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A REVIEW ON AEROSPACE THRUST REVERSERS' DESIGNS AND CLASSIFICATIONS

Lijalem Gebrehiwet
Researcher, Mechatronic Engineer, Aerospace Engineering and SATCOM,
Ethiopian Space Science and Geospatial Institute, Addis Ababa, Ethiopia
Email: lijalemgg2013@outlook.com

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ABSTRACT

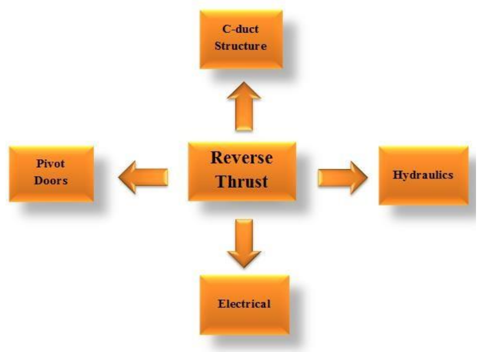
Thrust reversers are part of some aircrafts which are used to reduce the landing distance. It is mostly activated during approach for landing. This review paper presents the different designs, classification, applications and their drawbacks during operation. The electro-hydraulic servo control system of thrust reverser of an aircraft is used to activate the system. The design of thrust reversers consists of different mechanical links, buckets, actuators, pipelines and servo-valve for smooth operations. The thrust reverser design is dependent on the fluid flow of the gases. In some designs it alters the direction of the exhaust gases produced by the engine. This can be activated by using a variety of methods such as deploying mechanical devices by redirecting the exhaust flow using vanes or nozzles. The exhaust gases are directed in opposite direction of the aircraft's motion which effectively acts as a brake slowing down the vehicle. They operate by hydraulic and electro-mechanical devices.

Keywords: Aircraft thrust reversers; Thrust reverser types; Actuators and Buckets; Reverse flow; Landing distance

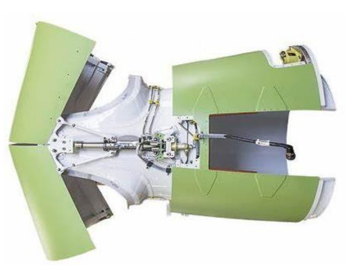
I.INTRODUCTION

In aerospace engineering, thrust reverser is a technology that reroutes an engine's thrust in the other direction. This is applied to slow down an aircraft or spacecraft during landing. It also used for maneuvering where a deceleration as well as direction changes is required during space missions. The vehicle can efficiently counterbalance its forward velocity and stop more swiftly and securely by reversing the thrust's direction [1]. The primary purpose of thrust reverser is to shorten the stopping distance. It makes it possible to land on shorter runways and reduces taxi distance and tire brake wear. It is also applied when takeoffs are denied. When it comes to stopping distance, reverse thrust is superior to brakes and drag parachute.

Enhancing the safety and effectiveness of spacecraft and aviation operations is one of the primary advantages of thrust reversal [2]. The primary parts of a thrust reverser are an electronic controller, servo valve, pipe lines connected to the central hydraulic system, and a hydraulic actuator with a piston rod attached to the mechanical linkage. As seen in the figure below [3], the thrust reverser design is divided into several major subsections, including hydraulic, electrical, pivots, doors, and c-duct. At high speeds, reverse thrust works better because the power and thrust produced are proportionate to the plane's speed. It should be applied as soon as possible after touchdown for best results [4].



(a)



(b)

Figure 1 Main subsections of thrust reverser (a) & (b)

II. TYPES OF AEROSPACE THRUST REVERSERS

In aerospace technology, there are various types of thrust reversers. They are frequently utilized in missiles, space technologies, and aviation. Commercial airplanes frequently use thrust reversal during landing to increase safety and shorten the distance needed for braking. Thrust reverser is also used in rocketry to slow down a spacecraft's fall, provide a smooth landing and direction or attitude changes. In some cases, it enables safe landing and future mission reuse, this method is especially crucial for reusable rockets [5].

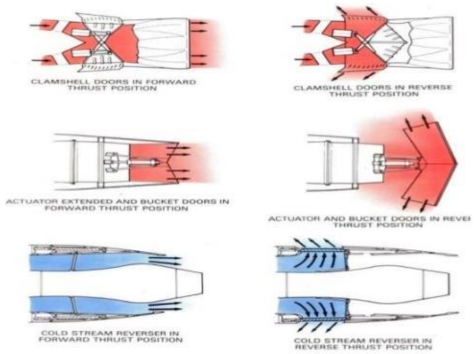


Figure 2 Types of aviation thrust reversers

Based on Newton's third law of motion, reaction control systems, which are composed of networks of tiny thrusters placed throughout the spaceship, are used to precisely control the approaching spacecraft. It helps push, slow down, and maneuver the spaceship toward the International Space Station (ISS) because there is no air resistance in space to obstruct the operation. Reaction control system thrusters are built to be very reliable and often fire in short, focused bursts [6].

In order for small satellites to perform orbital transfers, attitude and orbit management, and end-of-life deorbiting, there are different designs of thrusters employed nowadays. It can be challenging to select the right thruster type for a CubeSat. This is a crucial step for any mission or service that requires movement and control while in orbit. As demonstrated here, docking is the most effective method for navigating small spacecraft [7].

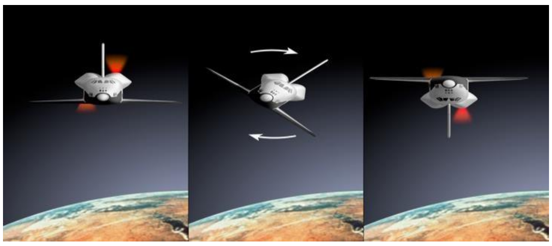


Figure 3 Thruster control in the arriving spacecraft

Four Apollo Reaction Control System (RCS) engines make up a quad, or cluster, which is its unique design. An essential rocket engine system for preserving the Apollo Service Module's (SM) orientation was the RCS. In addition to performing small midcourse velocity corrections, abort separations, and emergency attitude maneuvers, it is utilized for space maneuvering [8].

Figure 4 Apollo Reaction Control Systems (RCS)

Modular components like CubeSat thrusters are being used more frequently due to New Space industry's explosive growth, and electronic miniaturization is opening up new satellite configurations and capabilities. Thruster is intended for use in launch vehicle applications or for controlling the attitude, trajectory, and orbit of bigger satellites, such as geostationary satellites [9]. To produce a moderate specific impulse at a low power level, pulsed plasma thrusters (PPTs) use a solid fuel like polytetrafluoroethylene (PTFE), better known by its brand name, Teflon [10]. In order to accomplish orbital maneuvers and regulate attitude, the propulsion system and orbit maneuver integration in CubeSats project seeks to address some issues. The basic issue is the difficulties associated with integrating a tiny electric propulsion system on a CubeSat. CubeSats, which normally lack propulsion systems are unable to navigate much outside of their initial orbits [11].

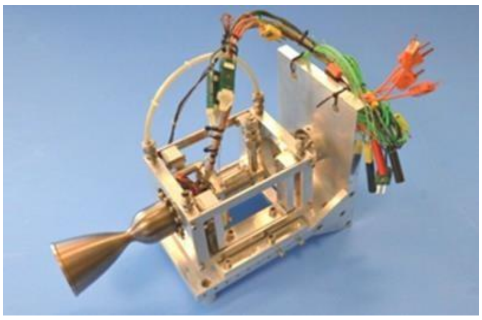


Figure 5 CubeSat thrusters [12]

As seen here, CubeSats employ passive electrospray thrusters as a precise Reaction Control System (RCS) to perform quick slews and precise low thrust maneuvers [13].

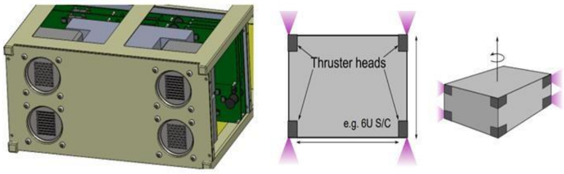


Figure 6 Electrospray thrusters as a precision CubeSat RCS

III. AIRCRAFT THRUST REVERSERS

When deployed, a thrust reverser enables the creation of a propulsion force directed rearward. The process of temporarily rerouting an aircraft engine's exhaust so that it is directed forward rather than aft is known as thrust reversal, or reverses thrust. This provides slowing by acting against the aircraft's forward motion [14]. Kinematics that is lighter and less expensive makes up the reverser [15]. The thrust from the engine can be reversed in a variety of ways depending on the design and configuration of thrust reversers. They have the following configuration: clamshell doors from the aft of the turbine, target type from the exhaust, and cascade (blocker) from the cold fan stream [16].

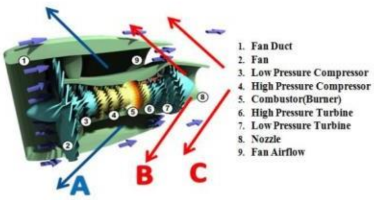


Figure 7 Thrust ways of reversing

There are three types of reverser designs; according to the airflow system namely Cascade, Target and Blocker (deflector) types [17]. From the designs of thrust reversers, there are various types of reverse thrust constructions and can be summarized as follows;

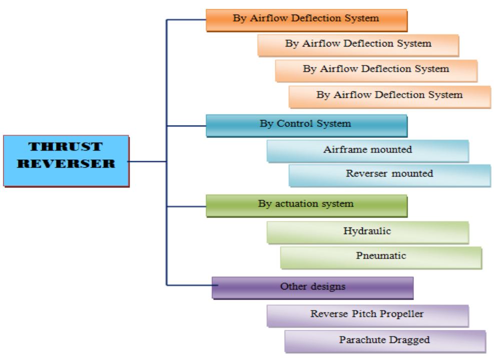
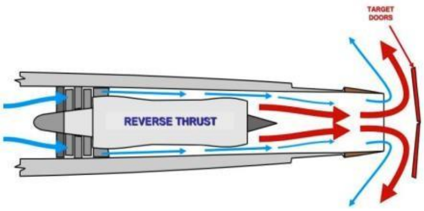


Figure 8 Classification of thrust reverser

The different reverse thrust designs are cascade, target, and blocker types. There are other designs using in aircraft reversing such as reverse pitch propeller and parachute.

i. Target-type Reverse Thrust

Hot stream duct or bucket target system (bucket type) is other names for it. The hot gas stream is reversed by bucket-type doors in the hydraulically operated bucket target system. A traditional pushrod method is used to operate the thrust reverser doors. The hot gas stream is reversed by bucket-type doors in the hydraulically operated bucket target system. Through two pushrods, one for each door, a single hydraulically driven actuator is coupled to a driving idler to actuate the doors. The drive idler maintains the synchronization of the reverser doors [18].



(a)

(b)

Figure 9 Target type thrust reverser (a) Sketch (b) Actual

The engine's convergent/divergent exhaust nozzle is formed by the thrust reverser buckets while the engine is in the forward thrust mode. As seen in the accompanying image, each engine has one reverse thrust and two bucket doors in each reverse thrust [19]. The figure below illustrates the three situations in which the target type thrust reverser mechanism can operate: forward thrust (no reverse), idle thrust reveres (partial reverse), and normal thrust reverser (full reverse) [16].

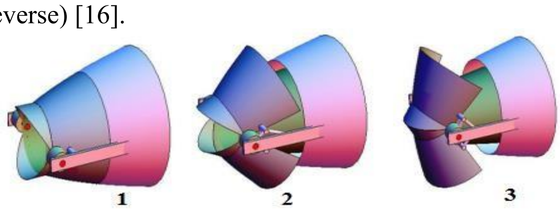


Figure 10 Target type thrust reverser modes of operation.

ii. Clam shell type

Pneumatic operation is used to actuate the clam-shell door or hot stream system. As soon as the reverser is turned on by shutting off the regular gas exit, the doors can rotate by shutting off the duct for the hot stream. As seen in the graphic below, cascade vanes are made to steer the gas stream forward so that the reversed jet thrust opposes the motion of the airplane. They are frequently found on turbofan engines, but because of the intricacy of the design, this system would not be as successful as the target system on turbojet engines. Clam shell thrust reversing nozzles are commonly used on both military and commercial aircraft. The DC-9 is an example of a common design [18] [20].

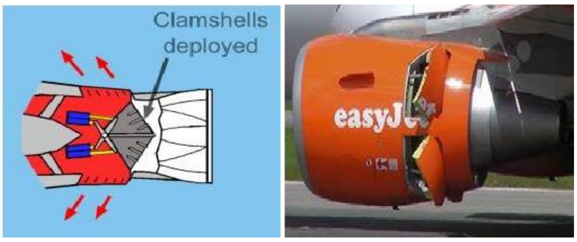


Figure 11 Clamshell reverse thrust design.

iii. Cascade (cold stream) type

A cascade design diverts the air in a direction opposite to the initial air stream flow by installing a series of cascade vanes around the engine nacelle. A sliding or hinged door covers the cascade designs incorporated into the side of the engine nacelle. When the door opens, the air streams that travel through the engine are immediately blocked off by reversing them. By converting the thrust into drag that prevents the airplane from moving ahead, this redirected air will reverse its direction. When we choose reverse thrust, the actuation system diverts the airflow through the cascade vanes by moving the translating cowl rearward and opening the blocker doors to blank out the cold stream final nozzle [21].

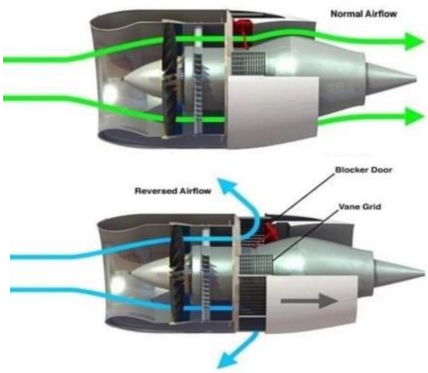


Figure12 Cascade thrust reverser design.

Cascades are typically applied to the hot exhaust gases that pass through the nozzle of a turbojet or turbofan engine as well as to the cool bypass air. The Boeing 737, DC-8, C-17, and other large military transport aircraft are among the commercial aircraft that frequently use them [22].

iv. Other Thrust reverser Designs

a. Drogue parachute

In order to create drag, decelerate the aircraft, and improve stability, these parachutes are released upon landing. Aircraft and spacecraft recovery systems employ them [23].

Figure 14 B-52 bomber during landing with extended parachute

b. Reverse Pitch propeller

Aircrafts can be slowed down by reverse pitch propellers using controllable propeller where the blade angles can be changed to a negative value during operation [24].

Figure 15 Hercules during landing with reverse pitch propeller

IV. DIFFERENT DESIGN FEATURES OF THRUST REVERSER WITH PATENTS

Nowadays there are different designs employed for different types of target type thrust reverser. Bucket target system is more efficient than the other thrust reverser mechanisms. There are different patents and inventions related to this and for design comparison are as follows;

i. Pivot Fairing Thrust Reverser

Two doors that cover matching portals in an exhaust duct between an inlet and outflow nozzle at opposing ends are part of a thrust reverser. Additionally, the duct has two side beams with actuators fixed to them. The reverser doors in pre-exit type thrust reversers are positioned upstream from the nozzle's discharge end. It integrates the doors in both the stowed and deployed positions usually require a more intricate construction [25].

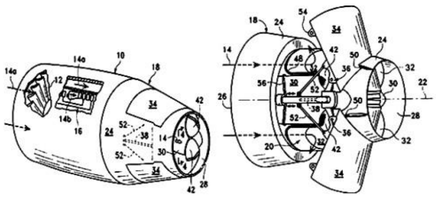


Figure 16 Pivot fairing thrust reverser in stowed and deployed positions

ii. Screw Jack Mechanism

Usually powered by a drive motor, this mechanism consists of two nested screw jacks. The blocker doors are translated aft by the inner screw jack and deployed into the engine jet stream by the outer screw jack [26].

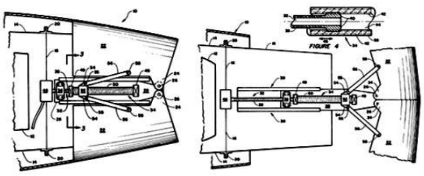


Figure 17 Diagrammatic side elevated section of aircraft screw jack mechanisms thrust reverser

iii. Fishmouth Thrust Reverser Nozzle

A target-type deflector door that is hinged for deployment about a fixed axis by means of actuation about single fixed pivots mounted on support structure on either side of the engine nacelle. The rearward portion is part of a thrust reverser nozzle for coaxial-flow turbofan engines [21].

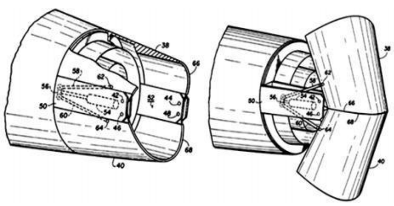


Figure 18 Section view of fish mouth thrust reverser

iv. Other patented designs

The thrust reverser system for a jet aircraft engine is the subject of this innovation. The invention specifically relates to a target-type thrust reverser system for an exhaust nozzle-equipped jet aircraft engine. In order to create a concave surface that contacts the engine exhaust gas stream and reroutes it in directions that produce a reverse thrust force tangent, the thrust reverser system works by translating pivoting doors [27].

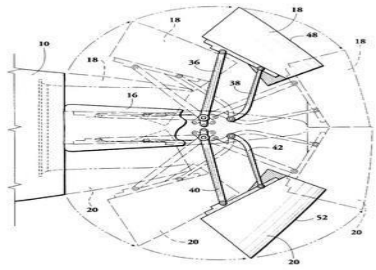


Figure 19 Reverse thrust door side filler tangent

In general, this invention pertains to jet engine thrust reversers; specifically, it concerns a target type thrust reverser where the doors are fixed to sliding pivot joints [28].

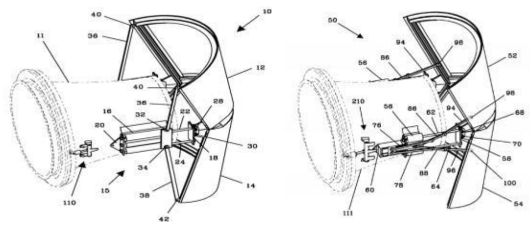


Figure 20 Thrust reverser with sliding pivot joint

System for adjustment of thrust reverser Fixed-pivot door target-type for coaxial-flow turbofan engine exhausts is the focus of the current invention [29].

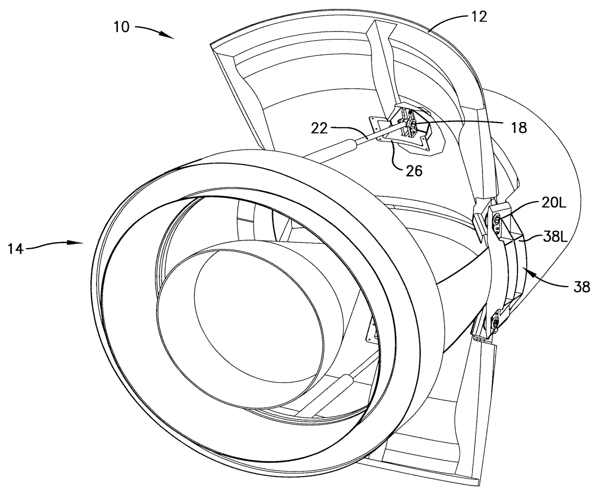


Figure 21 Thrust reverser with fixed pivot

V. TARGET TYPE THRUST REVERSER BUCKET ANGLE AND THRUST CHARACTERISTICS

The reversed exhaust stream should ideally be pointed directly ahead. This isn't feasible for aerodynamic reasons, therefore a 45° angle is used instead, which makes it less effective than it could be [14]. If the gas were rotated sufficiently and allowed to attach to the external fairing, reverse thrust ratio values of up to 84% may be achieved [30].

Figure 22 Aircraft Target type thrust reverser in deployed position

All three types of reversers produced reverse thrust ratios more than 40 percent, both with and without reverse flow attachment and with controlled reverse flow patterns.40% was given by the ring type with a 7^0 external fairing, 49% by the target type with a 7^0 fairing, and 73% by the tail pipe-cascade type with a 0^0 fairing. Maximum reverse thrust can be achieved at 75^0, but the flow is connected to the cowl. The flow is separated from the cowl and the maximum reverse-thrust ratio is preserved by actuating the reverser to the 90^0 position [31].

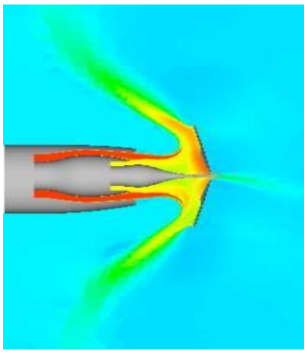


Figure 23 Exhaust deflection at maximum angle at $\alpha=90^o$ [32].

I use the thrust-modulation characteristic below as my primary reference to determine the thrust at various actuation angles. In the figure below, the actuator, torque, and reverser actuation position, will be examined. Plotting the reverse-thrust ratio versus the reverser's angular location is done. Percentages of forward thrust correspond to negative reverse-thrust ratio numbers. Additionally, reverse-flow boundary sketches are displayed. The relative magnitude of the reversed-flow velocity is shown by the darkening inside the reverse-flow boundaries. The reverser does not intercept the jet during the first 15^0 actuations. A 1^0 change in actuation angle results in a roughly 3-percentage-point variation in thrust between 30^0 and 75^0. Maximum reverse thrust can be achieved at 75^0, but the flow is connected to the cowl. The flow is detached from the cowl at an actuating position of 90º. At this angle the maximum reverse-thrust ratio is maintained [33].

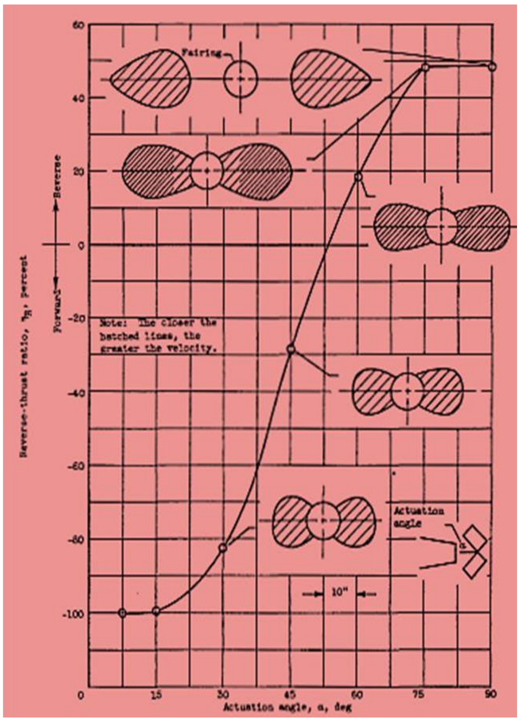


Figure 24 Thrust-modulation characteristics of cylindrical target-type thrust reverser.

VI.CONCLUSION

A thrust reverser is used for the rearward-directed thrust force applied when deployed. Thrust reversing is a technique used to change attitude or to maneuver in different axes. They have a wide application in aerospace. It is reviewed different thrust reverse designs, types and their operating mechanisms. Thrusters are frequently used in space technology such as CubeSats. Different reversers' designs are reviewed such as cascade, blocker, target, drogue parachute, reverse pitch propellers types in aviation as well as thrusters for small satellites. There are different inventions and patents in these areas which show there are gaps in designing unique thrust reverser or thrusters. There should be some safety mechanisms and sensors to facilitate the operation of synchronized buckets. Different patents and designs are analyzed in the review paper for target type thrust reversers since they are simplest when compared to others. All target type thrust reverser's actuation angle and thrust relationships are plotted on thrust modulation characteristic graph. This should be programmed in more accurate and vast data to analyse for different engine type, bucket design and performance characteristics.

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