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INTRODUCTION

In October 1966 the AGARD Fluid Dynamics Panel published the **AGARDograph 109** on the subject of "WIND TUNNEL WALL CORRECTIONS". This comprehensive compilation of knowledge of wall corrections available at that time was edited by J. Garner (National Physical Laboratory, England) with contributions from E.W.E. Rogers, W.E.A. Acum also of NPL and E.C. Maskell (Royal Aircraft Establishment, England). Without doubt this AGARDograph 109 has been one of the most successful publications of AGARD and is still today the wind tunnel engineers most authoritative source of wall correction methods and data.

The wall correction methods outlined in AGARDograph 109 are based on subsonic linear and inviscid aerodynamics. In most cases the wall effects are correlated with the measured total aerodynamic forces and simple image methods are used to calculate and correct for the wall effects. Most of these theories were published before 1950 and some appeared as early as the 1920's.

By the time of AGARDograph 109 the computer had not had a significant impact on the calculation of wall interference corrections. Computers had begun to be used for reducing raw wind tunnel data to dimensionless coefficients and for applying simple wall corrections. However, the wall correction methods themselves had not been influenced to any degree by advances in computer technology.

Typical wind tunnel engineers are normally experimentally-minded people who are not really enthusiastic about computational fluid dynamics. A consequence of this is that the adoption of computational methods in practical wall correction schemes has been slow. Routine correction methods, such as those formulated by pioneers such as Prandtl, Glauert, Durand, Goethert, Riegels and Maskell have remained in use even in large high quality wind tunnels in the thirty years since these and other methods were described in AGARDograph 109. Nevertheless, during this period of large amount of theoretical and experimental studies of wind tunnel wall interference were done and these developments have been influenced by the rapid improvements that have been made in computing speed and power. Computer based methods that have been developed include :

1) *Panel Methods*

These methods have made it possible to represent more accurately than linearised theory methods subcritical flows over complex model configurations in the constraining presence of the tunnel walls. Panel methods have also permitted wind tunnels with working sections of relatively small and/or non-standard cross sections (not amenable to treatment by classical image methods) to be modelled. These methods require considerable computing power and for this reason have not yet found wide favour with the wind tunnel testing community. Further discussions of methods of this type will be found in Chapters 2 and 3.

2) *Boundary-measurement methods*

These methods were developed to exploit information available from measurements of the flow at or near the tunnel walls. The general technique is not entirely new, as can be seen in AGARDograph 109, where reference is made to the use of wall pressure measurements to determine the blockage correction in solid-wall wind tunnels. The serious application of these techniques became possible by the development of computers during the '60s and '70s which enabled wall interference velocities to be computed from a large number of flow measurements. Methods of this type can be used to aid the modelling of the flow in the near region of the model for solid wall wind tunnels, for which the wall corrections are critically dependent on the model representation. For perforated or slotted wall wind tunnels, they can be used to provide information on the wall boundary conditions where suitable model representation is available.

Finally, where both normal and streamwise velocity components are measured at the bounding surface, no model representation is needed. These methods and examples of their application are described in Chapter 4.

3) *Computational Fluid Dynamic (CFD) methods*

The current generation of boundary-measurement methods is based on the assumption that the wall-induced flow field satisfies the Prandtl-Glauert equation. However, for many types of transonic flows, particularly those for which the supercritical flow reaches the walls , this assumption is no longer valid. Recognition of this problem led to the use of CFD methods able to model transonic flows and these methods are discussed in Chapter 5.

The increased use of computational methods have arisen from a number of factors including :

1. the growing need for accuracy in wind tunnel testing mainly for commercial transport aircraft development.
2. the recognition that the ability to test at flight Reynolds Numbers in cryogenic wind tunnels, such as the National Transonic Facility at NASA, Langley Research Centre and the European Transonic Wind Tunnel at Cologne, is only valuable if the wall interference corrections can be estimated with sufficient accuracy.
3. the need to perform accurate wind tunnel assessment of CFD methods.

Several times in the past the complete breakthrough of Computational Fluid Dynamics was predicted with the automatic consequence, that the wind tunnel as a scientific tool in fluid dynamics will be obsolete. In this case, further work on wind tunnel wall corrections would be unnecessary.

Today most scientists and engineers working in the field of aerodynamic aeroplane development agree, that the mystery of turbulence guarantees a long life of wind tunnels as an indispensable tool in fluid dynamics. Neither the wind tunnel nor computational methods are able to create progress in aeroplane aerodynamics on their own. Only an intelligent combination of both tools enable the aerodynamicist to create a successful new aerodynamic design.

With these developments in mind the editor on the occasion of the Fluid Dynamics Panel Meeting at Turin in May 1992 proposed that a new AGARDograph on the subject of wind tunnel wall corrections should be produced not to supercede AGARDograph 109 but to complement it. This proposal was approved by AGARD, and during the Fluid Dynamics Symposium in October 1993 at Brussels on the subject of "Wall Interference, Support Interference and Flow Field Measurement" a small group of specialists met for a preliminary discussion. From this group an international team of authors was formed. The aim was to produce an AGARDograph which provides the wind tunnel engineer with a comprehensive review of modern methods, mainly reflecting the new developments in wind tunnel wall corrections since AGARDograph 109.

During the work leading to the AGARDograph 336 there was some controversy over the issue as how to correct data for buoyancy or pressure gradient effects. Chapter 1.2 presents a method due to Taylor. Effectively this method ignores the influence of the wind tunnel walls on the development of the boundary layer on the model and it yields the correction to drag coefficient

$$\delta C_D = -C_D \varepsilon$$

for low speed flow. For thin-wake flows Taylor has argued that the wake blockage component may be ignored so that the equation above may be replaced by :

$$\delta C_D = -C_D \varepsilon_S$$

where suffix S refers to solid blockage. This is in agreement with the classical result for low-speed flow given in AGARDograph 109.

Chapter 6 describes a method recently developed by Hackett [1], which gives a correction to drag coefficient

$$\delta C_D = -C_D \varepsilon_w$$

where suffix w refers to wake blockage. Hackett's method, like Taylor's method, is based on concepts valid for inviscid flow, although both can make use of information provided by wall pressures which sense the behaviour of the real flow. Hackett's method has been shown to be more accurate than the classical method or Taylors method for high blockage, high lift flows. However, neither method has been validated for flows in which viscous effects are significant but not severe enough to cause wholesale separation. Flows of this sort are of particular importance in aeronautical applications. The question of what needs to be done to resolve this issue is dealt with under the heading of "Future necessary work in Wall Corrections" by Steinle in Chapter 12. For more details on this wake drag controversy see also the detailed discussion between J.E. Hackett and several other authors of this AGARDograph in [2].

References

[1] Hackett, J.E., "Tunnel-Induced Gradients and their Effect on Drag", AIAA Journal, Vol. 34, No. 12, 1996, pp. 2575-2581.

[2] Discussion on [1] by J.E. Hackett, P.R. Ashill, C.R. Taylor, Kevin R. Cooper and M. Mokry, AIAA Journal, Vol. 36, No. 2, February 1998.