THE MAGNETIC SUSPENSION OF WIND TUNNEL MODELS: THE PRINCIPLES AND APPLICATION TO DYNAMIC TESTING

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1. Introduction.

Most wind tunnel engineers will not be familiar with the technology associated with the magnetic levitation of the model. For this reason I felt that it would be useful to divide this lecture into two main parts. Some of the unfamiliar technology associated with levitation technology and the measurement of steady aerodynamic loads will be addressed first. The next part will cover some of the extensions of technology required for the measurement of unsteady aerodynamic loads, together with data examples.

The idea of suspending wind tunnel models by magnetism has several appealing features which are balanced, in the practical implementation of the idea, by several problems as will be seen. Appealing features include the important ones that the model can, in principle, be the same shape as the flight article, say an aircraft, without the usual modification of the exterior shape to accommodate supports. For example in conventional testing at higher airspeeds a support sting and the attendant modifications to the external shape of a model can be, respectively, quite large and extensive. The avoidance of mechanical supports also can be seen as a real advantage. A further advantage of magnetic suspension is that in principle the model may be suspended in any attitude or be induced to undertake any unsteady motion without mechanical restriction. It can be adapted, again in principle, to give modes of motion in all six degrees of freedom together or with any combination and all direct and indirect stability derivatives can be measured.

Notionally a magnetised model might be levitated by means of an array of permanent magnets repelling from below. However complete control in this way is impossible according to Earnshaw's theorem[1], but if one degree of freedom of motion of the model is stabilised in some other way then the model may be levitated by such a set of repelling permanent magnets as will be demonstrated. The levitated object will be seen to exhibit some limited control of motion in another four degrees of freedom, vertical and lateral translations and associated rotations. It will be seen also that the stiffness of support is positive but low in these four degrees of freedom and that the model will resonate about its mean position following displacement. The remaining motion, roll, is uncontrolled and motions in these five degrees of freedom are very lightly damped. The issues that therefore remain to be addressed by an improved levitation system include raising the stiffness and damping of the support and of providing the means to select the attitude of the model, incidence for example, and of adapting the hardware to simultaneously act as a force and moment balance.

The levitation of a magnetised model by means of magnetic fields of controlled strength allows most of these difficulties to be circumvented and was the technique universally adopted for wind tunnel testing. The model must contain a suitably shaped magnetic core which could be a permanent magnet, a soft magnetic core held well magnetised by an applied field, or a wire coil carrying an appropriate alternating or direct current. The test section of the wind tunnel is surrounded by an array of electromagnets which operate on the model, the number and designs of the electromagnet coils depending, among other things, on the desired number of degrees of freedom of model motion to be controlled. To illustrate this point, tests on an axi-symmetric model at zero incidence may be carried out with active control being exercised over just the three orthogonal translational degrees of freedom by means of suitable electro-magnets, provided that the model is stable in pitch and yaw, wind off and on.

Suspension systems have been used for serious aerodynamic testing with provision for control over three degrees of freedom of model motion as just touched upon, up to the full six degrees of freedom in other designs now including control over the three rotations. The speed range covered by the various designs between them ranged from low speeds up to Mach 16 excluding perhaps the transonic range. The latter omission was caused partly by the high dynamic pressures hence aerodynamic forces usual in such facilities and therefore high demands on electro-magnetic force and current, and partly by the perceived need in transonic tunnels to position the electro-magnets a distance away from the walls of the test section to provide room for a plenum chamber. This reduces the effectiveness of the electro-magnets and, for a specified duty, demands more power in what are already difficult circumstances.

This is a hint of the existence of a difficulty, namely that the provision of the required force and moment capability to resist aerodynamic loads is rather expensive and has only been realised in the designs of equipment for small wind tunnels. In this business a 1 foot, 30cm test section is quite large. The starting loads in some supersonic and hypersonic tunnels were particularly demanding of electrical power. It was early apparent that the cost of magnetic suspension and balance systems for testing models at Reynolds numbers approaching those of aircraft in flight was probably prohibitive. Other difficulties appeared to be the provision of propulsion flows, the actuation of flight controls and, because of the sizes of the electro-magnets, restricted access to the exterior sides of the walls of the test section. While solutions to these problems were not necessarily impossible they were surely going to be difficult and perhaps costly to implement.

The inadequate Reynolds number capability of the current generation of magnetic suspension tunnels was the reason for the invention[2,3] of the cryogenic wind tunnel. This was devised as a means to increase Reynolds number capability without increasing the size of the tunnel or