# Multiple Nozzle Concepts in a Single Engine

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## Abstract

*Today, thrust vectoring has become a very important research subject which can dramatically change the way aircraft maneuvering in the future and their performance. This paper tries to present a unique approach to this topic. This paper highlights a concept defined as SIMO (Single Inlet Multiple Outlet) in detail. This can be explained by having multiple nozzles for exhaust purpose than those conventional one or two nozzles as we know of presently. This idea may yet not be able to apply directly to VTOL (Vertical Take off & Landing), but can be applied very well to change thrust direction of the aircraft effectively including thrust reversal and hence reducing the dependability on the primary control surface to great extent.*

## Symbols and Nomenclature

$V_2$ Inlet velocity in the nozzle before expansion in the nozzle
$V_1$ Inlet velocity in the nozzle before expansion in the nozzle
$\alpha$ Angle of the vectored thrust

L Velocity loss due to thrust vectoring of secondary nozzles
SIMO Single Inlet Multiple Outlet
VTOL Vertical Take off & Landing

## Introduction

In present day aircrafts, power plants constitute the lifeline of the plane. And for military aircrafts, power plant has become more significant since it is the one which provides the aircraft of almost all its performance characteristics. Nozzle is a very significant part of the aircraft engine and which not only propels the aircraft but now even can assist the aircraft in performing maneuvers (TVC Nozzles used in JSF-Joint Strike Fighter, USA; Sukhoi 30MKI, India to name a few). The above stated aircrafts use advanced nozzle technology called THRUST VECTORING.
Present day aircrafts currently employ one nozzle per engine. This paper presents a new concept called ***SIMO*** *(Single Inlet Multiple Outlet)* which employs five nozzles instead of one nozzle to single engine. With four of these five nozzles equipped with thrust vectoring we can achieve all directional control of the aircraft thus reducing our dependence on the control surfaces. This paper discusses following aspects concerned with this concept.

1. Mechanism
2. Aerodynamic Effects
3. Engine Thrust Aspects
4. Loss Analysis
5. Possible Applications

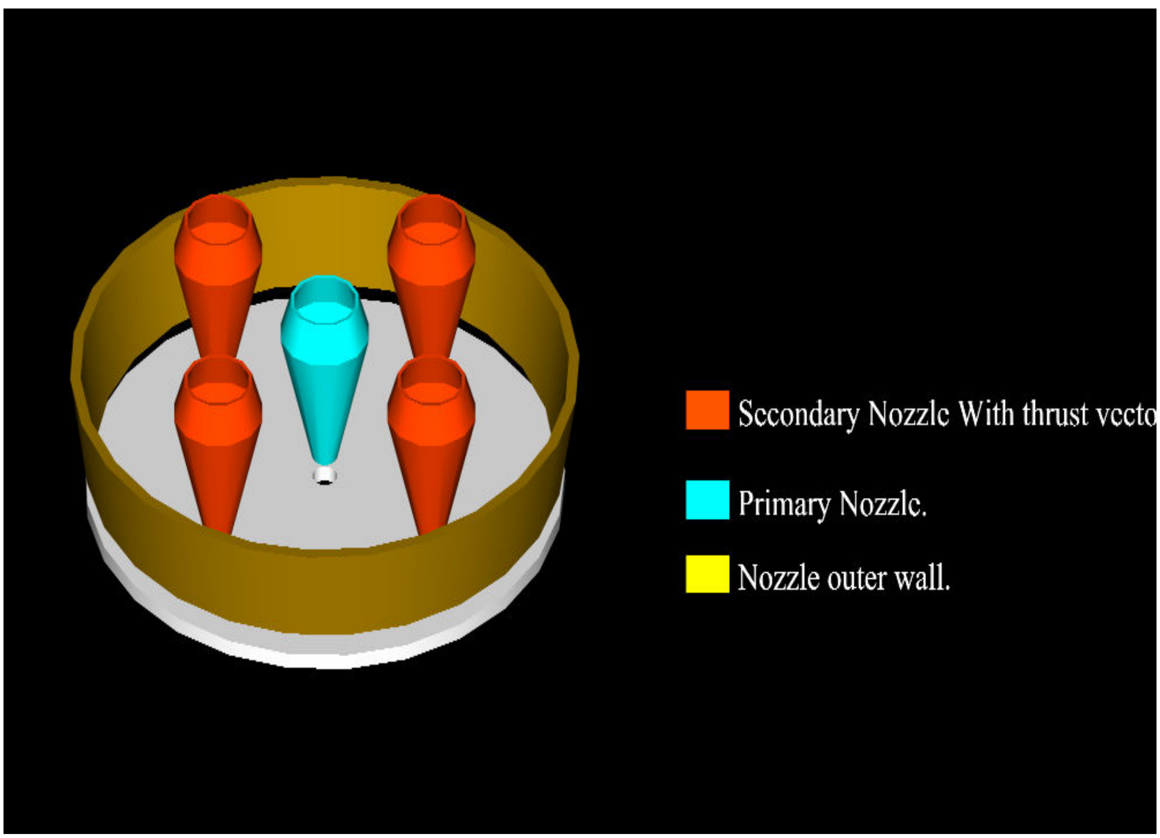
## Mechanism

The mechanism of the multiple nozzle system is explained this section. The mechanism is based on *Nozzle Actuation System*. The actuation system employs the tilting of the secondary nozzles over their hinged joints at the required angle. The nozzle actuation system is similar to the TVC nozzle actuation system employed by present day defense aircrafts like the US-JSF (Joint Strike Fighter), Su-30MKI (Sukhoi 30 variant for Indian Air Force).
The nozzle tilting angle has to be kept minimum to avoid thrust losses and nozzle efficiencies due to unparallel fluid flow in the nozzle with respect to the tilted nozzle axis. This mechanism requires the fluid flow in the nozzle to be as parallel to the nozzle axis as possible with minimum angle variation between the two. The primary nozzle is in the centre location of the nozzle system with no variation in the nozzle angle whole throughout, in other words the primary nozzle is not equipped with Thrust Vectoring System. This is done to provide stability to the aircraft as this primary nozzle will provide steady thrust in one direction only. This will avoid the aircraft to go into a continuous rolling motion or auto rotation as rockets and missiles normally undergo during their flight. The secondary nozzles are equipped with thrust vectoring system.

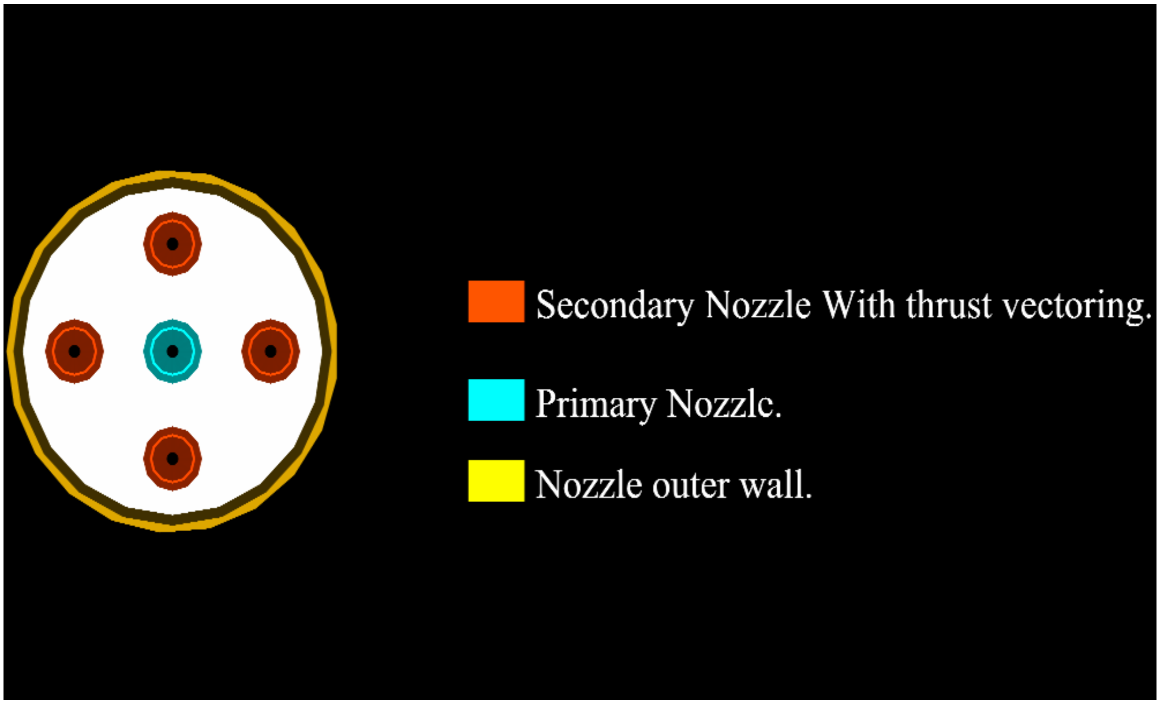
The arrangement of the secondary nozzles will be in *Diamond Formation* around the primary nozzle. This secondary nozzle cluster is in diamond formation rather than in rectangular formation so as to avoid over heating of secondary nozzle walls during the deflection of the secondary nozzle walls. In rectangular nozzle walls, performing yaw and pitching maneuvers will lead exhaust from the two secondary nozzles almost directly heating the other two adjacent secondary nozzle walls.

In diamond (rhombus shape) arrangement of the secondary nozzle system they are located around the primary nozzle shape in a rhombus formation. During any maneuver, pitching or yawing the exhaust from the secondary any one secondary nozzle wall will lead to the heating of the outer primary nozzle wall whole throughout. Therefore, the cooling of the outer wall of the primary nozzle wall is of prime importance and will be discussed further later in the paper.

Both the diamond and rectangular arrangement of the secondary nozzle arrangement is shown in the diagrams below.

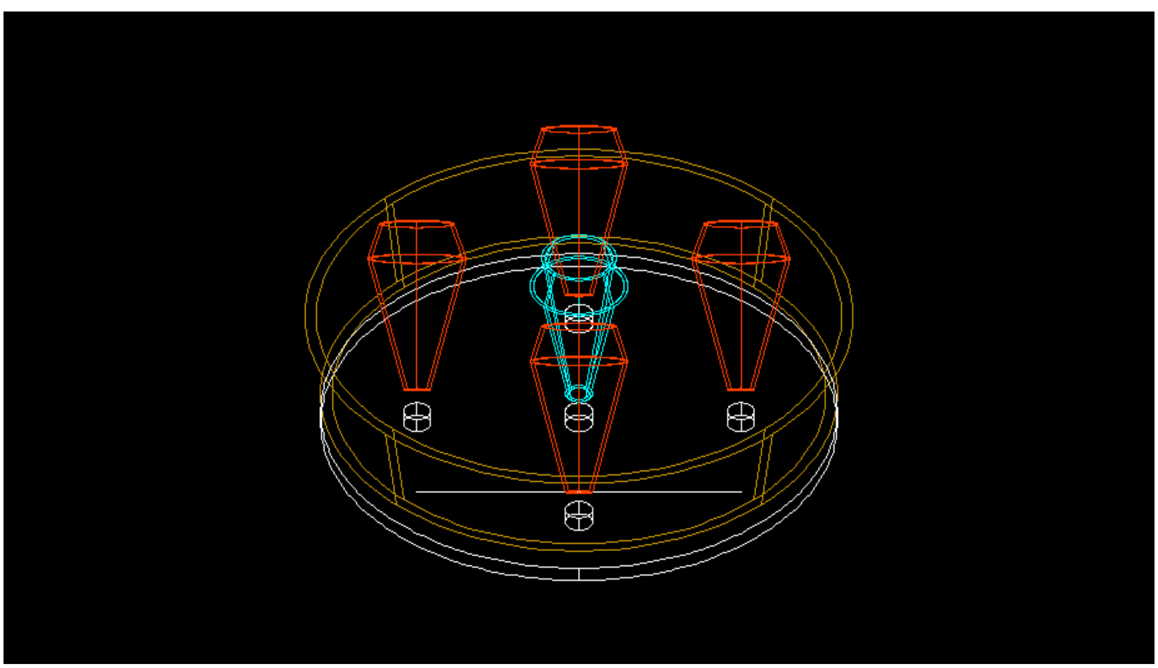



**Rectangular Arrangement**

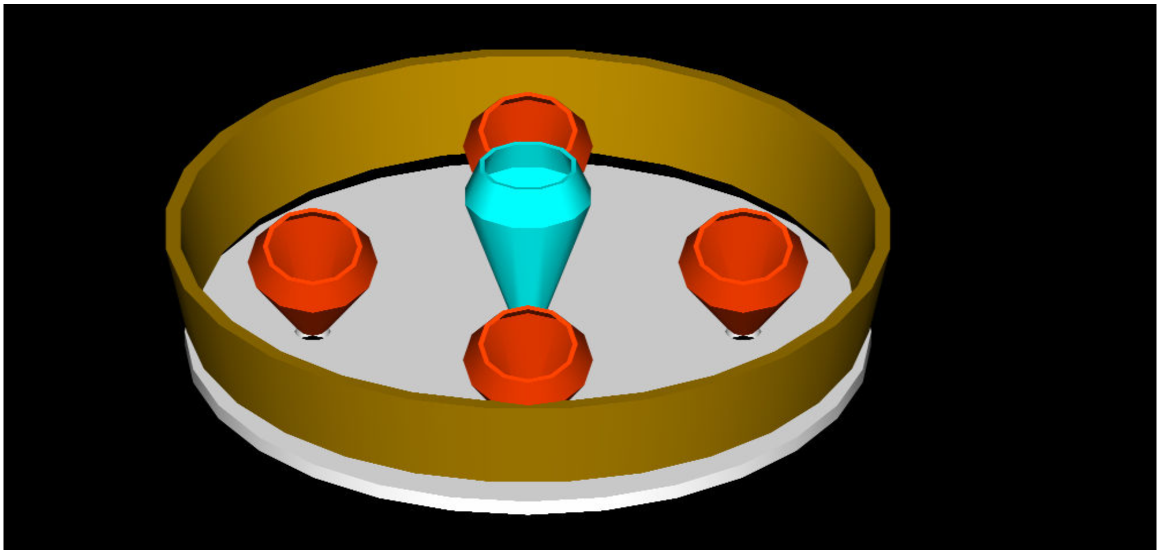



## Diamond (Rhombus) Arrangement

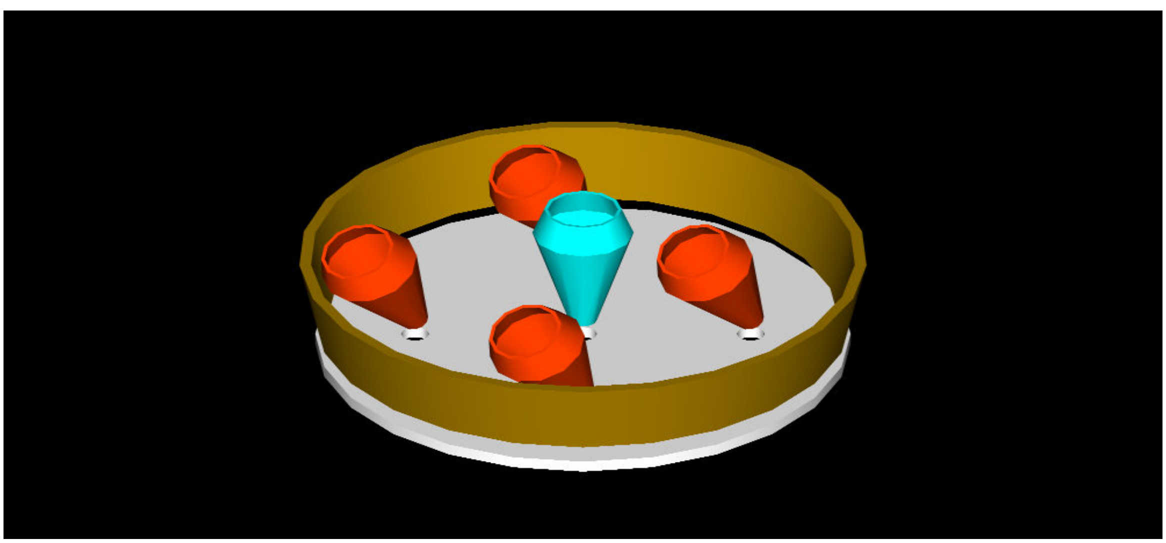
Since we have chosen the diamond formation, hence an isometric view of this type of nozzle arrangement is given below,



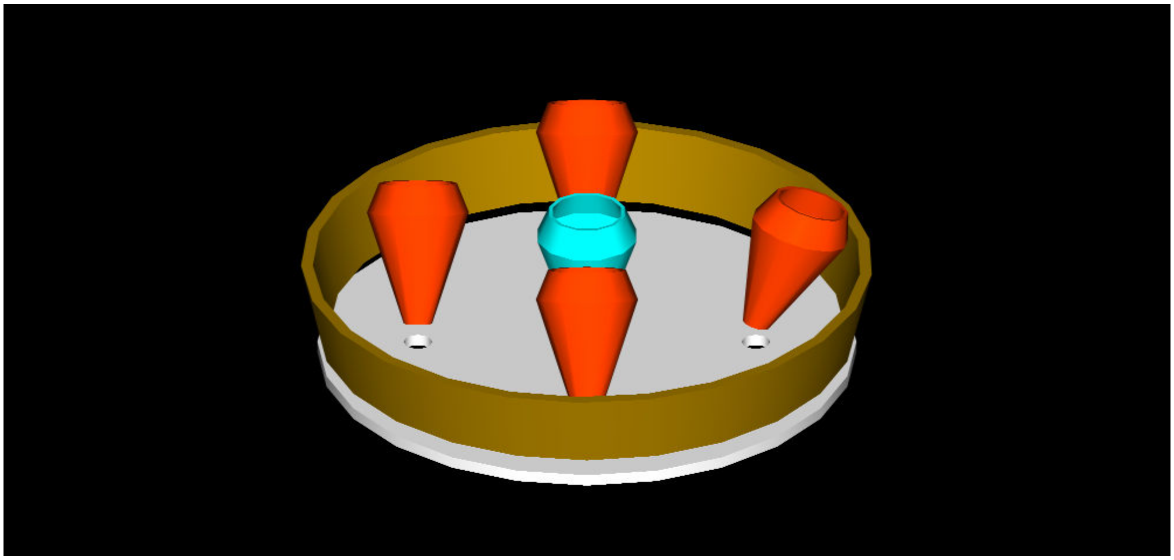
This SIMO concept can very well be applied to perform any aircraft maneuver. Following are the diagrams which illustrate the movement of secondary nozzles to perform basic aircraft maneuvers i.e. *Pitch, Yaw, Roll*.



**Pitch**



**Yaw**



**Roll**

NOTE: Color coding of the above diagrams is same as that of the diagram depicting diamond (rhombus) arrangement.

## Aerodynamic Effects

The aerodynamic characteristics of the aircraft will not be affected much as the nozzles are perfectly streamlined to reduce any aerodynamic losses due to drag and other factors. The nozzles are in diamond like arrangement which will prevent the interference of streamline flow due to the secondary nozzles at the outer periphery of the nozzle arrangement. The other aerodynamic aspects of the nozzles will be same as that of the conventional nozzle systems used in other aircrafts.

## Loss Analysis

The losses will be mainly due to the vectored thrust arrangement. The velocity vector in the direction (in case of downward component of velocity) the component will be $V_2$*COS $\alpha$ where $\alpha$ being the angle of the vectored thrust or the angle by which the secondary nozzles will change tilt or shift.

The loss in this case will be $V_2 - V_2 \cos \alpha$
Where,
$V_1$ = Inlet velocity in the nozzle before expansion in the nozzle
$V_2$ = Outlet velocity in the nozzle after expansion in the nozzle.
This loss will be compounded in the form of four secondary nozzles. So the total losses can be found as to be
$L = 4 * (V_2 - V_2 \cos \alpha)$
This loss can be minimized reducing the angle $\alpha$, by reducing this angle we can control the losses in this nozzle system.
The angle $\alpha$ can be effectively reduced as for an angle we have four corresponding secondary nozzles, each of which will generate an equal amount of thrust in the required direction.

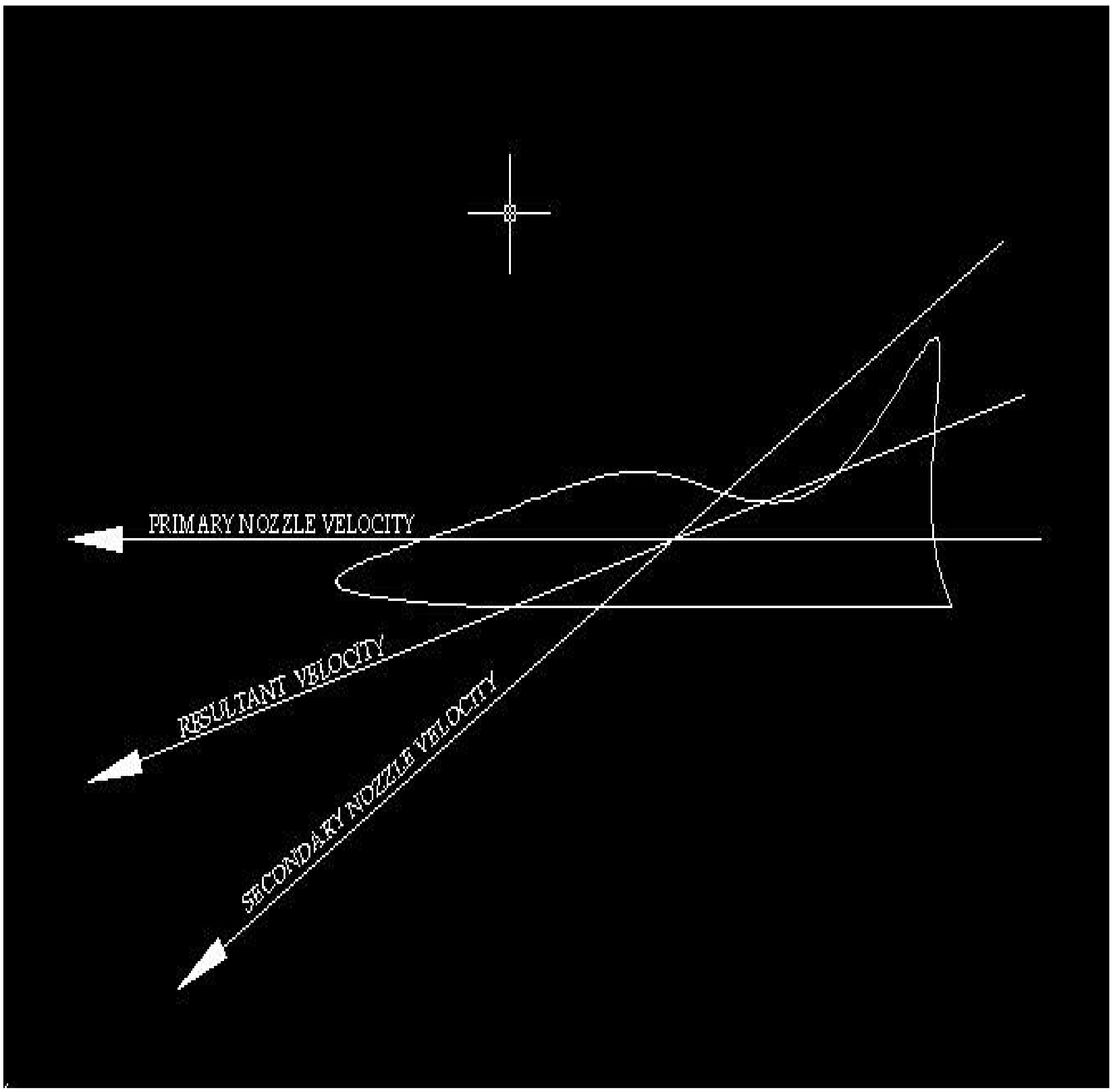
## Engine Thrust Aspects

**Thrust vectoring** is the ability of an aircraft or other vehicle to direct the thrust from its main engine(s) in a direction other than parallel to the vehicle's longitudinal axis. The technique was originally envisaged to provide upward vertical thrust as a means to give aircraft VTOL or STOL capability. Subsequently it was realized that the use of vectored thrust in combat situations enabled an aircraft to perform various maneuvers not available to conventional-engine planes.

Most currently operational vectored thrust aircraft use turbofans with rotating nozzles or vanes to deflect the exhaust stream. This method can successfully deflect thrust through as much as 90 degrees, relative to the aircraft centerline. However, the engine must be sized for vertical lift, rather than normal flight, which results in a weight penalty. Afterburning (or Plenum Chamber Burning in the bypass stream) is difficult to incorporate and is not practical for Take-off/Landing, because the very hot exhaust leaves scorch marks on the ground. Without afterburning it is difficult to reach supersonic flight speeds. A fluidic nozzle diverts the thrust via fluid effects

Given below is a diagram to explain as to how this nozzle system will help to get change in direction of the aircraft using engine thrust. As we can see in the diagram shown below, the horizontal velocity component is due to *Primary Nozzle* and the far oblique velocity going extreme downward is the *Secondary Nozzle* velocity component (due to the vectoring of the upper and two side secondary nozzles in the upper direction with the required angularity). As a result, we have a resultant velocity in a direction between these two primary nozzle and secondary nozzle velocity components. Hence, we can use the engine thrust to direct the aircraft to the required direction and sense. To generate max thrust in the downward direction we close all the nozzles except the top one which is vectored upwards with maximum angularity to give us the maximum thrust in that direction. Similarly we can also generate maximum thrust in all the four directions by leaving only the corresponding nozzle open and can generate the required thrust in any direction by working the primary nozzle and secondary nozzle in perfect co-ordination and in tandem.

Hence, below in the diagram we have shown clearly how the aircraft velocity will be in this kind of nozzle arrangement. The primary nozzle velocity will keep changing its direction downwards and the operating nozzle will also go downwards and hence the resultant velocity will also keep going downwards and hence proper control of the vectoring nozzles is required to make this nozzle arrangement a very effective tool for increasing aircraft performance, its maneuverability and its safety.



The primary nozzle will account for 40% of the thrust generated by the engine.
The rest 60% of the engine thrust is divided among the secondary nozzles with thrust vectoring capability. This 60% of the thrust is divided into 15% in each of the secondary nozzle to achieve reasonable engine performance with appropriate expansion of the gases coming out of the combustion chamber.

The thrust to weight ratio of the aircraft installed with this kind of thrust vectoring capability can be adjusted to acceptable range by reducing the wing aspect ratio to a minimum with reduced dependability on the primary control surfaces. These control surfaces can compliment this nozzle system in performing the necessary maneuvers. This kind of arrangement between the nozzle system and the control surfaces gives the aircraft an extremely high degree of maneuverability and make it very competitive in air dogfights.

The cooling of the primary nozzle due to the vectoring of the secondary nozzle is taken care of by having an effective cooling system in place for the primary nozzle. Of all the cooling systems available regenerative cooling is the most effective method of cooling the primary nozzle wall. This will increase the reusability of the primary nozzle and thereby reduce the cost as well. The regenerative cooling is done by building a cooling jacket around the nozzle and circulating the fuel through it before it is fed to the injector. The heat is taken away by way of cooling is picked up by the fuel and fed back to the combustion chamber, so it is not lost. It’s quite an effective method in applications with high chamber pressure and high heat transfer rates. This method hence, does not effect the fuel consumption of the engine and consequently does not produce or influence fuel efficiency of the engine in any way.

Further research into this regard may completely eliminate the use of primary control surfaces and reduce the function of the wing to just generate lift for the aircraft.

## Possible Applications

With thrust reversal system installed on all the nozzles we can achieve thrust reversal too giving the aircraft unprecedented maneuverability and ease of slowing down the aircraft during landing.

With these kind of nozzles very high degree of maneuverability can be achieved. In defense aircraft, these maneuvers can give very high precision of targeting in air dogfights.

These nozzles when installed with conventional thrust reversal systems, they can keep the aircraft in air at a very low speed and may also help in reducing the stall velocity which can hence lead to safer landings.

These can also be applied to space propulsion particularly as it can control the direction of spacecraft in space which is normally difficult to control.
These nozzles can be made to work in tandem with primary control surfaces so that some day in future in case of failure of primary control surfaces occur, the aircraft can still be maneuvered and saved thereby avoiding loss of million of dollars worth of property, aircraft and most important pilot’s life.

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