# THRUST VECTOR CONTROL

## 1. WHY T.V.C?

1.1. The methods of providing the controlling or disturbing moments have traditionally been by geometric changes (trailing edge flaps and controls, all moving surfaces) which alter the aerodynamic forces and particularly moments to achive the desired manoeuvre. The practice, started on aeroplanes, was carried over directly to guided missiles, both flap controls and all moving controls being most commonly used. The benefits and advantages of these methods are manifold, i.e.

(1) The control moment varies in a similar way with flight speed to stabilizing moment.

(2) All moving surfaces can be designed to require very small actuation power, due to the low hinge moments.

(3) Virtually no drag penalty is incurred by the controls, since invariably, the stabliser effect of the surface is already required.

(4) Minimum non linearity in the control moment slope due to incidence variation.

We have never been searchingly critical of the use of moving aerodynamic surfaces per control of missiles, since we have been conditioned from the start of initial training that this method is the one to use because they are always used on aeroplanes aren't they?

1.2. Consequently, first and most second generation guided missiles used moving surfaces for control: then, a critical appraisal began, which when coupled with less conventional requirements for missile performance, lead to the consideration of other fundamentally different ways of providing the control moment. For instance, if control is required at very low speed (low that is compared to the operating range of speeds, which are typically high transonic or supersonic), the aerodynamic surfaces can provide only a limited aerodynamic moment, due to the low dynamic pressure ($\frac{1}{2}\rho V^2$); therefore some alternative is required. Such an alternative would not have to rely on aerodynamic pressure for effectiveness at low speeds; one idea is to alter and control the direction of the thrust of the propulsion system. This is known as Thrust Vector Control (TVC):- whereas this is nothing new in space launchers and applications it is relatively new in missile work in the lower atmosphere. Since all missiles (or very nearly all) use rocket propulsion for at least some phase of flight, vectoring the rocket thrust is the preferred means of achieving control.

## 2. ADVANTAGES AND DISADVANTAGES

It would be worth outlining the advantages and disadvantages of a TVC system, which we would expect.

Firstly the advantages:-

(1) The control force and moment is dependent on the thrust of the rocket and deflection, and not on missile speed and altitude (hence dynamic pressure).

(2) Large control moments are available at low missile speeds compared with stabilising moments.

Secondly the disadvantages:-

(1) As missile speed increases (towards high dynamic pressure) the control moment becomes increasingly inadequate: without very careful control of the servo dynamic stability; the reason is mainly that the control moment is high due to the high rocket thrust/weight ratio. By implication, this means an acceleration or boost phase, whilst at high speed, further acceleration is not usually required or desirable. The thrust level must therefore be lower.

(2) Potentially higher actuation power required, since there is no possibility of aerodynamic balancing.

(3) Technical difficulties with moving nozzle designed, sealing, erosion - in the high efflux temperature environment.

(4) Roll control can only be achieved with a multinozzle arrangement.

Clearly, there are some disadvantages, but it is considered that for low speed use, especially, TVC offers a very powerful means of achieving high manoeuverability.

It is worth noting here that it is believed that effectivness at high missile speeds is limited, due to the large aerodynamic stabilising moments. Clearly it could be postulated that this difficulty could be overcome by careful configuration design, so that only a small stability margin is selected. This in effect means that the centre of pressure of the normal force must be near to the missile centre of gravity. Life is such with missiles that the centre of pressure moves with changing body incidence and Mach number, which means that if a small margin of stability is chosen at high incidence (when aerodynamic force is high), there is likely to be insufficient stability, even instability at lower incidences. Similarly the system can only be optimised at one speed. Selection of the configuration, therefore, requires some care, but on the credit side, since aerodynamic control surfaces are not required, the opportunity is offered of a small c.p. shift. The reason for this is that, whereas in a two aerodynamic surface design (fore and aft), the variation in downwash at the aft surface with incidence is large, causing a large c.p. movement, there is very little downwash effect (from the forebody vortices). Thus, the use of T.V.C. at high dynamic pressure (high speed and low altitude) implies contraints on the configuration and on the operating speed and incidence ranges.

## 3. METHODS OF VECTORING THE THRUST

We shall tacitly assume that the missile is propelled by a rocket motor, the nozzle of which is aligned with the missile longitudinal axis when no control force or moment is required.

The control side force, which acts at the nozzle is given, for small thrust deflections by T , and the control moment by $T\gamma l$, where

$T$ = rocket thrust
$\gamma$ = thrust deflection
$l$ = distance of nozzle from missile c.g.

Methods of altering the thrust direction fall into two main categories.

(1) those employing mechanical techniques
(2) those employing fluid dynamic techniques