A REVIEW ON THRUST VECTORING AND ITS EFFECT ON VERTICAL TAKE-OFF AND LANDING SYSTEMS

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ABSTRACT: Thrust vectoring is a technology that has not been effectively put into use at a commercial scale but has the potential to greatly influence the aircraft propulsion system due to its high controlling capabilities and easy maneuverability. Aircrafts using vectored thrust rely to a lesser extent on aerodynamic control surfaces such as ailerons or elevator to perform various maneuvers and turns than conventional-engine aircrafts and thus have a great advantage in combat situations. A thrust vectoring system comprising a working fluid source mounted to an aircraft, and a vectoring nozzle connected to the working fluid source which has an extendable conduit defining a passage from an inlet to an outlet. The passage is adjustable so that the direction of the working fluid exiting the outlet is different than the working fluid entering the inlet when the conduit of the vectoring nozzle is extended. This conduit provides a way to change the direction of working fluid exiting the nozzle and correspondingly change the thrust vector of the aircraft. This review explores the advantages and disadvantages of various types of thrust vectoring. It also makes an overview of how vectored thrust has been utilised in the development of V/STOL Aircraft over the years and how it can contribute to the development of next generation of fighter and civilian aircrafts.

Keywords: Thrust vectoring, Propulsion, V/STOL Aircraft

NOMENCLATURE

MATV Multi Axis Thrust Vectoring
MKI Modernised Commercial Indian
P/YBBN Pitch/Yaw Balance Beam Nozzles
SERN Single-Expansion-Ramp Nozzles
TVC Thrust Vectoring Control
V/STOL Vertical/Short Takeoff and Landing
2DCD Two-Dimensional Convergent-Divergent

1. INTRODUCTION

1.1 Concept of Thrust Vectoring
Thrust vectoring is the deflection of the thrust line in order to create multi-dimensional forces and moments which can enhance aircraft performance and control.

Thrust vectoring can provide control effectiveness superior to conventional aerodynamic surfaces at some flight conditions, and it can extend the aircraft performance envelope by allowing operation in the post-stall regime. The use of thrust vectoring can allow the reduction, and possibly even the elimination, of conventional aerodynamic control surfaces such as horizontal and vertical tails. This would reduce weight, drag, and radar cross section, all of which can extend an aircraft's range and capabilities [1].

1.2 History of V/STOL Aircrafts
VTOL aircrafts combine the vertical flight capability of the helicopter with the superior forward flight performance of the fixed wing airplane. The history of development of these platforms is littered with many unsuccessful attempts mostly plagued by technical shortcomings and lack of performance or financing.

In 1957, the Bell X-14A, developed under a US Air Force contract achieved its VTOL capability from swivelling cascade nozzles that redirected the exhaust from two Armstrong-Siddeley Viper engines. It was successful as a research vehicle and was converted to a variable stability vehicle for NASA in 1968.

In the 1950s the development of an engine and control system intended for V/STOL application was begun by the name of the Pegasus engine. Michael Wibault, a Frenchman, sold the idea of the rotating nozzles to the Bristol Co. Of England which then revised the engine design to an axial flow configuration with the help of funding from the US and subsequently developed the Pegasus engine. In 1960, the British Ministry of aviation ordered six prototypes of the P.1127 Kestrel aircraft employing the Pegasus engine. It was from this aircraft that the Harrier aircraft evolved.
The Hawker Siddeley Harrier AV-8A was the first generation of the Harrier series. It was powered by a single Pegasus turbofan engine mounted in the fuselage. The engine was fitted with two air intakes and four vectoring nozzles for directing the thrust generated: two for the bypass flow and two for the jet exhaust [2].

2. LITERATURE REVIEW

Over the past several decades, propulsion nozzle research has led to the development of multi-mission exhaust nozzle technologies that can provide efficient operation over a broad flight regime. Of the many exhaust nozzle technologies under consideration today, studies [1] have shown that thrust vectoring is perhaps the most promising, for numerous reasons.

There are a host of potential benefits for incorporating thrust vectoring into the development of military aircrafts which include enhanced turn rate, improved maneuverability, vertical and short take-off and landing (V/STOL) capabilities, and elimination of control surfaces. The use of fluidic injection for thrust vectoring instead of mechanized hardware offers significant improvements in aircraft signature, weight, and drag. These mechanisms proved efficient for thrust vectoring under static conditions, but resulted in detrimental penalties for installed conditions. Throughout the 1970's, a variety of non-axisymmetric nozzles such as two-dimensional convergent-divergent (2DCD), wedge, and single-expansion-ramp nozzles (SERN) were investigated for their ability to accommodate thrust vectoring. Non-axisymmetric, thrust-vectoring nozzles offered integration and installed performance benefits over the conventional axisymmetric nozzles [3, 4].

Fluidic injection for thrust vectoring was investigated in the 1990's [5, 6]. The fluidic thrust vectoring techniques which have been developed till date include throat skewing, shock vector, counterflow [7] and coflow [8]. An important factor which affects fluidic thrust vectoring is the Coanda effect [9]. The Coanda effect is the phenomenon in which a jet flow attaches itself to a nearby surface and remains attached even when the surface curves away from the initial jet direction.

The jet stream exiting the nozzle of a thruster is affected by Coanda effect, since the bottom of the hull is an adjustable flat surface. This results in two significant thrust losses:
1. Friction of the jet stream where it flows along the bottom plating of the pontoon at high velocity.

2. Pressure of the jet stream exerted on the opposing pontoon.

2.1 Fluidic Thrust Vectoring Techniques

2.1.1 Fluidic Throat Skewing

The fluidic throat skewing concept for nozzle flow control features symmetric injection around the throat region to provide aerodynamic throttling for jet area control and asymmetric injection to subsonically skew the sonic plane for thrust vector control. An injection slot is located at the throat and nozzle flap on both sides of the nozzle. By injecting asymmetrically at the throat, the sonic plane is actually reoriented, which subsonically turns the nozzle primary flow. Supplemental injection ports downstream of the throat injection ports are also used to further skew the sonic plane and increase the vector angle. By controlling the injection flow rate at the throat and flap, vectoring can be provided at all throttled operating conditions [10].

2.1.2 Shock Vector Control

Shock vector is achieved by fluidic injection into the divergent portion of the nozzle, which causes a shock in the primary flow, and turns the flow supersonically. Since there is no mechanical hardware other than control valves associated with fluidic thrust vectoring, the problems associated with movable flaps are eliminated.

However, shock vector fluidic thrust vectoring has a disadvantage that the secondary stream draws air from the primary air supply, which reduces the maximum possible thrust that can be achieved by the engine [11].

2.1.3 Co-Flow Method

Co-flow thrust vectoring is achieved by utilising the Coanda effect [9] to alter the angle of the primary jet from an engine exhaust nozzle. Due to the presence of the Coanda surface, entrainment by the secondary jet is inhibited on the side nearest to the surface.

This entrained air must then accelerate over the Coanda surface producing a local low-pressure region, which results in a pressure gradient perpendicular to the primary jet centreline. By positioning curved surfaces to the rear of the engine nozzle of an aircraft and introducing a secondary stream of co-flowing air parallel to the Coanda surface, thrust vectoring of an aircraft can be achieved.

2.1.4 Counter-Flow Method

The counterflow thrust vectoring concept is attributed to the generation of a “countercurrent”
shear layer along the suction side of the jet [12]. Each shear layer entrains mass from the surrounding ambient fluid, but the presence of the suction collar inhibits this process, and causes low pressure along the collar surface. Because of the increase in organized vortical and turbulent activity in the countercurrent shear layer, it entrains more mass from the surrounding ambient fluid than the coflowing shear layer, and pressures on the counterflow side of the collar will be lower facilitating thrust vectoring.

2.2 Fluidic Thrust Vectoring Systems

Over the past few decades fluidic injection for thrust-vector angle control and throat area control in exhaust nozzles has undergone critical analysis. A background research on different thrust vectoring systems which have been developed accordingly lists out the following systems.

2.2.1 Fixed Nozzle Systems
Fixed nozzle systems refer to nozzles that are solid mounted in the frame of the vehicle. The flow inside the nozzle itself is then changed to move the thrust vector.

2.2.2 Liquid Injection
Liquid injection encompasses any addition of a fluid that changes the characteristics of combustion. By changing the combustion on one side of the nozzle, the vectored thrust can be changed. Advantages of this method are that it has a fast response capability and it adds to the thrust by adding mass to the fluid stream.

2.2.3 Gas Injection
Gas injection is similar to liquid injection, the difference being that instead of new gas being added to the fluid stream, combustion gases are rerouted from behind the nozzle into the diverging section changing the flow through the nozzle itself. The advantages of this method are that additional fluids do not need to be stored onboard and so the system overall is lighter in weight.

2.2.4 Jetvane
The jet vane deflector is characterized by any fin or plate that is directly placed in the exiting flow of the nozzle. As the plate or fin moves it will cause the flow exiting the nozzle to deflect from the centreline of the rocket. An advantage of this system is that the forces on actuators are low and thus they can be capable of quick response times.

2.2.5 Jetavator
The Jetavator is conceptually similar to the jet vane with the difference that instead of the vanes being in flow of the nozzle, they are positioned around the perimeter of the nozzle and are parallel to the flow. The advantages of jetavator include that the its deflection is linearly related to the deflection of the thrust vector.

2.2.6 Jet Tab
The jet tabs stem involves a plate at the end of the nozzle that can be rotated into and out of the nozzle disrupting the flow. The advantage is that the thrust deflection is proportional to the area of the tab that is exposed to the flow.

2.2.7 Movable Nozzle
Movable nozzle controls the direction of the exiting flow by allowing movement of the nozzle itself. Movable nozzle systems are broadly classified on the basis of types of flow inside the nozzle as Flexible Joint, Rotatable Joint, Rotating Segment Setup and internal Maneuvering Vanes.

2.3 Application of Vectored Thrust in V/STOL Airplanes

The Harrier is an example of a VTOL airplane which uses a vectored-thrust turbofan engine (Rolls-Royce Pegasus) [2] for take-off and landing.

The configuration of a vectored-thrust turbofan engine is a bypass engine where the air through the fan is directed through the forward set of nozzles, while the turbine exhaust flows through the rearward set of nozzles. When the forward and rear air flow leaves the engine, they are turned twice. First, the air is turned 90° and directed outward. Then the flow is turned another 90° by a nozzle that can swivel to vector the exhaust momentum over a range of directions from slightly forward of vertical to the rear. For the vectored-thrust configuration, the exhaust must be turned by a vectorable nozzle. This is accomplished by means of a cascade of airfoils that must be carefully designed to provide the desired turning without excessive losses.

There are two phenomena relating to the performance of VTOL airplanes employing lifting jets that are important: suckdown and fountain effect.

Suckdown is similar to an augmenter such that at an altitude a vertical jet can entrain a secondary flow downward around the airplane. If this flow flows around the bottom of the fuselage, it can produce a low pressure resulting in a downward force. In addition to the reduced pressure at the bottom of the fuselage, the downward flow can
produce a download on other parts of the airplane. Collectively, the sum of these forces is called suckdown.

In fountain effect, a jet impinging on the ground will spread radially outward. However, if another jet is present, the jets interact in the region between them, causing a “fountain” to be directed upward. This upward flow increases the pressure underneath the fuselage resulting in increased lift [2].

2.4 Current Developments

For many years, AV-8 aircraft have employed thrust vectoring during air combat engagements. The Sukhoi Su-30 MKI, produced by India under license at Hindustan Aeronautics Limited and in active service with the Indian Air Force employs 2D thrust vectoring.

The F-15 Advanced Control Technology for Integrated Vehicles test program being conducted at NASA’s Dryden Flight Research Centre aims to expand the flight test envelope in which useful thrust vectoring is available to enhance aircraft performance, maneuverability and controllability with production-representative nozzles. Initial flight test results demonstrated the successful operation of the Pitch/Yaw Balance Beam Nozzles upto Mach 2 in non-vectoring flight at and Mach 1.6 in vectoring operation with no new stability problems [13].

3. CONCLUSION

Thrust vectoring is the most suitable technology for the development of airplanes with high thrust-to-weight ratio because of its many advantages that include higher mach speed, higher altitudes, improved transonic control, high agility, post-stall operation, short takeoff/landing roll, enhanced air to ground performance, improved both low and high speed control and reduced drag. High engine power helps to avoid any situation in which an aircraft can stall and thrust vectored systems even assist in spin recovery thus contribute to improving the overall aerodynamic performance of the aircraft. However there are certain technical shortcomings in the implementation of thrust vectoring systems. A disadvantage of known systems for secondary injection thrust vector control is the relatively large quantities of fluid which they require to produce the desired degree of control. Also, since valves used to control the flow of gases from the combustion chamber to the thrust nozzle of the rocket are subjected to a severe temperature and extreme atmospheric conditions, they become inoperative after a short time. But many active flight research programs are being carried out for the application of thrust vectoring in the aircraft systems, both military as well as commercial, providing hope for improvement in the performance and application of thrust vectoring systems in future aircrafts.

4. REFERENCES