International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Special Issue - AMET-2019

A Review of Aerodynamic Thrust Vector Control

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Abstract: Thrust vectoring nowadays has become an imminent technology which changes the way aircraft and all aerial vehicles maneuver and their performances in different conditions. This paper tries to review the thrust vectoring technology and its various characteristic concepts. This concept has been applied in military aircrafts, guided missiles and satellite launch vehicles. This technology has replaced the aerodynamic control surfaces in their modes of failures in low speed regions

Keywords: Actuators, Aircraft Control, Engine Control and Systems, Safety Critical.

I. INTRODUCTION

Thrust vectoring, also thrust vector control or TVC, is the ability of an aircraft, rocket, or other vehicle to manipulate the direction of the thrust from its engine in order to control the attitude or angular velocity of an aircraft. Thrust vector control is effective only while the propulsion system is creating thrust. At other stages of flight, separate mechanisms are required for attitude and flight path control. Thrust vectoring is a way to reduce a missile's minimum range, before which it cannot reach a speed high enough for its small aerodynamic surfaces to produce effective maneuver. For example, anti-tank missiles such as the ERYX and the PARS 3 LR use thrust vectoring.

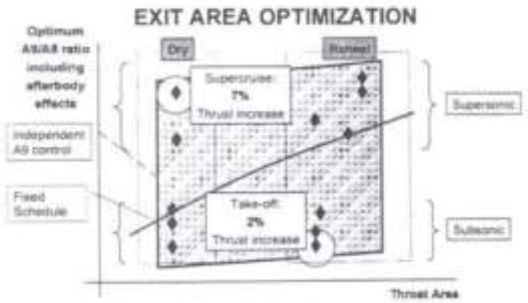
II. THRUST VECTORING NOZZLES.

Thrust Vectoring constitutes the next step in nozzle optimization and increased functionality. The nozzle is used to direct the jet in directions other than the engine axis in order to generate lateral forces and moments around the aircraft center of gravity that can be used for aircraft maneuvering. In 2-D Pitch only nozzles the jet can be deflected within the vertical plane, so the nozzle complements horizontal control surfaces. There are several types of Thrust Vectoring Nozzles. For example, there are 2-D and 3-D Thrust Vectoring Nozzles. The ITP Nozzle is a 3-D Vectoring Nozzle. Also, there are different ways to achieve the deflection of the gas jet: the most efficient one is by mechanically deflecting the divergent section only, hence minimizing the effect on the engine upstream of the throat (sonic) section. Depending on the level of control upon this divergent section, Con-Di nozzles can be of two types:

- **One-parameter Nozzles**: also called 1-DOF nozzles; A8 is fully controlled, and A9 follows a pre-defined relationship to A8. The current EJ200 nozzle is of this type.
- **Two-parameter Nozzles**: also called 2-DOF nozzles; A8 and A9 are fully controlled independently. This type can match the Divergent section to the exact flight condition in order to obtain an optimized thrust.

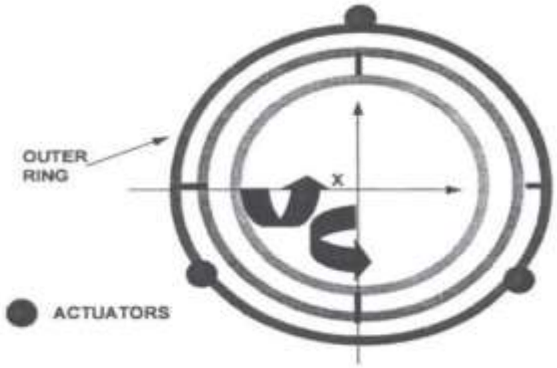
III. NOZZLES AREA CONTROL

In conventional military mono-parametric nozzles the ratio exit area to throat area is given by mechanical design and optimized only for certain engine settings and flight conditions. Having this capability represents a potential for enhancing engine and aircraft performance due to two reasons: exit area to throat area ratio can be optimized and hence thrust maximized; and after body drag can be reduced by increasing the exit area in supersonic flight. .



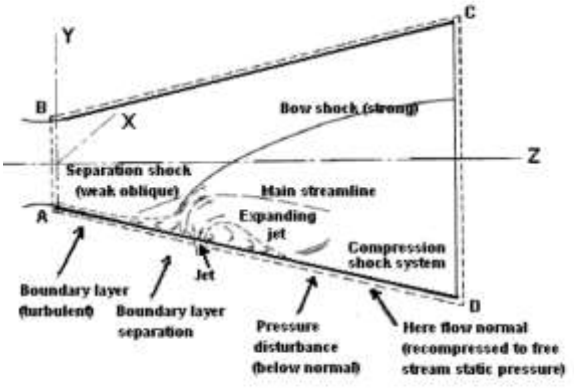
THREE RING SYSTEM

This system consists of three concentric rings which are linked by pins and form a universal (or “cardan”) joint. The inner ring is linked to the convergent section of the nozzle, the outer ring is linked to the divergent section through the reaction bars, and the intermediate ring acts as the crossbar between the inner and outer rings. The actuators are linked to the outer ring only. The design of the rings and reaction bars is such that a small tilt angle on the ring is amplified to a large deflection angle on the divergent section. The outer ring can be tilted in any direction while the inner ring can only keep a normal orientation to the engine centerline, but they both are forced to keep the same axial position along the engine. This is the key factor that permits a full control of the nozzle by acting on the outer ring only, hence minimizing the total number of actuators.



IV. NUMERICAL STUDIES ON THRUST VECTORING

Numerical studies have been carried out using a validated two-dimensional RNG k-epsilon turbulence model for the design optimization of a thrust vector control system using shock induced supersonic secondary jet. Parametric analytical studies have been carried out with various secondary jets at different divergent locations, jet interaction angles, jet pressures. The results from the parametric studies of the case on hand reveal that the primary nozzle with a small divergence angle, downstream injections with a distance of 2.5 times the primary nozzle throat diameter from the primary nozzle throat location warrant higher efficiency over a certain range of jet pressures and jet angles. We observed that the supersonic secondary jet opposing the core flow with jets interaction angle of 40^O to the axis far downstream of the nozzle throat facilitates better thrust vectoring than the secondary jet with same direction as that of core flow with various interaction angles. We concluded that fixing of the supersonic secondary jet nozzle pointing towards the throat direction with suitable angle at a distance 2 to 4 times of the primary nozzle throat diameter, as the case may be, from the primary nozzle throat location could facilitate better thrust vectoring for the supersonic aerospace vehicles.[1]

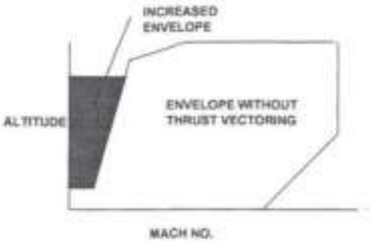


V. ADVANTAGES OF THRUST VECTORING

1. Extended flight envelope.

Conventional flight control surfaces require high dynamic pressure and therefore high speed (higher as altitude increases and air density decreases) to be operative. Traditional fighters' flight envelopes do not cover low speed areas. In thrust vectored aircraft, lack of control surfaces action at low speeds is traded by the nozzle lateral forces, allowing for stationary flight in low speed regions (Rauh and lost, 1999).

Figure shows qualitatively the new envelope areas reachable by having Thrust Vectoring capability. This also means that higher angles of attack can be flown, even in post stall conditions. Normal maximum angle of attack in a non-thrust vectored fighter is around 30°, while up to 70° angle of attack was demonstrated for the X-31. This capability represents a very clear advantage for air superiority, especially for close-in combat.



2. POTENTIAL FOR SAFETY IMPROVEMENT.

Although Thrust Vectoring constitutes a complex system susceptible of suffering failures leading to critical situations, it can also constitute not just a complementary control surface but a redundant one if adequate control modes are implemented within the flight control system. These modes would come into place once a failure in an aerodynamic control. surface is detected and would comprise logic for fault detection and isolation as well as reversionary laws.

Once the Thrust Vectoring system is validated as an alternative to aerodynamic control surfaces it might be possible to gradually reduce them and replace their functionality with Thrust Vectoring. This approach will lead to two additional advantages: mass reduction and improved stealth characteristics of the aircraft.

3. USE OF THUST VECTORING IN AIRCRAFT TRIMMING

Having a somehow new aircraft control surface allows for further optimization of Thrust Vectoring and surfaces deflection hence improving the lift drag characteristics of the aircraft in all phases of flight.

In cruise. Thrust Vectoring can be traded with aerodynamic surfaces deflection reducing drag.

However, depending on the aircraft configuration, there might not be a great potential for drag reduction if aerodynamic surfaces are already operated close to the minimum drag position (i.e. aircraft with canard).

In takeoff and landing. Runs can be reduced as, for landing, Thrust Vectoring allows for lower approach speeds and quicker de-rotation and, for take-off, the aircraft can be rotated earlier and lift off at a lower speed.

In sustained and instantaneous maneuvers. Thrust Vectoring also allows for a lower deflection of the aerodynamic control surfaces so reducing drag and increasing maneuverability potential.

4. Space Applications of Aerospike Nozzle Space

Although aerospike nozzles have long been known for their altitude-compensation ability during endo-atmospheric flight, they also present significant potential advantages for purely in-space applications. Aerospike nozzles can be both more efficient significantly smaller than conventional high-expansion ratio bel nozzles. Given a fixed vehicle base area, an aerospike nozzle ca present a higher area expansion ratio than a bell nozzle, providing better performance in a space environment or near-vacuum environment like Mars. The increased specific impulse (*I*sp) due to a higher possible expansion ratio using an aerospike nozzle translates to a 8–9%decrease in the propellant mass and total system weight for space and near-space applications. Additionally, one of the often-overlooked properties of the aerospike nozzle is the ability to achieve thrust vectoring aerodynamically without active mechanical nozzle gimbals or differential plenum throttling. This property offers a significant potential for reduced system complexity and weight. With traditional thrust vectoring in conical or bell nozzles, the secondary injection port is far within the nozzle, making thrust vectoring without active primary flow impractical. In contrast to conventional nozzles, thrust vectoring performed by secondary injection on an aerospike nozzle could also be used for attitude control independent of main thruster operation. Aerodynamic thrust vectoring on aerospike nozzles offers a potential replacement for both gas attitude control thrusters and main engine thrust vector gimbal control.

Despite the potential benefits of aerospike nozzles over conventional nozzle designs, because of a perceived low technology-readiness level, the aerospike configuration has never been deployed on an operational space vehicle. One of the major reasons for this perception is the lack of high-quality ground and flight test data and its correlation with analytical flow predictions. This dearth of data is especially true with regard to off-nominal design performance, thrust vectoring, an thruster-out scenarios for clustered aerospike configurations

ACKNOWLEDGEMENT

This review paper was supported and guided by Prof. P.M. Patane who provided us insight and expertise that greatly assisted us. We would also like to show our gratitude to the Mechanical Department of MIT College of Engineering ,Kothrud,Pune(India).We are thankful to all our professors to give us the opportunity to explore this field

We thank reviewers for their insights. Errors may have occurred and these errors are our own and should not tarnish the reputations of these esteemed persons and institution.

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