# LECTURE 2

## GENERAL WEAPON AERODYNAMICS

### 1 INTRODUCTION

In this lecture I propose to consider the main aerodynamic effects, coefficients and derivatives which are of importance in the design of weapons, and to indicate in broad terms some of the methods that may be used to estimate their values. It is not my intention to treat any particular aspect in depth, or to give a comprehensive set of equations that may be used. Other lectures in the course will deal with specific aerodynamic characteristics - for example, wing-body and wing-tail interference, base drag - and I will therefore be brief in discussing these topics.

As I have said in my first lecture, the job that a guided weapon is required to do usually dictates that its configuration is very different from that of an aircraft, particularly a commercial aircraft. It may be that, for a comparatively long-range weapon with a substantial period of cruising flight, a configuration like that of an aircraft is very suitable, and in that case aerodynamic design methods appropriate for aircraft may be used. In particular, it may be worth while to consider the design of suitable aerofoil sections for efficient flight. It must always be remembered however, that there is usually a strong incentive to keep the production costs of weapons as low as possible, so that a shape which requires many man-hours to produce will be unpopular with the project managers. For the great majority of weapons, the configuration will be of lower aspect ratio than for aircraft, and the shapes will be as simple as possible to permit ease and cheapness of production. For example, wings may have simple double-wedge or hexagonal sections, probably with a specified non-zero thickness at leading and trailing edges.

It is clear therefore that we will probably not be concerned with the fine details of aerodynamic behaviour, such as the threedimensional boundary layer over the wings. The accuracy required in the estimation - and measurement - of the aerodynamic characteristics of weapons can not be defined in general terms. It will be determined as a result of performance calculations, when the sensitivity of the performance to various changes to the aerodynamic coefficients and derivatives can be studied.

In the great body of experimental and theoretical work that has been built up over many years for application to aircraft design, two of the most useful simplifications have been the assumption of twodimensional flow in the design of lifting surfaces, and the restriction of angular attitudes to small values so that the assumption of linear perturbations may be justifiable. In the case of weapons, the great majority of designs are of small aspect ratio so that the usual two-dimensional assumptions are invalid. Also weapons usually attain angles of incidence, yaw and roll which are large enough to introduce non-linear variations of the aerodynamic characteristics. For example, one of the lecturers in this course will be dealing with forces and moments at incidence angles up to $90^{\circ}$.

Because of the characteristic shape of weapons, however, a variant of twodimensional theory, namely slender-body theory, does have considerable value in two respects: firstly, to provide a quick first estimate of some of the main aerodynamic characteristics such as normal force and pitching moment; and secondly, to provide a practicable theoretical approach to some of the more complex characteristics - for example, the forces and moments in non-uniform flow. The textbook "Missile Aerodynamics" by Nielsen[1] gives a detailed exposition of slender-body theory and many of its applications. Slender-body theory is essentially an inviscid theory and so does not cover the effects of flow separation which, on low aspect ratio shapes at large incidence angles, can be very significant. The theory is usually developed and applied with the further assumption of linear characteristics, but even within the bounds of potential flow this is not essential, and second-order effects also can be calculated. Non-linear effects due to viscosity, which are much more important than second-order potential flow effects, can not of course be calculated by slender-body theory, and have to be allowed for separately. A useful complementary volume to Ref 1 is "Missile Configuration Design"[2], by Chin, which deals with aerodynamics in a less rigorous fashion but includes other topics such as propulsion and structural design.

The importance of non-linear characteristics in weapon aerodynamics means that estimation methods for practical application should be checked by comparison with experimental results, and the latter analysed to provide empirical or semi-empirical modifications to theory. Wind tunnel test results on models of missile projects are usually restricted in their distribution because of their security classification. Moreover practical weapons may have features such as launcher lugs and aerials, which make generalised analysis suspect. There are however many sources of test results on generalised models, some of which are listed as References 3-23. Unfortunately this mass of useful experimental data has seldom been subjected to thorough analysis, and one feels that there is a rich mine of information waiting to be exploited. This is probably because the number of aerodynamicists working in the weapons field is comparatively small, and the demands of project design and development take priority over analytical research.

In the rest of the lecture, I shall take different aerodynamic coefficients and derivatives in turn, and consider their importance and methods of estimating their value. It is customary in weapons work to use a system of axes fixed with respect to the body. This may have two forms - a set in which the axes roll with the body and a set in which they do not. The x-axis in both systems coincides with the body axis. In the non-rolling system the z-axis is always in the incidence