A MODEL CASCADE THRUST REVERSER DESIGNED BY CHANGING OUTLET VANE ANGLE AND DECLINING CASCADE TOWARDS ENGINE CENTRE LINE.

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Abstract – A thrust reverser uses for fan jet type aircraft gas turbine engine. A nacelle assembly for turbo fan engine includes a translatable sleeve and blocker in such way that the air flow in the bypass duct is directed out the cascade assembly. The paper is aimed to increase the performance of conventional cascade assembly with two alternative designs and achieved by calculating Thrust Reverser of prototype which is designed on Solidworks and parts are 3-D printed.

Key Words - 3-D printing, cascade, engine centre line, innovated, nacelle, outlet vane angle, solidworks, thrust reverser.

I. INTRODUCTION

Landing is the least section of operation, during which the aircraft returns to ground. \cite{1} For landing purpose, breaks are responsible for conversion of excess kinetic energy into thermal by increasing the friction, thereby reducing the speed of aircraft vehicle. There are three methods for deceleration of aircraft namely, Mechanical breaks, Hydraulics and pneumatics retardation systems. Mechanical breaks are operated by the use of linkages, leavers, cams etc. while on other the hand, fluid pressure act as primitive for hydraulic breaks and air pressure for pneumatic breaking. \cite{2} Although, from very beginning mechanical breaking systems were dominating, however there are substantial stresses established on wheel and additionally these system are inadequate. These conventional breaks are ineffective especially for adverse conditions like icy or wet runways, short runway and/or rejected take-offs. \cite{2}

In order to overcome this, principle of thrust reverse is came to existence and it states ‘Create an opposing force of aircraft carrier using the exhaust gas in reverse direction of vehicle motion. The developed opposing force produces drag force which slows down the aircraft carrier.’ Reducing stopping distance is major concern of thrust reverser. It provides ample opportunity to alleviate runways, amortizing wheel tear and taxi distance. Typically, there are three types of thrust reverser 1. Clamshell, 2.External Bucket Type and 3. Cascade/ Blocker door type. Figure, 1 shows, three type of reverse thrusts, where A, B and C indicate Blocker door type, clamshell type and external bucket type thrust reversers respectively. \cite{3} In figure 2, a relation between work done and landing run with respect to utilization of thrust reverses in icy/wet runways and suggest that landing run is abridged by 2.5 kilometres. \cite{4}

II. PROBLEM DEFINITION AND AIM

2.1 Problem Definition

During the reverse thrust operation, a translatable sleeve is moved from stowed position to deployed position and exposes the cascade assembly and blocker door. \cite{5} Which in turns exposing a cascade assembly and blocker door. In this deployed position, the blocker door redirects the airflow in the bypass duct to exit through nacelle out the cascade assembly.

The conventional cascade assembly though are not fully efficient due to two reasons. Firstly, as shown in figure 3, the outlet vane angle of cascade in 60\degree, from equation of reverse thrust the maximum reverse thrust is obtain when this angle is ideally 0\degree. Also at least from the experimental and empirical data, because of momentum of the bypass airflow in the bypass duct, the majority of reverse thrust is generated within the aft portion of the conventional cascade assembly. At this
particular region the duct has created ‘Dead Zone’ in which the majority of airflow is crowded into relatively small area of assembly, which restricts the airflow existing though cascade assembly. The restricted airflow results in a reduced airflow exit velocity and eventually it’ll reduce reverse thrust. Thus, both of them, the typical 60° outlet angle and crowded zone nullify the reverse thrust produce by thrust reverser. [6] Figure 4 describes velocity couture; at particular dead zone it’s created supersonic flow which is not appropriate. [7]

2.2. Aim

The paper illuminate following objectives. The prior art aims at increasing reverse thrust. In order to achieve so, modify the outlet vane angle, increase outlet velocity and noteworthy subsiding lading distance and ensure safe aviation.

III. DESIGN AND THREE-DIMENSION PRINTING

3.1. Solidwork Design

This chapter contains the detailed designs and complete assembly; it includes data collection as primarily to design nacelle and cascade assembly.

3.1.1. Nacelle Design

In order to calculate reverse thrust, replicated design of 1:25000 scaled model of GE nx 1B is designed on Solidworks. The table 1 shows, specification of GE-nx 1B. [8] Figure, 5 shows solidwork design GE-nx 1B nacelle design.

3.1.2. Cascade Assembly

Firstly, conventional cascade with outlet vane angle 60° is designed [7]. Additionally, two modified design respectively 45° outlet vane angle and 45° outlet vane angle including with 6° declined toward engine centre-line. Table 2 shows, all the three type of cascade and their specification; additionally figure 6 shows sectional view of three cascades respectively.

3.1.3. Complete Assembly

Figure 7 shows detailed assembly of complete model for thrust reverse calculation.

IV. CALCULATION AND EXPERIMENT

4.1. Derivation of Reverse thrust equation

The air is drawn through right to left through axial fan. As shown in figure 8, when aircraft lands the door close the portion and forces air to exhaust out from cascades.

Assumptions,

- Neglecting thrust in Y and Z direction.
- Considering the only steady state condition.
- The density of air is constant throughout the section.
- There are no effect of pressure and temperature.
- Considering the law of mass equilibrium.

Diameter of fan $D_{fan} = 2$ m
Mass of air $m_{air}$
Angle of deflection of thrust reverser is $\theta$
Entering Velocity $V_1$
Leaving Velocity $V_2$

The momentum equation o X-direction can express as,

$$\sum F_x = \frac{\partial \int_{CV} u p dV}{\partial t} + \int_{CS} u p V \cdot n dA$$

Under steady state conditions, the above equation (1) the term $\frac{\partial \int_{CV} u p dV}{\partial x} = 0$. 

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Thus,

$$\sum Fx = \int_{CS} u_p V \cdot n \, dA \quad (2)$$

Now, the only force acting on control volume is the force of thrust reverse on the air. This force causes momentum in negative x-direction at 1 and in both direction y and positive x-direction at 2.

Summing up the net force acting in C.V., is actually in positive x-direction, because the airplane is flying with certain velocity from left to right. Hence, reverse thrust on air is in positive x-direction and from Newton’s third law of motion, the reverse thrust on aircraft is in negative x-direction.

$$\vec{F}_{\text{reverse} \rightarrow \text{air}} = \int_1 u_p V \cdot n \, dA + \int_2 u_p V \cdot n \, dA \quad (3)$$

Further simplifying the equation, following equation is used to calculate reverse thrust.

$$F_{\text{reverse}} = - (\rho A_1 V_1^2 + \rho A_2 V_2^2 \cos \theta) \quad (4)$$

From the above equation the variables are $A_1$, $V_1$, $A_2$ and $V_2$.

### 4.2. Experiment and Data Collection

In order to calculate reverse thrust, from the equation 4, $V_1$ and $V_2$ have to calculate. Velocities can be calculated using Anemometer.[10] For the current practical, HE-81 Anemometer was used. The table 3 shows average inlet, outlet velocities, calculated reverse thrust for all the three cascade elements.

### V. RESULT AND DISCUSSION

The results consist of mass comparison, vane exit velocity, outlet velocity verses thrust reverser, outlet vane angle and T/R and finally declination angle and T/R.

#### 5.1. Mass Comparison and Reverse Thrust

The aim of present invention is to reduce the weight of cascade assembly. The weight reduction is effectively achieved in innovated cascade. Table 4 shows, increment or decrement in mass and thrust reverse. Also chart 1 shows them graphically.

Talking about comparison of convention cascade and inclined cascade. The mass reduction is achieved by 13 per cent approximately and its reduced reverse thrust by marginally 1 per cent.

However, on other hand, the results are incredibly for second alternative design. Although the weight reduction is similar, the amount of thrust reverse has hiked by 7.37% due to inclination of cascade segments towards decline position by 6º.

#### 5.2. Vane Outlet velocity and T/R

The equation (4) suggests that, T/R is directly proportional to square of outlet velocity and this statement is equally justified by chart 2.

#### 5.3. Outlet vane angle and T/R

According to equation (4), as angle $\theta$ tends to 0 or 180 the reverse thrust would be maximum that is equal to forward thrust and provided exactly cent per cent revere thrust efficiency. But the result are contradict. According to theory, the value of T/R for 45º expected to be higher than 60º, however the T/R is reduced by 0.91% for 45º opposing to theory.

#### 5.4. Declination and T/R

As explained by figure 3 and 4, the Dead Zone has created in duct produced by inner nacelle and outer engine assembly. In this region, the total exit velocity is reduced and eventually lowered the value to T/R.[7] When the cascade assembly is declined, it has create the scoping action and resulting higher reverse thrust. The declination in this prototype is 6º and has approximately 7 per cent T/R increment.
VI. CONCLUSION

This research area as discussed worked on two innovated cascade designs, namely first one to change the outlet vane angle from 60º to 45º and second is situated at the declined position towards engine centre-line. The main aim and objective as stated is to increase the amount of reverse thrust and mitigate the dead zone.

The reverse thrust depends upon outlet cascade vane angle; the outlet vane angle varies 0º to 180º. The conventional cascade outlet vane angle was 60º, but from the equation (4) as angle tends to zero the thrust reverse efficiency is max. Fortunately, vane angle of zero degree is next to impossible rather the effective angle is 45º. The 45º vane outlet angle so designed to have approximate 13% less weight. However, after the experimental approach the results are unexpected. The overall thrust reverse efficiency is lowered by fractional margin. Notable results are achieved and only reduction by 0.91% and justify that ideal outlet vane angle is 60º.[9] Considering weight factor, previous arts performed several attempts to reduce the cascade weight by 5% & 10% and achieved reverse thrust of -2.5% & - 2.2% respectively. Chart 3, illustrates the difference between prior art attempt and our design. Hence, the research art mention has higher reverse thrust at higher reduced weight. In attempt, although revers thrust is reduced, the supersonic flow, which existed in the original design, was eliminated after altering the design and weight reduction. [7]

The amount of thrust reverser is hiked by 7% in declined position. As mention in Patent no. US 9068532 B2 ‘Translatable Sleeve Thrust Reverser with Movable Cascade’ [6] and research paper ‘The Aerodynamic Performance of a Thrust Reverser Cascade’ [7] discussed a dead zone in which relatively little or none of the bypass airflow is converted into thrust reverse application. The innovated concept of declining the cascade towards engine centre-line (imagination line) by 6º provides high exit velocity. It mitigates the phenomena of a major bypass airflow crowded into relatively small area and restriction of reverse thrust practice. The declined cascade through experimental approach proved to increase exit vane velocity, in turns increase reverse thrust. This improves the reverse thrust efficiency. An improved thrust reversing could serve as reduce fuel consumption at landing roll and enable safer aviation.

Conclusively, the innovated concept of reverse thrust cascade towards engine centre line gives both advantages of reduced weight and higher revere thrust. The advanced and improved reverse thrust may recognize as a revolutionary design in research area of cascade thrust reversers.

Figure 1 Type of T/R
Figure 2 comparison of work done and landing run

Figure 3 Deployed Cascade Assembly

Figure 4 Dead Zone

Table 1 GEnx 1B Specification

| Sr. No | Characterises | 787 Engine GEnx-1B |
|-------|---------------|---------------------|
| 1     | Type          | Turbofan            |
| 2     | Manufacture   | General Electric Aviation |
| 3     | Bypass Ratio  | 9.6:1               |
| 4     | Overall Pressure Ratio | 50 |
| 5     | Thrust Class  | 240 – 330 KN        |
| 6     | Fan Diameter  | 111-112 in          |
| 7     | Fan           | 1                   |
| 8     | Length        | 4.69 m              |
| 9     | Diameter      | 2.88 m              |
| 10    | Landing Speed | 75-85 m/s           |
Table 2 Cascade Specification

| Cascade Segments        | Crucial Description                                      |
|-------------------------|----------------------------------------------------------|
| Conventional Cascade    | Outlet Vane Angle 60°                                     |
| Inclined Cascade        | Outlet Vane Angle 45°                                     |
| Declined Cascade        | Outlet Vane Angle 45° and Declined to engine centre-line by 6° |

Figure 5 GE9x 1B Nacelle

Figure 6 Cascade Specification

Figure 7 Detailed Assembly
Table 3 Experimental Data

| Sr.No | $V_1 (m/s)$ | Convention | Inclined | Declined |
|-------|-------------|------------|----------|----------|
|       | $V_2 (m/s)$ | $F_{rev}(N)$ | $V_2 (m/s)$ | $F_{rev}(N)$ | $V_2 (m/s)$ | $F_{rev}(N)$ |
| 1     | 8.283       | 1.172      | 0.729848 | 1.065    | 0.714753 | 1.555    | 0.76594498 |
| 2     | 8.319       | 1.204      | 0.735912 | 1.102    | 0.73570476 | 1.62     | 0.7807301   |
| 3     | 8.283       | 1.130      | 0.725174 | 1.119    | 0.7204377 | 1.824    | 0.80573766  |
| Avg   | 8.295       | 1.1687     | 0.730311 | 1.0953   | 0.72363182 | 1.6663   | 0.78413758  |

Table 4 Mass and Thrust Reverser Design

| Design   | Mass | Thrust Reverser |
|----------|------|-----------------|
| Conventional | -    | -               |
| Inclined   | -12.82 | -0.91          |
| Declined   | -15.17 | 7.37           |

Chart 1 Mass and Thrust Reverser

Chart 2 Outlet Vane Velocity Vs. T/R
REFERENCES

[1] Phases of Flight Defination and Usage Notes, International Civil Aviation Organization, 2011
[2] ShrutiNiar, Shreya Nair, ‘Aircraft Braking System’ Vol 4 Issue 1, International Journal of Mechanical Engineering and Technology, April 2014
[3] MohdAneesSiddiqui, ‘Utilization of Thrust Reverser Mechanism in Turbofan Engine- A Review’, Vol 1, Issue 3, International Journal of Technical Research and Application, July-August 2013
[4] J. A. Yetter, ‘A Compilation of Airline Industry Responses to a Survey Regarding the Use of Thrust Reverser on Commercial Transport Airplanes’, Why Do Airlines What and Use Thrust Reverses? , NASA Langley Research Centre, January 1995
[5] Jihad. I. Remlaoui, ‘Cascade Type Aircraft Engine Thrust Reverser with Hidden Link Actuator’, United States Patent (Patent Number US5228614), Jul. 20, 1993
[6] Timothy Gormley, ‘Translatable Sleeve Thrust Reverser with Movable Cascade’, United States Patent (US 9068532 B2), Jun. 30, 2015
[7] H.Yoa, J. Butterfield, S. Raghunathan, R. Cooper and E. Benard, ‘The Aerodynamic Performance of A Thrust Reverser Cascade’, International Congress of The Aeronautical Science, 2004
[8] GE Plans mid-July nod for GEnx Siblings. Retrieved from Flight International: http://www.flightglobal.com/news/
[9] John H. Povolny, Fred W. Stefeen and Jack G. MaArldld, ‘Summary of Scale-Model Thrust Reverser Investigation’, Report 1314, NASA
[10] Gerard J. McNally, ‘A Thrust Anemometer for The Measurement of The Turbulence Wind Vector’, Research Division, New York University, School of Engineering and Science, University Heights, N.Y. 10453, Geophysics Sciences Laboratory TR 70-1