single example among a number of such methods.

THE VGK METHOD

The VGK method[4] uses a finite-difference scheme to solve the potential (inviscid) flow equations around an aerofoil in a compressible, subsonic free stream. This solution may optionally be coupled with an integral boundary layer[5] method, which models the flow in the layer of air immediately adjacent to the aerofoil surface, where viscous effects are important. Although solutions are restricted to a subsonic free-stream, the method will produce successful solutions where there are patches of locally supersonic flow, terminating in a shock wave (Figure 1) (i.e. it will deal with the design of transonic aerofoil sections).

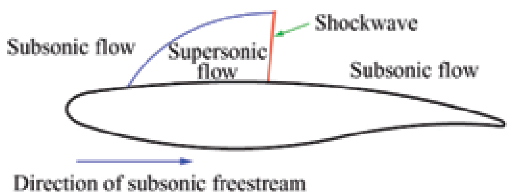

Figure 1. Shock wave and areas of subsonic and supersonic flow on a transonic aerofoil (schematic)

The design of aerofoil sections for use at transonic speeds is difficult because the boundary layer can separate from the surface, producing a thick wake, either because of the sudden pressure rise through the shock wave or because of strong pressure gradients near the trailing edge, which are likely to occur on this type of section. When such extensive boundary-layer separation takes place, CFD models will not produce accurate solutions if, indeed they converge to a solution at all. VGK gives warning of likely problems by outputting values of local skin friction, since if this is locally small or zero, separation is likely to be immanent. Achievement of a successful design cannot be automated and relies heavily on a good understanding of the physical nature of the flow over the aerofoil. Such understanding is gained as a result of past experience and is greatly aided by expositions on aerofoil and wing design methods[6, 7], which facilitate the interpretation of evidence produced by such tools as VGK. VGK is particularly useful in the design-optimisation process in that it is economical to run, requiring a few seconds on a standard PC. It provides comprehensive output of parameters relating to the boundary layer and wake development, as well as the potential flow. It also predicts key design parameters, such as viscous and shock wave drag, with good accuracy. However, in its original form, data input was inconvenient, which made running a family of cases tedious.

INITIAL DEVELOPMENT OF VGK

VGKWORK.NAM
VGKWORK.VIN
VGKWORK.IEH
VGKWORK.VEH
VGKWORK.FUL
VGKWORK.BRF
VGKWORK.GRD
VGKWORK.UNF
1
VGKAFILE.DAT
1

2a*.NAM file

VGKWORK

2b *.SIR file

0 cast10b
160 0 0.5000 2.0000 0.00001.9001.0000.8000.250 0
01000 30 1 0.000001 100.00
1000 1
-1 1
100 1 0.5000 2.0000 0.00001.9001.0000.8000.250 1
1
1 1 0 160 1 1.00 0.00000 0 0.0000 0.5000
1 -1
200 1 0.5000 2.0000 0.00001.9001.0000.8000.250 1
1 1 0 161 1 1.00 0.00000 0 0.0000 0.5000
0 -1
0 0

(c) *.VIN file

Figure 2. VGK input files (excluding aerofoil coordinate file)

VGK is written in standard FORTRAN77 and, in its original form, preparation of the data file is a lengthy process, which is prone to error. Apart from the aerofoil coordinate data file, three input files are required, two specifying working file names and the third (*.VIN file) providing control data, input in a cryptic manner and requiring strict formatting (Figure 2).

Subsequent to the acquisition of rights to market VGK, a pre-processor program (VGCKON.exe) was written at ESDU to generate the three input files, shown in Figure 2, by the use of a simple intuitive dialogue, in which the user inputs a series of parameters, such as freestream Mach number, in free format. Default values are offered for a number of parameters peculiar to the method and required to ensure convergence of VGK, although the user can choose to override these. The facility is also provided to generate a series of input files from a single run of VGKCON. VGK outputs the *.BRF results file, which enables easy transfer of data into, for example, Excel. This allows pressure distributions to be assessed. More detailed results are output in the *.FUL file and include full details of boundary layer and wake data. Modifications were made to allow easier plotting of the solution grid than is possible with the original code.

The development of this improved user interface paved the way for the development of a number of special applications of VGK.

Following these developments, a need became apparent for a simpler interface providing direct graphical output, to enable rapid evaluation of the effects of parameters in a "what if" design development scenario. This led to the development of the Windows interface to the basic program.

WINDOWS VERSION OF VGK

The Windows version of VGK was written using Winteracter©, a package specifically designed to port FORTRAN programs into a Windows environment. The primary aim was to provide an intuitive GUI to facilitate the input of data to VGK and to provide instant graphical output
of a large range of parameters allowing rapid evaluation of results.

Figures 3a-c show the main user interface windows used to input data. At any time during a session, any of the specified data can be modified. It is also possible to save the program status for resumption in a subsequent run.

Figure 3a shows the initial input window for the main flow parameters, such as Mach number, Reynolds number, incidence and transition location.

Figure 3b shows the input window for parameters governing features such as calculation convergence. Default values are initially displayed and these will only require alteration in rare cases for which guidance is given in the reference document[4].

Figure 3c shows a third input panel, superimposed on the main program window in which the aerofoil profile is plotted. This window allows rapid alterations of Mach number and incidence to be input, facilitating the investigation of the effect of these parameters in a particular case.

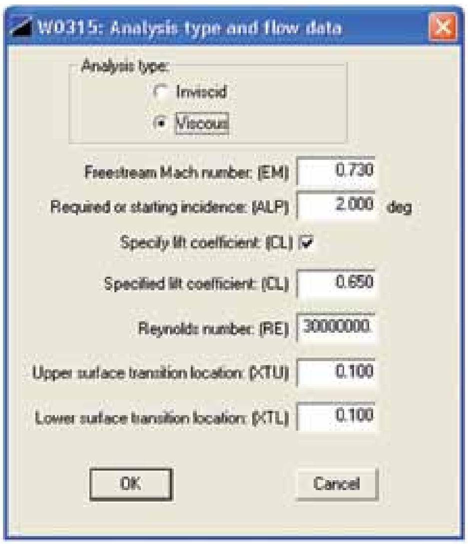

Figure 3a. VGK for Windows: Data Input, Main Parameters

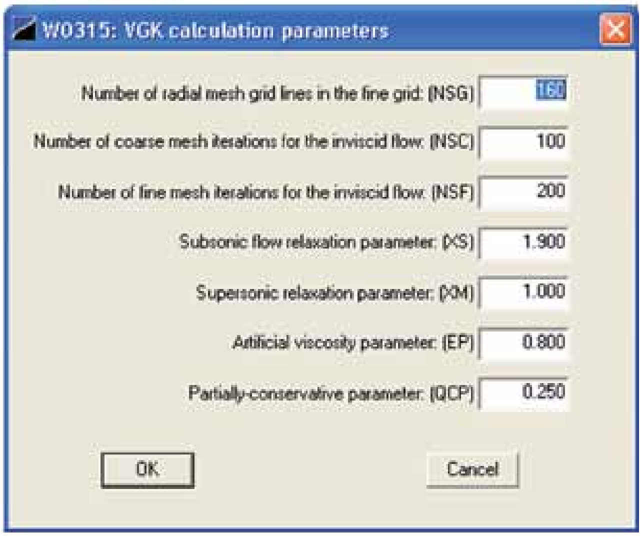

Figure 3b. VGK calculation parameters (default values shown)

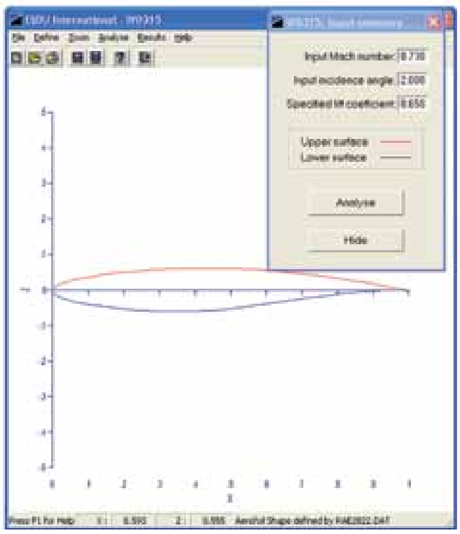

Figure 3c. Plot of aerofoil profile and Mach number/incidence

VGK for Windows outputs the standard results files described in Section 3. To facilitate user interaction with the program, this is supplemented by an on-screen display of the basic results (Figure 4a), together with selectable graphical displays of a number of parameters such as chordwise pressure distribution (Figure 4b) and boundary-layer and wake data (Figure 4c). The ease with which input data may be changed and the readily available graphical output facilitate rapid user interaction with the program.

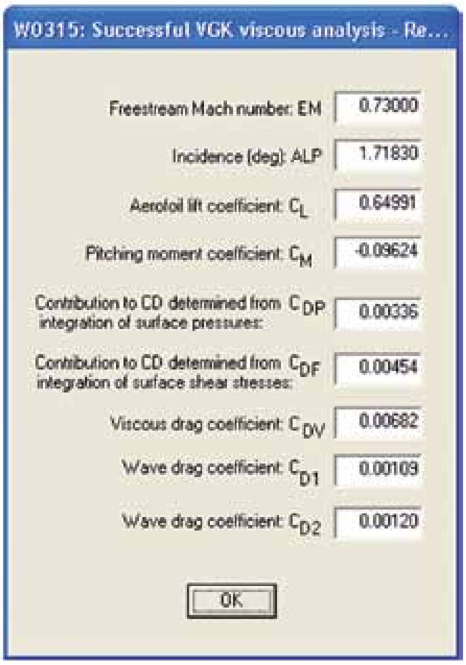

Figure 4a. VGK for Windows: Typical Output, Summary of results distribution

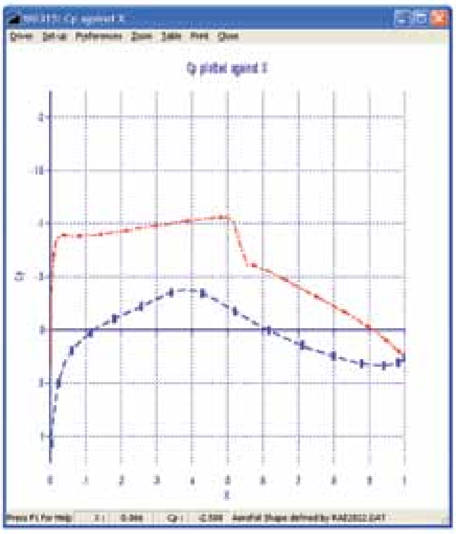

Figure 4b. Graphical output-surface pressure

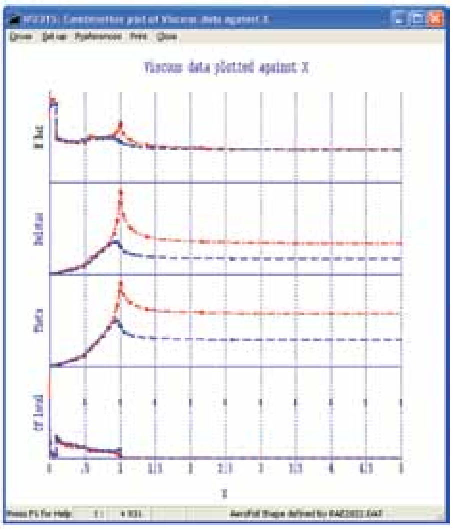

Figure 4c. Graphical output-boundary-layer and wake data

DEVELOPMENT OF SPECIAL APPLICATIONS

Following the development of the initial command- window interface, based on VGKCON.exe. It was realised that the comprehensive flow data output by the program and available both in the external flow and within the boundary layer, permitted application to problems apart from the flow at given conditions, over simple aerofoil geometries. Applications currently issued[4], or under development[8, 9], are:

a) Aerofoils with simple hinged flaps.

b) Design of an aerofoil to a specified upper-surface pressure distribution.

c) Estimation of separation boundary in transonic flow.

d) Calculation of excrescence drag.

e) Estimation of maximum permissible surface roughness for wind-tunnel models8.

f) Estimation of transition strip height required for wind-tunnel tests[9].

For (a) to (d) above, additional free-standing programs are provided which are coupled to VGK by the use of suitable BATCH programs. For example, in (a), a program is supplied, which generates aerofoil-coordinate data files for a specified aerofoil with a given flap deflection.

The BATCH program then allows a series of cases to be run with minimal user intervention.

Figure 5 shows typical output from the “flap version” of VGK (VGKF) for an RAE 2822 aerofoil operating at constant freestream Mach number (M_{∞}), Reynolds number (R) and angle of attack (a) compared with wind tunnel results.

The second application, (b), enables an upper surface pressure distribution to be specified and VGK will then run with successively modified aerofoil geometries until this distribution is achieved to a specified accuracy.

Applications (c) to (f) above rely on the output of detailed boundary-layer information from VGK and similarly require additional calculation to be made, dependent on the particular application. This generally involves multiple runs of VGK and, for (c) and (d), BATCH files are provided to automate the task.

Applications (e) and (f) are more recent developments and are concerned with the production and testing of wind-tunnel models and will form part of the ESDU documentation currently being produced on wind-tunnel testing. BATCH files for these applications are not yet available. However, Excel based methods have been used as a development tool for these applications and it is anticipated that final versions be issued soon.

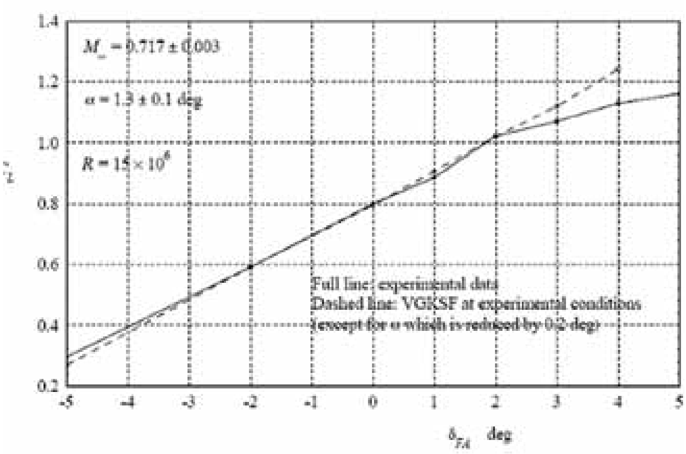

Figure 5. Typical data obtained from VGKF (the "flap version" of VGK) showing the variation of lift coefficient (CL) with flap deflection (dFA) for an RAE 2822 aerofoil

VGK DOCUMENTATION

In common with all ESDU products, VGK is documented fully. The principles on which the method is based are described in detail in an introductory item and the method is calibrated against available data from a variety of sources. Each version of the program is fully documented and advice given to the user on possible modifications to default parameters which may be used to deal with unusual cases, such as difficulty in producing convergence in a run. Throughout, the limits of applicability of the method are clearly stated and guidance is given to enable results to be interpreted usefully in a practical engineering context.

CONCLUSION

The VGK transonic aerofoil method is an example of an engineering design tool which is well validated and robust. The provision of user-friendly interfaces has transformed the basic program into one which can be used rapidly to explore the effect of changes in input parameters. It has also led to the successful and easy application of the code to a number of related engineering problems.

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