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Noise Reduction Technology

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ABSTRACT

Aircraft noise is one of the major problems the aviation world is facing. The biggest challenge for the engineers in today‘s world is to minimise the noise and increase the performance of an aircraft. Due to the growing concern regarding the noise reduction, international organisations pushed the red button and drafted a few targets to reduce noise in the coming years. They even introduced few regulations. During the past few years many noise reduction technologies have been introduced and had a positive result. Some of them are ultrahigh bypass ratio, scarf inlets, forward swept fans, chevron nozzles, etc. In this report one of those advantageous noise reduction technologies will be discussed. Scarf inlets are the main focus in this report. The types of scarf inlets, design approach, and working of scarf inlets were discussed in detail. An analysis in terms of increased performance and decreased noise were accomplished. Fortunately, the results are quite advantageous and encouraging. In addition, the future scope of scarf inlets which is the rotatable scarf inlet is recognised and is under design process.

1. INTRODUCTION

Noise is technically defined as a series of vibration which is being transformed as sound. The biggest question for us is ―What are the prone areas which have a tendency to produce sound and what are the factors that contribute to them?‖ It depends upon various factors such as the mechanism, magnitude of operation, orientation, use of proper metals suitable for it, proper acoustic knowledge and regular maintenance. On the above note, in-depth analysis have put forward some of the areas of consideration. The magnitude of operation is major factor because a mechanical engine is harmful if they are operating at high speed because on high potential they tend to produce high vibrations, which can lead to the ageing of aircraft and tend to decrease the efficiency of engine as well as drive the energy in producing sound. Usage of proper metals and orientation of metals is also important because no metal is designed to be used for all purposes; for example, alloys of magnesium are basically meant to be used in the helicopter gear box and the blade transmission section due to their heavy damping property toward vibration. These are some of the factors which shall be discussed and studied in brief further. In regards to noise production it is transformation of energy from one form to another form. It is obvious to consider it as a loss which can be reduced to certain extent so that it will constitute in increasing the efficiency and optimising engine to enable an economically suitable flight and environmental flight. It is important to discuss because the trend is predicted so that by 2050 there would be a 200% increase in the air-traffic in coming years which draws attention and caution to _NOISE‘.

2. TECHNOLOGY BACKGROUND

2. a. Noise Reduction Technology- WHY?

The factors that led to the introduction of noise reduction technologies are as follows:

1. Usage of older aircrafts
2. Surge in the Demand
3. Environmental Concerns
4. Individual effects on a person

The use of very old aircraft by the airliners, the rapid increase in the number of passengers flying by air, the environmental effects caused by the aircrafts, and the personal consequences suffered by an individual due to continuous exposure to the aircraft noise are some of the factors that propelled the need to reduce the noise emissions of an aircraft engine.

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2. b. Source of Noise

Broadly, the sources of noise are engines, airframe, parasitic tones and other maintenance issues. The major sources of noise for an aircraft engine can be as shown in the chart below.

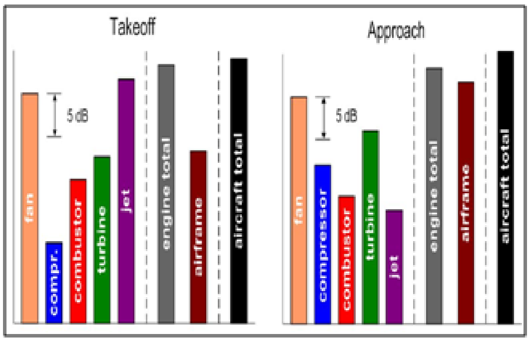

Fig: Noise emission from the aircraft

(Adapted from ―Aircraft engine noise footprint reduction via a non-uniform inlet liner concept by DominikBroszat)

1. Engine:

The main source of noise in an aircraft is the engine. It is because of substantial interaction with air and transformation in thrust. Usually they are primarily due to: take-off engine thrust, reverse thrust during landing, engine ground running (engine idling), and bleed air.

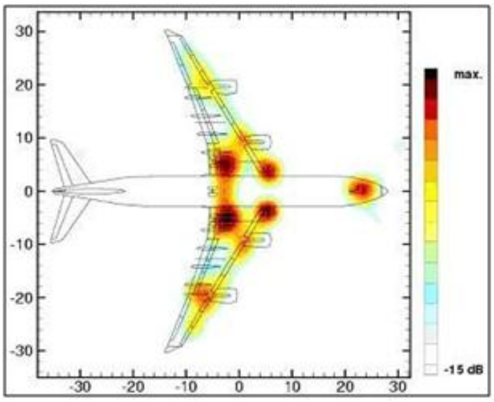

Fig: Sources of noise in an aircraft

(Adapted from ENVIA, E. 2002. Fan noise reduction: an overview. International Journal of Aeroacoustics,1, 43-64.)

2. Airframe:

High lift devices such as slats, slat horn and flaps undergo vibration and generate noise. The noise is generated by the air flow distribution over the wing. When the air is flowing over wing, there is a disturbance in the flow which leads to noise generation. The landing gears also contribute in generating noise.

3. Parasitic tones:

The nacelle de-icing ducts are also the sources of noise for the aircraft. The ducts of the aircraft tend to change the flow of the air flowing over it. The air flow above the duct and the air flow below the duct create flow disturbance. This result in minute swirls and flow variation at the rear of the ducts. Due to this variation of flow the noise is generated.

4. Maintenance issues:

Aircraft undergo huge stress and energy changes due to the forces and temperature changes acting upon it. The consequences of these forces are the wear and tear of the aircraft components. Due the wear and tear of the component the noise is generated.

2. c. Types of Noise Reduction Technologies

The various noise reduction technologies that are incorporated in aircraft are as follows:

1. Ultra high bypass ratio:

As the major sound is generated at an upstream point of engine due to separation and leading to formation of vortices, whirls leading to magnitude of vibration. These vibrations are transformed into noise at downstream point so having a Ultra-high bypass ratio thus provides solution for many problems as depicted in the research done by NASA and validated by both experimental and theoretical manner. As depicted in below diagram it clearly states that the emissions level both for co2 and noise reduces and TSFC increases due to the application of it. As the propeller gets big the stresses over the blade increase and may experience sonic conditions or beyond conditions at the tip, because of these conditions they tend to create some shock waves and distortions across the boundary layer separation.

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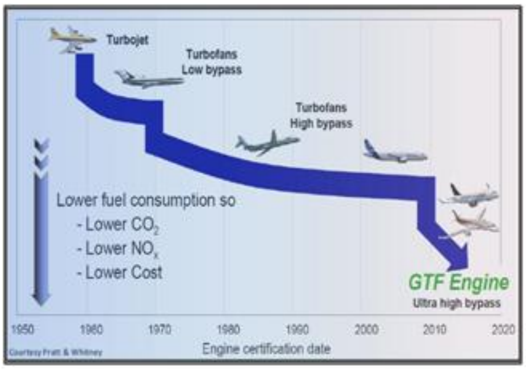


Fig: Decreased TSFC due to Ultra high bypass ratio

(Adapted from ENVIA, E. 2002. Fan noise reduction: an overview. International Journal of Aero acoustics,1,43-64.)To address the above issue the ultra-bypass ratio offers a solution in which the nacelle and engine cowling has a wide gap and increase in length which allows the air to distribute properly so that the distortions do not take place and resulting in excess thrust production without a considerable increase in propeller length.

2. Scarf Inlets:

Due to symmetry at inlet the air which enters through the lower surface and does not have a proper orientation in engine passage which results in disturbance across the whole path in engine which is not desirable and it is not mandatory for the scarf inlet to be same for all aircraft in all regime. To justify this, the aircraft‘s maximum operational speed, stall speed, and stalling angles majorly supports on the factor to calibrate known as β(Beta). It‘s basically an angle measured either in Degrees (o) or gradients. Depending upon the Beta value the inlet and nacelle are designed. This is the further research but as an example we have demonstrated a set of designs.

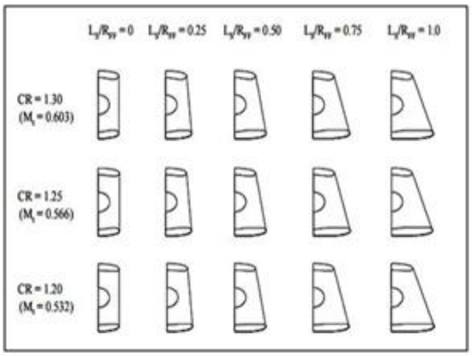


Fig: Family of Subsonic Scarf Inlets for β=180deg

(Adapted from ENVIA, E. 2002. Fan noise reduction: an overview. International Journal of Aero acoustics,1,43-64.)Figure shows the Cut out section at different Mach regimes and different operating conditions along with the front view is provided below too.

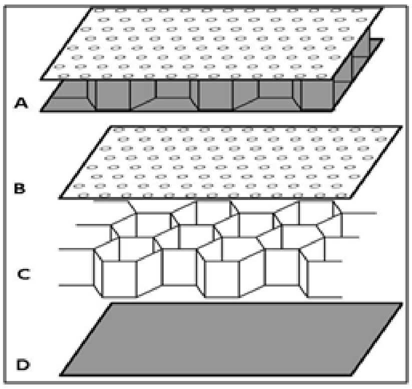
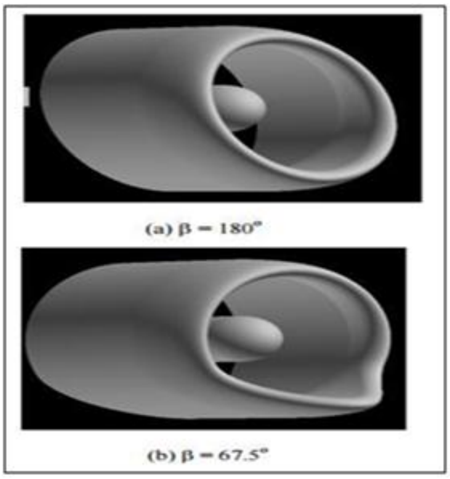


Fig: Scarf Inlets

(Adapted from ENVIA, E. 2002. Fan noise reduction: an overview. International Journal of Aeroacoustics,1, 43-64.)

3. Acoustic Liner:

The basic principle to damp the engine noise is to prevent it from entering into aircraft cabin. Acoustic liners are to be applied on internal walls of engines and across every duct. The structure generally has 3 layers Face porous layer, internal partitions (Honey comb structure) and impervious layer (Back sheet).



Fig; Acoustic Liner

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(Adapted from ENVIA, E. 2002. Fan noise reduction: an overview. International Journal of Aeroacoustics, 1,43-64.) Above figure basically creates and awareness that Layer D is the impervious layer which is our back side and have a tendency to hold varying extreme conditions which damps the noise to some extent. The layer C performs most in this phenomenon because the moving fluid damps the magnitude of noise and the fluid is considered as air in the normal condition it can be replaced with water or any extinguishing agent if there is any fire breakdown.

4. Swept stator and fans:

The main objective is to control the incoming air and should not let it lose its laminar part of flow so according to the literature review it is suggested to have a swept section in both fan and stator in compressor. The principle behind a forward swept in fan is to diffuse the internal air with appropriate decrease in its velocity and having forward swept increases the efficiency with reduction in noise. The forward swept angle shall vary and differ.

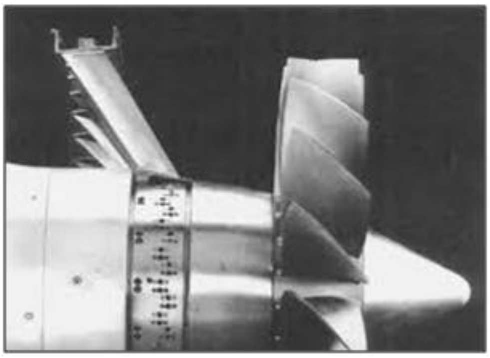

Fig: Swept stator and fan

(Adapted from ENVIA, E. 2002. Fan noise reduction: an overview. International Journal of Aeroacoustics, 1,43-64.)Swept stators are a major breakthrough because if free air stream strikes a body which is exactly perpendicular to it , it will create a large amount of loss in terms of stagnation, loss of momentum and large amount of noise. Swept stators allow the free stream to divert its way across path without creating any kind of loss and reduce the amount of noise. The swept depends on many factors such as engine spool, compressor stages, over all pressure ratio, type of engine and many.

5. Chevrons:

Typically chevrons are located at the end of engine at exhaust. It serves to maintain a exhaust so that both the jet stream and ambient merge properly and whirls which are major source of noise. This happens majorly because of variation in pressure across both the states which lead to production of sound. For an example a sonic boom, as seen mostly it is a phase where an aircraft enters in the sonic phase by creating a ring of gas across due to pressure variation in both phases and creating a large sound but the main thing to be notice is that it forms at exit of engine.

Fig: Chevrons

(Adapted from airindia.com/pictures) Chevrons enable a proper mixing. There are many chevrons in application with varying calibration and depending upon the requirement it is been developed in CFD virtually (tested) and put into practices.

2. d. Limitations

The major limitation of any research program is the technology. In thesis, the theory and analysis of the thesis is so complicated that the technology falls short for the implementation of the concept. The basic limitations of noise reduction technologies are effects of maximum speed, shock wave, stall, and sonic boom on the existing technology. The maximum speed limits and shock wave generation at the propeller tips disturb the flow and increase the velocity of the air which in turn complexes the system. The sonic boom generation also creates a situation for the aircraft to minimise the effect of noise reduction. When the aircraft stalls or tens to stall, the aircraft performance parameters vary and complexity increases. These are some of the constraints that are observed for noise reduction.

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2. e. Regulations

According to the Chicago Convention (ICAO), the noise evaluation measure is the Effective Perceived Noise Level (EPNL) in EPNdB.

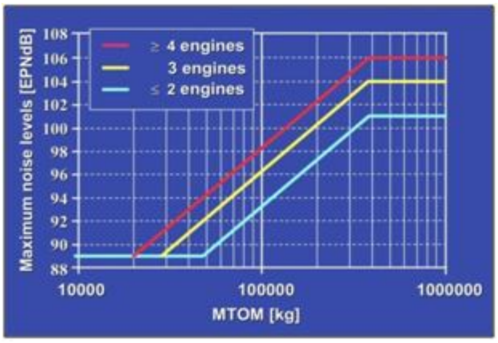

Fig: Maximum noise levels Vs MTOM

(Adapted from Noise Reduction Technologies for Turbofan Engines by Dennis L. Huff Glenn Research Centre, Cleveland, Ohio- NASA/TM—2007-214495)

3. SCARF INLETS

According to the report drafted by Dr. R. K. Nangia&Dr. M. E. Palmer,Nangia Aero Research Associates, the environmental demands for quieter, more efficient, civil aircraft are major design constraints. The trend is towards higher by-pass ratios implying large engines. Power demands are increasing (bigger aircraft with fewer engines) and this encourages large engines.

The increase in size/power produces more fan noise. The engines will be closer to the ground during take-off (ramp to lift-off) and landing (touch-down to ramp) resulting in stronger ground vortices and increased possibility of foreign object damage. Civil engines must meet current / future noise standards in the flight envelope.

In the recent years, the development of propulsion system with high performance and high maneuverability has gathered a lot of interest amongst researchers. Some of those concepts proposed are the non-axis symmetric and impose very high angle of attack requirements on the propulsion system's inlets.

The flow without the separation at severe operating condition is one of the major considerations for obtaining high performance.

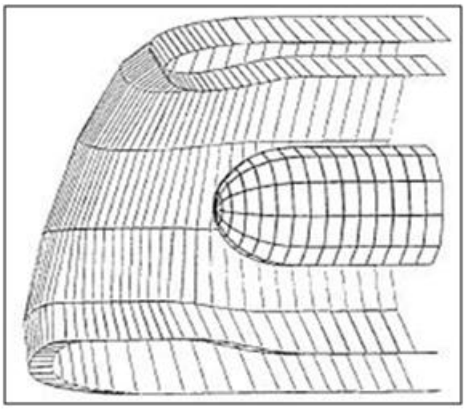

Fig: Scarf Inlet

(Adapted from Noise Reduction Technologies for Turbofan Engines by Dennis L. Huff Glenn Research Centre, Cleveland, Ohio- NASA/TM—2007-214495) Scarf Inlet is characterized by having a longer lower lip than an upper lip. Scarf Inlet is one which the inlet lip extrudes less at the crown and more at kneel. This scarf inlet design is capable of reducing inlet radiated fan noise.

It works by redirecting some acoustic energy up and away from the people on ground. In addition, a computational study observed that the scarf inlet reduces the tendency to ingest foreign objects on runway during take-off and landing. It also maintains adequate internal flow at higher angle of attack when compared to the axis symmetric inlets.

3. a. Types of Scarf Inlets

Scarf Inlets can be classified into three types as follows:

1. Positively Scarfed Inlet
2. Negatively Scarfed Inlet
3. Rotatable Scarf Inlet

The Positively scarfed inlet is one which has longer upper lip than the lower lip. The Negatively scarfed inlet is one which has longer lower lip than upper lip.

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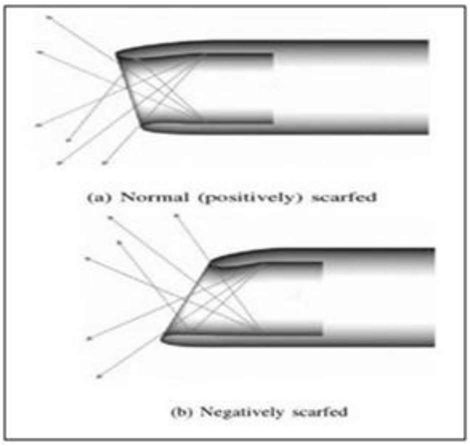

Fig: Scarf inlets

(Adapted from Noise Reduction Technologies for Turbofan Engines by Dennis L. Huff Glenn Research Centre, Cleveland, Ohio- NASA/TM—2007-214495)

The rotatable scarfed inlet is a combination of both positive and negative scarfed inlets. It is under design phase and has a lot of scope in the future. It has its own advantages in increasing the performance of the aircraft. It is supported at the forward end portion of nacelle. It is controllably rotatable relative to the engine nacelle to a plurality of angular positions to inhibit ingestion of foreign object debris or to improve airflow characteristics, depending on whether the aircraft is taxiing, taking off from a runway, or operating in a cruise condition. The method involves controllably rotating the rotatable scarf inlet with respect to the engine nacelle to a corresponding one of the plurality of angular positions.

3. b. Design approach of Scarf Inlets

Subsonic, transonic, supersonic, incidence and side-slip factors are thought of, with varied degrees of importance, at every loop of the design method. Most significant are the low speed, α, handling aspects (take-off and landing). The planning at this stage should take into account environmental constraints. Side-slip effects at low speed are very crucial and certification requirements should be met.

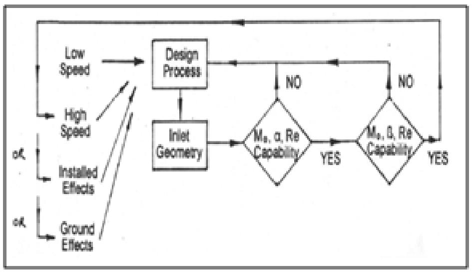

Fig: Design Approach of Scarf Inlets

(Adapted from APPLICATION OF NEGATIVE SCARF TO INLET DESIGN FOR ACOUSTIC REDUCTION, AERODYNAMIC ASSESSMENT AT SUBSONIC & TRANSONIC SPEEDS by Dr. R. K. Nangia&Dr. M. E. Palmer)

At high speed (cruise), economic factors dominate the design method and low drag and high inlet efficiency become the driving factors. The complete design theme would wish to think about low and high speed, α and β, ground effects and installation effects. Inlet performance (attached flow range) is assessed, at distinct points around the highlight. The performance is also improved by modifying the local stream wise profile to increase or shift the connected flow ranges. The applying of camber, locally, can shift the connected flow band without changing its range. Changes to local thickness can extend or minimise the connected flow range a few nominal mean.

3. c. Working of Scarf Inlets

The working of the scarf inlet can be demonstrated as shown in the figure below.

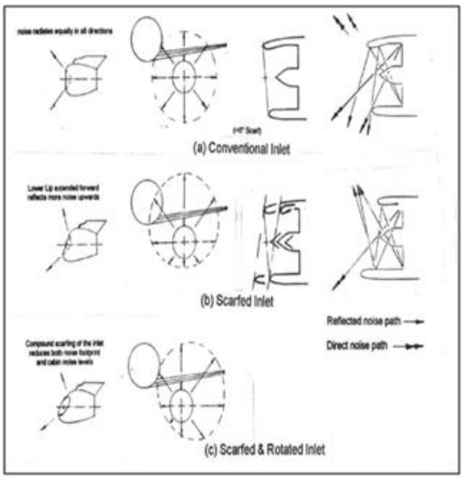

Fig: Working of Scarf Inlet

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4. ANALYSIS OF SCARF INLETS

4. a. Performance Analysis

$I \propto V_J^8$

After a critical analysis — Technical University of Munich‖ came up with this relation and which states that Intensity(I) is always proportional to the jet exit velocity (VJ) Thus we can come up to a conclusion that as the speed of the jet exit velocity increases thus the noise increases. And the jet exit velocity is a direct factor of thrust thus high mach number orientated aircraft tend to produce more noise to larger extent.

Scarf inlet wall analysis:

In aircraft sound travel in convection wave form. Thus a critical analysis should be done on the wall of inlet because the air stagnates and tend to create high noise at that section only. To obtain a formulation better reflecting the type of this differential equation, and to separate the individual constituents, the pressure variable is further decomposed into its radial, circumferential, and axial components.

$$p_0(r, \theta, z) = \hat{p}(r) \cdot e^{\pm im\theta} \cdot e^{\pm ik_z Z}$$

In above equation $\hat{p}(r)$ stands for the radial variation of the pressure (its exact characteristic will be determined in the following), m defines the circumferential periodicity, and kz is the axial wave number determining the propagation into the axial (z-) direction. According to Helmholtz theorem which discuss about convection of energy which also follows sounds. It provides us an equation stating the movement of sound as a convection of sound in free space.

$$\frac{\partial^2 p}{\partial r^2} + \frac{1}{r}\frac{\partial p}{\partial r} + \frac{1}{r^2}\frac{\partial^2 p}{\partial \theta^2} + \left(1 - M^2\right)\frac{\partial^2 p}{\partial z^2} - 2iMk\frac{\partial p}{\partial z} + k^2 p = 0$$

On combining the above two equations it results as

Using the Bessel and Neumann functions to solve the above functions, it tends to give Eigen values in return and solving them results to final equation as:

$$p(r, \theta, z, t) = A_1 \cdot J_m(K_{mn}) \cdot (A_2 \cdot e^{-ik_{zmn} z} + B2 \cdot e^{+ik_{zmn} z}) \cdot (A_3 \cdot e^{-im\theta} + B^3 \cdot e^{+im\theta}) \cdot e^{i\omega t}$$

The above equation states the relation between the pressures created by the wind which converts its form into sound. It is clear that noise depends upon:

r – Radius of inlet

θ – Angle of scarf

z- Side slip angle (Constant to 1 for just upper or lower extension, Varies for typical shapes)

t - Thickness.

The acoustic properties are as important to analyse in designing of the part, because every part is not having desired acoustic properties and below two are necessary properties to be analysed.

Acoustic Impedance (Z) :

It is defined as the ratio of the pressure created on the material to the normalised velocity. It is considered to be a critical factor to design. Higher thee impedance is higher chances to produce noise.

Mathematically: Z = P/VN

Acoustic admittance:

It is the criteria of material to absorb the acoustic vibration and tend to be favorable if the value is a bigger in number and less favorable if it is small in number.

Mathematically, AA = 1/Z = VN/ P.

4. b. Comparison of Pressures Counters

It is clear from contours showed in the document that the sound at inlet has got a very high velocity and due to that reason the stagnation creates high pressure which in turn converts into noise which can be seen as red part in symmetric inlet.

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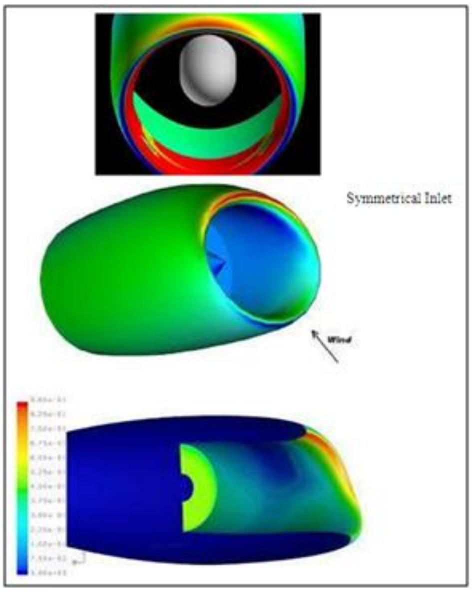

Fig: Scarf Inlets

Whereas the scarf inlet has the tendency of throwing the air pressure towards the sky which tends to divert the noise to the sky. Thus the graph is in blue contour and in a favorable regime. Thus it can be said that the scarf inlet is mechanically robust.

4. c. Results

Thus on the end note after the analysis made by the team, it is more favorable to use scarf inlet because of its variable design which helps to deviate the sound energy away from the observer which is on ground. Other than that the scarf inlet proved to be more efficient at high angle of attack due to high suction of air. There is a lot of scope of improvisation due to the scarf inlet and as per the vision 2020 stated by NASA it can be said that by the end of the 2020 there shall be application of more than 3 active noise reduction techniques to a single aircraft intake. Some other combinations we can actively see in research are like scarf inlet with active noise liners and forward swept blades with chevrons at the end.

4. d. Advantages of Scarf Inlets

The advantages of Scarf Inlets are as follows:

1. Noise Reduction

The results of noise reduction by the scarf inlets are encouraging.
It was observed that they tend to reduce at least 12 to 15dB. This could help us achieve the objectives drafted by the international organisations.

2. Improved foreign object damage resistance

A study observed that the scarf inlet reduces the tendency to ingest foreign objects on runway during take-off and landing. Due to the increased length of the lower lip, the scarf inlets can obstruct any foreign materials that could enter the engine and cause a catastrophe.

3. Reduction of turbulent flow at the nozzle

Due to the presence of the scarf inlet, the flow has less chance of going turbulent and this result in a uniform flow at the nozzle which is always desirable for increasing the thrust and performance of the aircraft.

4. Tail pipe emissions

As we can have a uniform flow from the inlet due to the scarf, the tail pipe emissions also have an improvement in its functioning and performance. The uniform flow helps to allow the burning properly which in turn increases the thrust produced. This improves the performance of the aircraft.

5. Improved lower lip higher angle of attack.

Scarf Inlets maintains adequate internal flow at higher angle of attack when compared to the axis symmetric inlets.

6. Thrust improvement

Finally, based upon the results obtained and the advantages stated gives the conclusion of increase in the thrust produced by the aircraft engine with the application of the scarfed inlets.

4. e. Disadvantages of Scarf Inlets

The Disadvantages of Scarf Inlets are as follows:

1. Reduced pressure recovery and increased pressure distortion at certain low speed conditions.

2. Increased drag at cruise due to increased surface area of the engine.

3. Decreased upper lip flow separation margin at lower angle of attack as the scarf angle increases.

5. SUMMARY

The first accomplishment is the recognition of the problem ―NOISE‖. Broadly, the sources of noise are engines, airframe, parasitic tones and other maintenance issues. There are many noise reduction technologies. The focus of this report was Scarf Inlets. Scarf Inlet is one which the inlet lip extrudes less at the crown and more at kneel. This scarf inlet design is capable of reducing inlet radiated fan noise. It works by redirecting some acoustic energy up and away from the people on ground. In addition, a computational study observed that the scarf inlet reduces the tendency to ingest foreign objects on runway during take-off and landing. It also maintains adequate internal flow at higher angle of attack when compared to the axis symmetric inlets. There are a lot of advantages of scarf inlets. They are namely, noise reduction, improved Foreign object damage resistance, reduction of turbulent flow at the nozzle, tail pipe emissions, improved lower lip higher angle of attack, thrust improvement.

The future scope of the scarf inlets is the rotatable scarf inlet. The rotatable scarfed inlet is a combination of both positive and negative scarfed inlets. It is under design phase and has a lot of scope in the future. It has its own advantages in increasing the performance of the aircraft. It is supported at the forward end portion of nacelle. It is controllably rotatable relative to the engine nacelle to a plurality of angular positions to inhibit ingestion of foreign object debris or to improve airflow characteristics, depending on whether the aircraft is taxiing, taking off from a runway, or operating in a cruise condition. The method involves controllably rotating the rotatable scarf inlet with respect to the engine nacelle to a corresponding one of the plurality of angular positions.

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