OVERVIEW ON THRUST REVERSER DESIGN

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Abstract. *Aircraft landing speed is usually high. Efficient braking system is essential. The braking system is improved with the use of thrust reversers. The higher the landing speed the higher efficiency on the thrust reverser is required. In adverse conditions, like wet and icy runways, when deceleration of the aircraft with the wheel brakes becomes poor, thrust reverser utilization is a must. In order to acquaint with the thrust reverser technology and design, a literature review was carried out aiming at the cascade-type thrust reverser. A design methodology was defined that is adequate for a cascade module design. To account for the total needed thrust reverser drag (braking force), several cascade modules may be assembled, directing the outflow to different directions, avoiding re-ingestion and contact with the aircraft surfaces.*
Example of thrust reverser cascade calculation ant total braking force is presented.

Keywords*: Reverser, thrust, cascade, CFD, boundary condition.*

1. Introdution

The study of thrust reversers reported here is within the scope of design and grid generation for thrust reverser developed by ITA. This paper deals with the proposition of a procedure for the aerothermodynamic design of a module of a cascade thrust reverser.

2. Literature review

At the 50's, a research program was inaugurated at the NACA Lewis Laboratory to isolate the more promising concepts of thrust reversers and to investigate its performance characteristics, as presented by Povolny, Steffen and McArdle (1957). Dietrich (1975) released some articles showing experimental tests that evaluate the influences of several thrust reverser installations parameters. A research on airline industry was made about the advantages and disadvantages of the use of thrust reverser on commercial transport airplanes by Yetter (1995). Johns (2000) showed the solution of an engine inlet compatibility problem in C-17 by CFD analysis. Recently the NASA Innovative Thrust Reverser Program released a report of six innovative thrust reverser concepts for very high bypass ratio engines, used in subsonic transport aircrafts as presented by Asbury and Yetter (2000). Chuck (2001), Trapp and Oliveira (2003) made simulations of external flow on commercial aircraft. Butterfield *et all*. (2004) studied the improvement of thrust reverser design by using computational tools.

3. Cascade thrust reverser

Thrust reverser is a device installed in the aircrafts to provide reverse thrust to decelerate the aircraft during landing. The cowl-mounted cascade thrust reverser is a pre-exit device composed of an internal blocker and a cascade located on the cowl. The flow is deviated by the blocker to the cascade that guides it forward producing reverse thrust.

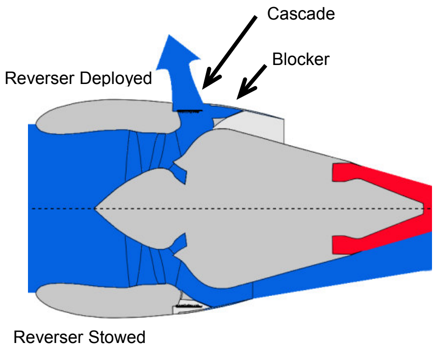

Figure 1. Cowl-mounted cascade thrust reverser

4. Thrust Reverser Design

The thrust reversers design comprises three main stages: the choice of the type of thrust reverser, the geometry design and drive mechanism design. The geometry design involves the definition of the aerodynamic and geometric parameters and its evaluation using performance parameters.

Up to 80% of the component total cost is associated with the design; thus, the development of tools capable of shorten this phase is of great importance. In this way, Finite Elements Analysis (FEA) and Computational Fluid Dynamics (CFD) have been successfully applied to thrust reverser design (Butterfield *et al.* 2004).

The thrust reverser design must attain the following requirements:

When stowed, it must:
- avoid extra drag and,
- not affect engine performance.

When deployed, it must:
- not affect the engine operation limits,
- avoid re-ingestion of the reverted jets,
- avoid foreign object damage (FOD),
- avoid impingement of the reverted jets on the fuselage,
- avoid buoyancy on the nose,
- avoid controllability problems,
- allow the cutoff speed to be as low as possible
- result in maximum reverse thrust.

It is an iterative process involving the following steps:
1. Establishment of the geometric configuration of the cascade thrust reverser;
2. Establishment of the fan exit design conditions, using an engine deck for engine simulation;
3. Loss estimation and design point cascade flow parameters calculation, to produce the module geometry;
4. Engine performance prediction with integrated reverser modules;
5. Reevaluation of the channel losses and cascade inlet angle based on axisymmetric flow calculations;
6. Repetition of steps 2, 3 and 4 until the results in 4 agree with the initial guesses;
7. Reevaluation of the cascade angles based on 3-D external flow calculations;
8. Repetition of steps 2, 3, 4, 5 and 6 until the results in 6 agree with the design requirements;

5. Performance Parameters

The thrust reverser efficiency η_y is defined in Eq. 1 as the ratio of the reverse thrust F_r under static condition $(V_0 = 0)$ and the engine forward thrust F_f at the same power conditions. According to Asbury and Yetter (2000), for a cascade thrust reverser its value is of the order of 0.3:

$$\eta_r = \frac{F_r}{F_f} \tag{1}$$

The area match parameter β is defined as function of the ratio of the thrust reverser effective area A_r to the fan nozzle effective area A_{fan} operating at forward thrust mode.

$$\beta = \frac{A_r}{A_{fan}} \tag{2}$$

6. Geometric Configuration of the Cascade Thrust Reverser

The channel geometry, when the thrust reverser is deployed, is dependent on the bypass channel and blocker geometries and on the axial placement of the cascades. It defines the cascade inlet aerodynamic characteristics. The azimuthal location, number and dimensions of the cascade sectors (modules) influence the area match and the thrust reverser performance on lateral wind conditions. A sketch of the modules located around the nacelle is shown in Fig. 2.

7. Fan Exit Design Conditions

A generic engine deck developed at ITA was used for the definition of the initial parameters at fan exit. Numerical values are obtained for:
- Stagnation temperature at fan exit;

- Stagnation Pressure at fan exit;
- Mass flow at fan exit.

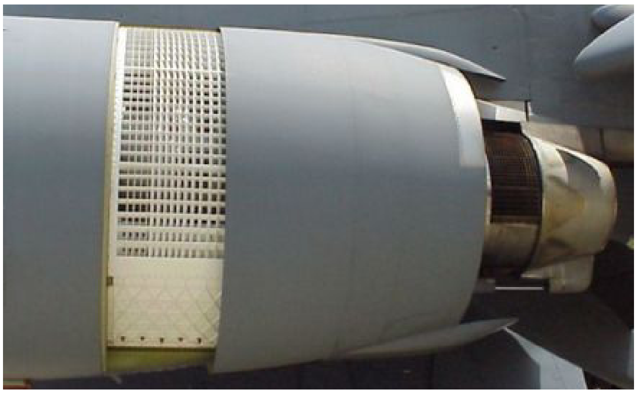

Figure 2. Example of modules placement around the nacelle and some modules

8. Cascade Calculation

For the sake of the thrust reverser performance prediction, preliminary geometry estimation for the standard cascade module is carried out, beginning with assumptions on the streamlines and cascade inlet flow angles, assuming 1-D and null incidence. The flow is considered compressible but the other properties are assumed constant.

8.1. Cascade inlet parameters

From Fig. 3 and additional dimensional data, the average inlet flow angle α_1 was evaluated. This angle may be estimated as starting guess from the geometry of the channel assuming streamlines distributed along the straight lines A and B shown in Fig. 3. Bidimensional CFD calculation will be used later to improve the initial guess.

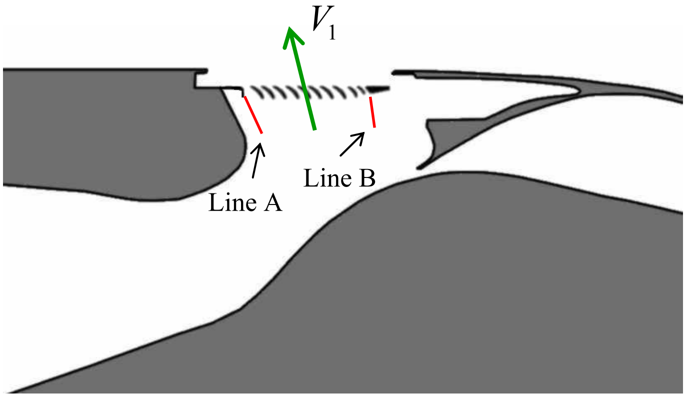

Figure 3. Engine section containing the relevant parts of the channel formed by the deployment of the thrust reverser.

The channel between fan exit and module inlet is considered as simple duct and the losses calculated using Idel'cik (1986) recommendations. As a result, numerical values are obtained for the cascade inlet:

- Stagnation temperature = stagnation temperature at exit of fan
- Stagnation pressure = stagnation pressure at exit of fan - calculated losses.
- Mass flow = mass flow at the exit of the fan – leakage (to be evaluated later, taking into account the geometry of the exhaustion system).

8.2. Module mass flow

Figure 4 illustrates a module of thrust reverser, with the cascade blades assembled at an angle ψ with the tangential direction. The evaluation of the engine installation on the aircraft will indicate the best distribution of the N modules around it, as well as the expected orientation of the thrust reverser flow. The angles $\psi_i, i = 1,\ldots, N$ are then determined.

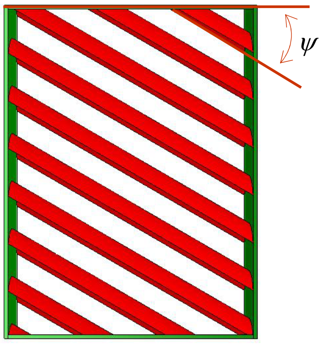

Figure 4. Module skew

The calculation of the mass flow, $\dot{m}_P$, in a standard module (in which $\psi = 0$) is made taking into account the angle ψ of all modules, see Fig. 5 and Fig. 6.

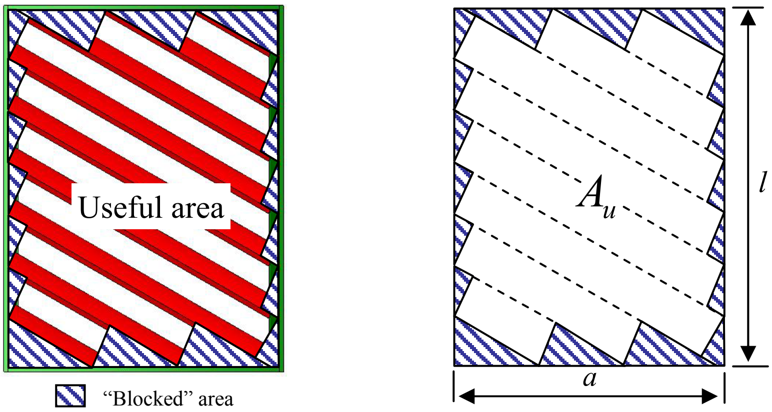

Figure 5. Module areas

A blockage coefficient, K_{B_i}, was defined based on the shaded area shown in Fig. 5.

$$K_{B_i} = \frac{A_{u_i}}{a.l} \qquad (3)$$

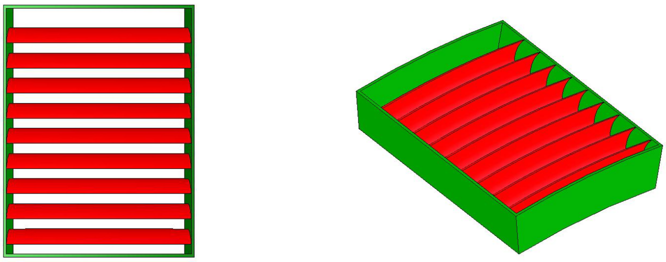

Figure 6. Standard module ($\psi = 0$)

The mass flow to be used for the standard module sizing is in Eq. 4, where $\%\dot{m}_{leak}$ is the fraction of blocker leakage and $\dot{m}_{BP}$ is the mass flow rate from the bypass.

$$\dot{m}_P = \frac{(1 - \%\dot{m}_{leak})\dot{m}_{BP}}{\sum_{i=1}^{N} K_{B_i}} \qquad (4)$$

8.3. Cascade parameters

The cascade exit angle α_2 is a key parameter to accomplish the design requirements. The cascade pressure loss is defined using Eq. 5 where P_{01} and P_{02} are inlet and outlet stagnation pressures and P_2 is outlet static pressure. Both are established at this point and will be checked later. The velocities, temperatures and pressures are obtained form velocities triangles and from continuity, energy, and isentropic relations.

$$Y = \frac{P_{01} - P_{02}}{P_{01} - P_2} \qquad (5)$$

The choice for the aspect ratio h/c involves manufacture, weight, aerodynamic and structural considerations. At this point, it will be made using the designer experience.

Cohen et al. (2001) consider profile loss as function of inlet and outlet flow angles, s/c and t/c, where t is blade maximum thickness, with the optimum value for s/c obtained as a function of α_1 and α_2.

Null incidence is initially fixed. The deviation δ, difference between the blade exit angle α_2' and α_2, is calculated using Carter's correlation (Horlock, 1966)

$$\delta = m_c \theta \frac{s}{c} \qquad (6)$$

where m_c is a function of outlet flow angle and θ is the camber angle.

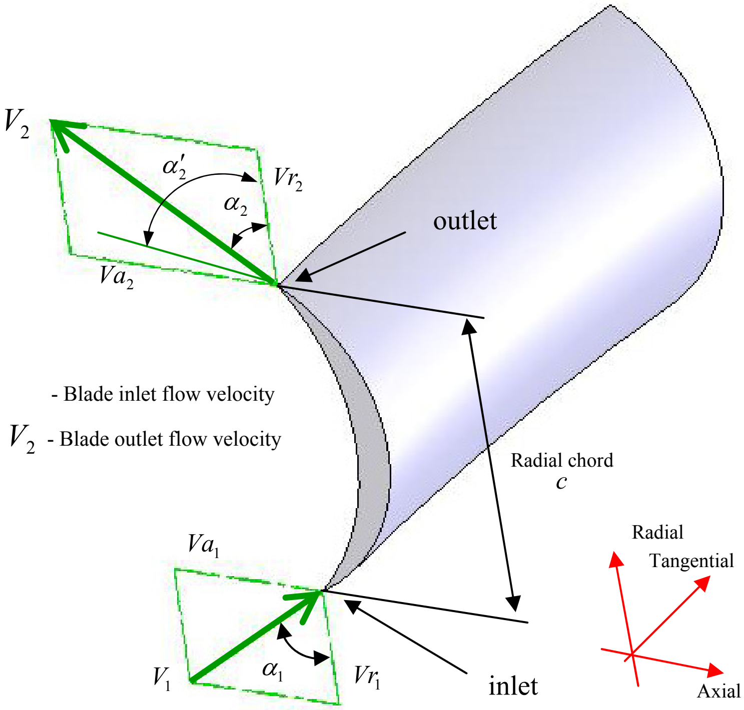

Figure 7. Blade section with indication of velocities, dimension and angles

Aerofoil sections for the thrust reverser blades were selected to guarantee low losses, therefore greatest exit fluid velocity and reverse thrust. However, Povolny (1957) suggests that the blades may also be manufactured from rolled plates, incurring in a loss of efficiency of about 5% in the reversion.

MCA airfoils of 3 arcs (see Fig.8) were selected for this study and eventually 5 arcs would be used instead.

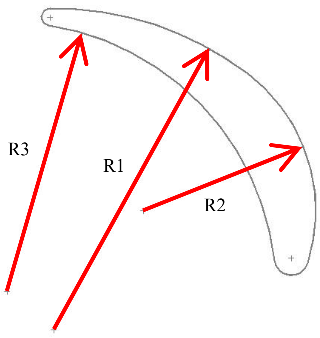

Figure 8. MCA 3 arcs airfoil

The losses are calculated by the Soderberg's correlation (Horlock, 1966), for an accelerating cascade, where Y' is a function of the flow deflection and the Reynolds number at outlet, Re_D, is calculated using the throat hydraulic diameter.

$$Y = \left(\frac{10^5}{Re_D}\right)^{1/4} \cdot \left[(1 + Y')(0.975 + 0.075.\frac{c}{h}) - 1 \right] \qquad (7)$$

The calculated pressure loss is used to confirm the initial guess made for Eq. 5.

8.4. Reverse Thrust

The reverser total thrust in the direction of the engine axis is given by Eq. 8, where F_i is the standard module thrust:

$$F_R = \sum_{i=1}^{M} F_i \mathrm{sen}\left(\alpha_{2_i}\right) \cos\left(\psi_i\right) \qquad (3)$$

Analysis of these calculations may indicate the need of revision of the initial assumptions. An interactive process may be established so that a set of parameters may be made available to proceed with the studies using 2D and 3D models.

9. Improvement to the cascade inlet boundary condition

A standard module, formed by the blades placed transversally to the engine flow as shown in Fig. 6, is dimensioned.

The initial assumptions concerning cascade flow inlet angle may be improved using the results of axisymmetric simulation of the channel flow leaving the fan and entering the cascade. The standard module design is iterative, use being made of a deck specially adapted for engine performance simulation and calculations 2D.

Although there is no flow axial symmetry, it will be admitted in order to better identify the parameters initially adopted: inlet flow angle, losses in the duct preceding the cascade, deviation, incidence, etc. This approach would give qualitative information used for the identification of regions with undesirable flow properties (high velocities, raised losses, etc.) and adequacy of the cascades geometry.

An interactive process would then be established to improve the quality of the results obtained during the preliminary design phase.

10. Engine-Aircraft Integration

This study must be carried out in order to confirm the adequacy of the thrust reverser integration to the engine and of the engine to the aircraft. One would be looking for jet flows colliding with surfaces, re-ingestion of exhaust gases, ingestion of ground debris, in additional to the total reverse force in the direction of the engine axis.

These verifications will be made through a 3-D simulation of the flow around of the nacelle and neighborhood.

11. Case study

Operating conditions ISA sea level
Forward thrust at 85% of fan design speed – 131581 N
Flight Mach number – 0.0
Stagnation temperature at reverser duct inlet – 324.1 K

Stagnation pressure at reverser duct inlet – 145.9 kPa
Fraction of blocker leakage – 0.1

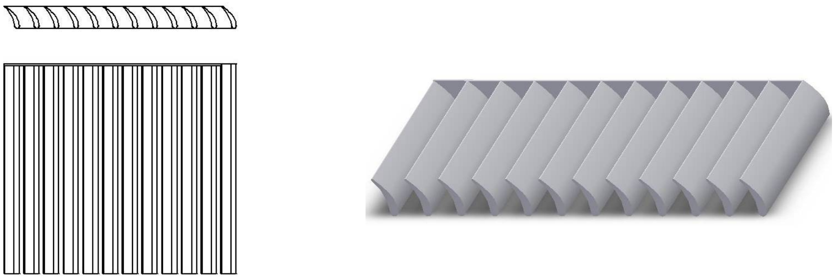

Figure 9. Standard module geometry

Number of modules – 12
Range of modules skew angles – 0 to 22 deg
Range of modules exit angles – 40 to 52 deg
Reverse thrust - 39187 N
Thrust reverser efficiency – 29.8 %

11. Conclusion

A procedure for cascade thrust reverser design is presented, comprising a one-dimensional cascade calculation, axisimmetric calculations for the internal flow analysis and tri-dimensional simulations for the external flow analysis. As this procedure requires an iterative calculation, the experience on adopting the first guesses is of fundamental importance for quick answers.

12. Acknowledgements

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6. Responsibility notice