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A Review on Jet Noise Reduction

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With introduction of Jet powered Aircraft in 1950s Engine Jet Noise menace. With the current rate of growth of aviation and extensive utilization of jet powered commercial airliners it is expected that total aviation (civil and military) is slightly to go by more than 4%. In these aircraft, modern technologies are being used where the use of jet engines is inescapable. All types of engines are generating noise which has negative impact on environment as well as human being. Although individual aircraft has become quieter over the past 30 years but flight frequencies have increased. High speedy supersonic aircrafts are also using for military purposes. This paper focuses on the review of various methods employed in the past to reduce the jet noise as also the future expected methodologies hence the subject deals with sources, causes of noise and its propagation with a solution to prevent. Though it is a vast field in aviation sector, this topic is discussed in brief.

Field of Research: Aerospace Engineering

Keywords: Jet Noise, Modern Technologies, Noise Propagation, Optimization.

1. Introduction:

Jet Noise is widely recognized to be one of the most objectionable impacts of aviation and an important environmental issue for those living close to airports as well as further afield under the main arrival and departure tracks. Therefore taking effective measures to control and mitigate the effect of aircraft noise is fundamental to achieving the sustainable development of the aviation industry. Although new jet transport airplanes in today's fleet are considerably quieter than the first jet transports introduced about 40 years ago[1], airport community noise continues to be an important environmental issue as the no of flights are increasing day by day. The expansion, as well as the construction, of airports, has brought high levels of noise to communities that had traditionally enjoyed a certain level of serenity. But it is the responsibility of the aircraft and engine manufacturers to ensure that an airplane meets certification standards in noise. The communities living beside the airport are played with jet noise menace leading to a necessary to impose certificatory standards. Jet noise is a large section of the field of aero acoustics that focuses on the noise generation caused by high-velocity jets and the turbulent eddies generated

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by shearing flow. Such noise is known as broadband noise and extends well beyond the range of human hearing (100 kHz and higher). Jet noise is also responsible for the loudest sounds ever produced by mankind. Hence, many researches and studies are going on all around the world to meet the appropriate solutions to reduce the jet noise but still now there are many requirements that have not yet fulfilled. Mostly the requirements are finding ways to limit the exposal of flight deck personnel to areas of high noise, the developments of better procedure to monitor the noise exposal and hearing loss of personnel, further development of noise abatement procedures to minimize the noise foot print around commercial and military air stations and finally more research into the physiological effects of the full spectrum of noise-including low frequency pressure levels on humans.

2. Goals of This Review:

The broad goals of the study on review of jet engine noise are to obtain a broad understanding of the genesis of jet noise, causative factors, its influence on the environment, the history of hearing conservation and practice around the commercial and military jet aircraft. Towards the end of the paper we review the available and involving technologies and procedure to mitigate jet noise and recommend a way–ahead.

3. Engine Jet Noise in Brief:

The word noise means any unwanted sound. In both analog and digital electronics, noise is an unwanted perturbation to a wanted signal; it is called noise as a generalization of the audible noise heard when listening to a weak radio transmission. Jet Engine Noise is noise pollution produced by any aircraft jet engine or its components, during various phases of a flight: on the ground while parked such as auxiliary power units, while taxiing, on run-up from jet exhaust, during takeoff, Underneath and lateral to departure and arrival paths, over-flying while en route, or during landing. Mixing of the jet core and bypass exhausts and mixing with the atmosphere produce a very broad, haystack-shaped sound frequency spectrum. The shape of the spectrum reflects the fact that the eddies that comprise the turbulent mixing process vary considerably, increasing in size progressively downstream of the exhaust nozzle and decaying in intensity as the average exhaust velocity falls and the mixing becomes complete. Jet mixing noise is a strong function of jet exhaust velocity. Consequently, noise reduction strategies are aimed at increasing bypass ratio to lower nozzle exit velocities, and designing bypass and core flows to improve mixing with each other and the atmosphere. If the jet exhaust velocity is greater than the local speed of sound, very high levels of broadband shock-associated noise and screech tones can be generated. Careful design of the jet nozzles may reduce these noises of a great extent.

4. Aircraft Noise Propagation:

The propagation of aircraft noise and sonic boom from source to receiver is a function of several factors, including relative distance; atmospheric attenuation due to wind, humidity, and temperature; and intervening noise barriers (e.g., large stands of trees and buildings). As acoustic energy spreads out over an increasingly larger area, the amount of sound energy per unit volume of atmosphere steadily decreases. For subsonic noise, this decrease is inversely proportional to the square of the distance between the aircraft; mathematically it may be stated as $Es \propto 1/d^2$ and the receiver (i.e., a decrease in acoustic intensity of approximately 6 dB for each doubling in relative distance).

4.1 Atmospheric Effects:

Atmospheric conditions affect noise propagation. Water vapor in the atmosphere is relatively effective at absorbing noise. Also, the higher noise frequencies are more readily absorbed. For this reason, high-frequency noise typically decreases with distance more rapidly than does either midrange or low-frequency noise. For aircraft in flight, air absorption has the greatest influence on noise propagation. Low temperature enhances the propagation while high temperature reduces it.

4.2 Altitude Effect:

Atmospheric temperature gradients also affect aircraft noise propagation. During periods of normal temperature gradients, where air temperature steadily decreases with increasing altitude, aircraft noise is, for the most part, deflected upward, thereby producing areas of little or no noise on the ground at certain distances from the aircraft. During periods of atmospheric temperature inversion, the reverse situation is true and aircraft noise tends to be deflected downward, thus increasing ground noise level.

4.3 Low-Level aircraft Operations:

During low-level aircraft operations, surface absorption and deflection may decrease the observed noise levels at low angles of observation. Intervening objects (e.g., hills, buildings) will also affect noise propagation as there may generate multiple reflection.

5. Why Engine Jet Noise:

There are many reasons for creating high noise in the engine. Some are discussed shortly below:

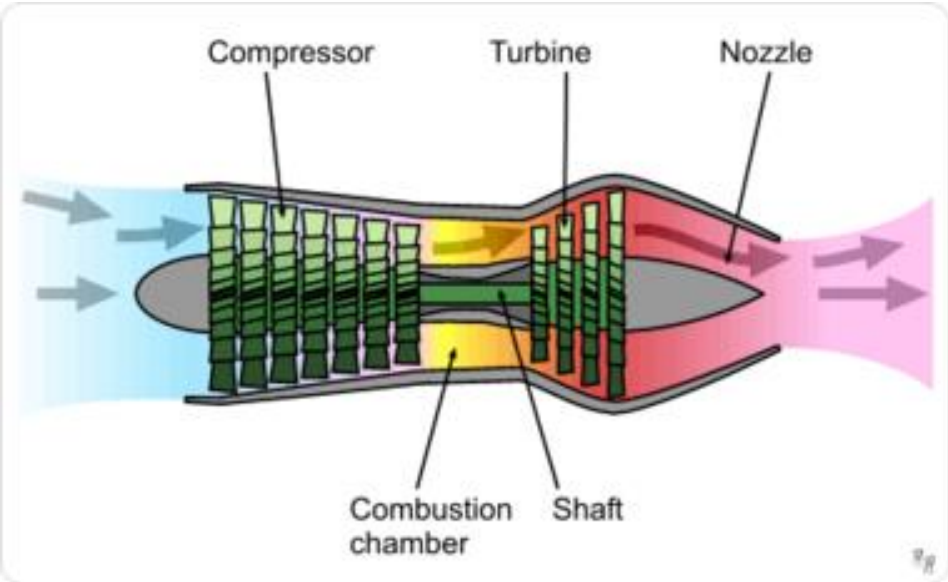
5.1 Exhaust Velocity:

The primary reasons of Jet Noise for a high-speed air jet (meaning when the exhaust velocity exceeds about 100 m/s) are "jet mixing noise". Though current jet-powered aircraft typically use turbofan engines with bypass ratios but in turbojets do not have a fan bypass, so for these engines all of the air passes through the core. Military engines for tactical aircraft have lower bypass ratios, which mean the exhaust jet velocities need to be high to produce thrust. The jet noise dominates over other noise sources for tactical aircraft and is a strong function of the jet exhaust velocity.
As one moves toward higher bypass ratio engines, the jet velocities are reduced to 6 to 800 ft /sec on the fan stream and 1000 to 1200 ft /sec in the core so the jet noise contribution goes down considerably. The noise contribution comes mainly from the fan on both the front and rear quadrants. The compressor, turbine, and core noise also provide a lower contribution to the noise spectrum.

5.2 Engine Components:

The other noise sources include the fan, turbine, combustor, and compressor. Commercial engines for subsonic aircraft use larger diameter fans to provide most of the thrust, which allow the jet exhaust velocity to decrease. For higher bypass ratio engines, the noise source distribution is significantly different, where the fan noise can be higher than the jet noise. Higher bypass ratios reduce both noise and fuel consumption, which is fortunate for commercial jet engines and unfortunate for high thrust-to-weight military engines.

Fig 1: Effect of Bypass Ratio and by Pass Air is shown in Pink Color (Pinker, 1991)[2]



5.3 Shock Waves Effect:

In Supersonic, or "choked" jets there are cells through which the flow continuously expands and contracts. Several of these "shock cells" can be seen extending up to ten jet diameters from the nozzle and are responsible for two additional components of jet noise, "screech tones" and broadband "shock associated noises". Screech is produced by a feedback mechanism in which a disturbance convicting in the shear layer generates sound as it traverses the standing system of shock waves in the jet. Even though screech is a side effect of the jet's flight, it can be suppressed by an appropriate design for a nozzle.

5.4 Non Laminar Exhaust Velocity:

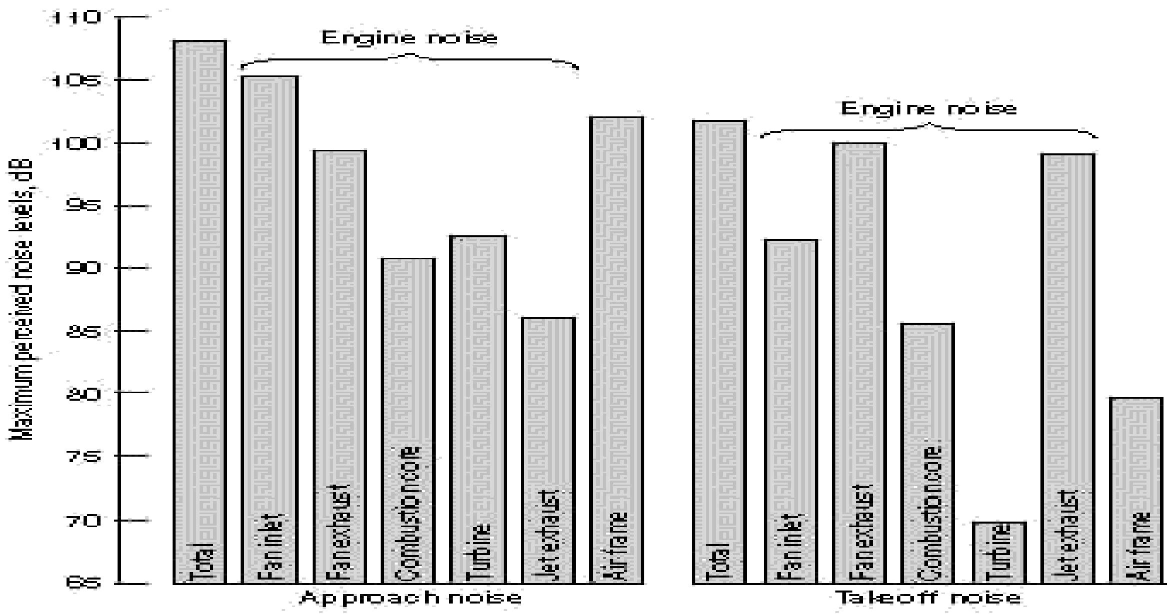
Jet noise results from highly turbulent air flow exhausting downstream of a nozzle. The Jet mixing sound is created by the turbulent mixing of a jet with the ambient fluid, in most cases, air. The mixing initially occurs in an annular shear layer, which grows with the length of the nozzle. The mixing region generally fills the entire jet at four or gives diameters from the nozzle. The high-frequency components of the sound are mainly stationed close to the nozzle, where the dimensions of the turbulence eddy are small. Further down the jet, where the eddy size is similar to the jet diameter, is where lower frequency begins. The primary sources: mixing of the shear layers, broadband shock noise, and screech, which is generated by violent combustion instabilities within the afterburner and is usually addressed in the design phase and is not a problem for production aircraft.

6. Sources of Engine Jet Noise:

The engine noise sources can be generated from:

- Fan
- Compressor
- Combustor
- Turbine

Fig 2: Example for Noise Source Breakdown for High by Pass Ratio/Low Fan Pressure Ratio Engine.



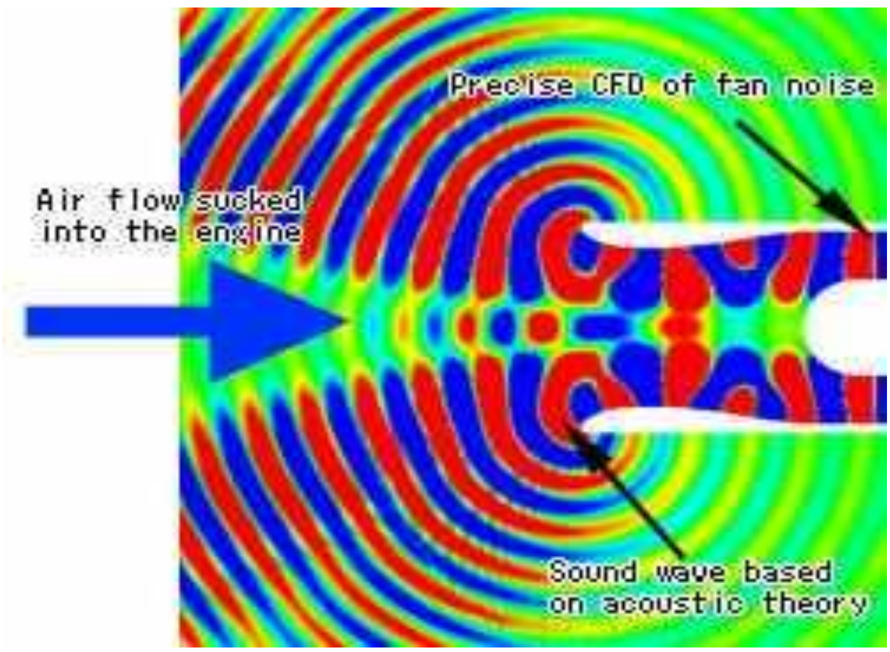
6.1 Fan Noise:

The relative contributions of the different components are a function of the engine designs as well as the power conditions at which the engine is operated (Figure 2). On a low bypass ratio engine the jet velocity can vary between 1500 ft to 2200 ft[3]. This relatively high velocity makes it the main source of noise for the propulsion system. The fan noise is eventually non-existent in most of the modern high by pass turbo fan engine and the rest of the noise components are dwarfed by the jet noise.

6.2 Why Fan Noise:

The rotor noise created to a great degree by the interaction of inflow distortion and the fan. It is primarily redirected towards the front of the engine.
The fan interaction noise with the outlet guide vanes and struts. This interaction is created by the respective potential field's interaction as well as the interaction of the fan walls and the downstream blade rows. Their relative strength is a function of the spacing between the blade rows.

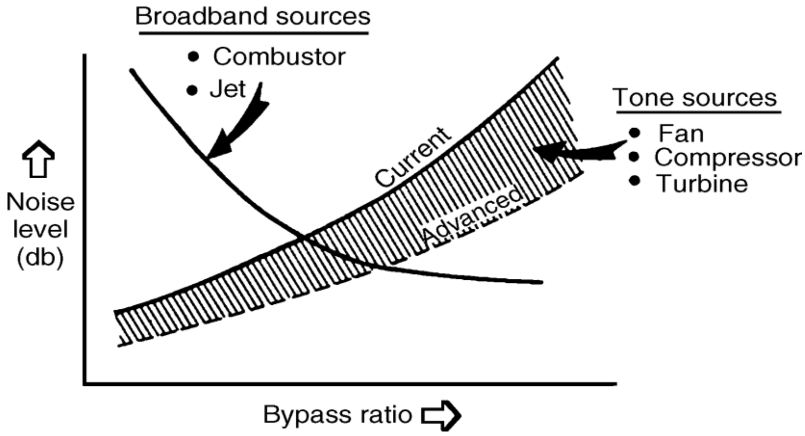
Fig 3: Fan Noise near the Intake of Jet Engine Compressor and Turbine as Noise Source



6.3 The Compressor and Turbine Noise:

The compressor and turbine noise are similarly created by the interaction between the adjacent blade rows. The core or combustion noise is created by the burning and flame stability in the chamber. The jet noise is indeed created by the mixing of the jet exhaust with the surrounding stream. As mentioned earlier, the relative importance of these sources is a strong function of the engine configuration, notably the bypass ratio as shown in Figure 4. A low bypass ratio machine (1950s/1960s)[4] is controlled primarily by the jet noise while a 1990s configuration is primarily driven by the noise generated by the fan.

Fig 4: Relative Importance of Noise Sources.



6.4 Operating Condition:

The relative levels of these noise sources will be different during takeoff and landing of an aircraft. The emphasis, as one move forward, is to work on all noise components. Primary attention has to be given to the fan and the jet, which pushes the manufacturers towards hyper bypass ratios. The turbine and combustion noises have to be kept in check as the other components are getting quieter. As engines are getting quieter and quieter the airframe noise driven by landing gears and high lift devices like flaps come into play and has to be addressed.

7. Reasons to Reduce Jet Engine Noise:

The noise problem can be broken into near-field and far-field. Near-field is the noise level in close proximity to the aircraft – normally considered to be the flight deck environment. Far-field noise (i.e. longer-range noise) is the noise experienced beyond the perimeter of an airfield. The far-field noise spectrum has, in the past, received the greatest attention.

7.1 Near-Field Health Issues:

Excessive noise can cause temporary or permanent hearing loss or tinnitus, a constant ringing in the ear. In addition, excessive exposure to noise can cause disturbances in mood, attention and cognitive function which would be an obvious safety hazard on the flight deck. While levels of VA (Veterans Affairs) compensation for hearing loss have been cited as a motivation for managing jet engine noise, the Panel found that the VA data lack sufficient noise source and hearing injury specificity to bound the problem. Accordingly, there is a compelling need to gather sufficiently "granular" data to allow useful comparisons between noise source levels and the human response to that noise.

- Hearing Loss / Tinnitus
- Temporary Threshold Shifts
- Non-auditory

7.2 Far-Field Community Issues:

Far-field noise continues to receive interest around many of our airfields. The introduction of new aircraft types requires an environmental impact statement to address the expected noise footprint during takeoff, approach, landing, and cruise flight conditions around airfields.

- Takeoff
- Cruise
- Approach

Each part of the human body has a different resonant frequency, and received noise has both a frequency and pressure level component. Although humans hear primarily between 80 Hz to 6000 Hz [5], engine generated near-field acoustic pressure levels are non-linear and comprised of frequencies below 10 Hz to above 10,000 Hz [7]. It must be noted that the impact on the human body when exposed to this wide spectrum of frequencies and pressure levels is not well understood.

8. Jet Exhaust Noise Reduction:

Jet exhaust consists of the fan stream and the core/combustion stream. The core flow stream is typically at a higher speed than the fan stream. As the two flow streams mix with each other, noise is created in the surrounding air. Of particular difficulty, the jet exhaust noise is actually created after the exhaust leaves the engine. This means that jet noise cannot be reduced where it is created, but must be addressed before the exhaust leaves the engine.
The theory of noise generation is being studied and computer codes that can simulate the theory are being developed. The final goal of this effort is to have a computer model for jet noise that will predict the source of the noise and how it is sent into the surrounding air.

8.1 Techniques of Jet Engine Noise Reduction:

In the past, following techniques have been employed:
(A)By Controlling the Source

- Reduce exhaust velocity-Enhance jet mixing (like chevrons [6]).
- Other methods show promise in laboratories, but need further development

B) By Controlling the Path

- Hearing protection-Acoustic enclosures/barriers

(C)By Variable Operation Control

- Minimize exposure time.
- Noise abatement procedures.

The ideal way to reduce noise is to address the problem at the source. Unfortunately, this is difficult to do for jet noise where the source is distributed over a region well downstream of the aircraft with very high sound amplitude. The flow is highly turbulent and is difficult to control due to the high velocities and temperatures in the jet. In addition, any method for reducing jet engine noise should not impact aircraft performance. The optimal approach to reducing jet noise is to reduce the velocity of the jet. While this has worked for commercial engines, it is not a viable solution for tactical aircraft due to high performance mission requirements. The next best approach is to carefully mix the exhaust stream using devices such as chevrons. The key is to reduce the low frequency jet noise without significantly increasing the higher frequency noise that results from the mixing process.

8.2 Reduction of Fan Noise:

In order to make progress on fan noise reduction, it is necessary to understand and be able to predict that noise. Therefore, as with jet exhaust noise, effort is being put into learning the theory of fan noise generation and developing computer codes that simulate that theory. The final goal of this effort is to have a computer code for fan noise prediction that can be verified.

A second approach uses the theoretical understanding of fan noise to develop a succession of ideas for testing, with each test providing both data upon which the computer codes are verified and results upon which the next test might be built. Fortunately, the fan thrust provides many options to explore and there are many components to vary. Besides basic geometry, there are blade-wake tailoring, boundary-layer (a thin layer of air along the duct wall that moves slower than the rest of the flow) effects, fan speed, number of blades and stators, and many more. Recently, model test data showed that a 3-dB reduction in fan noise can be achieved. As with jet exhaust noise, the final goal is to demonstrate a 6-dB reduction.

8.3 Current Technologies:

Chevrons are the only demonstrated practical method to achieve noise reduction with current engines that reduces jet noise at the source . It’s minor cjange in nozzle configuration is not re-design.

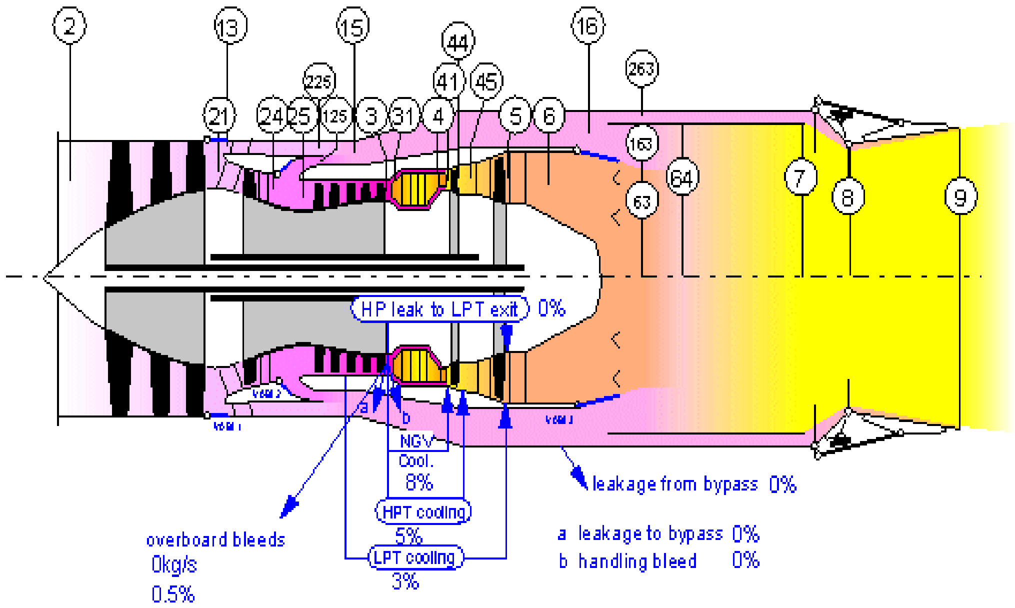
8.3.1 Chevrons Technology Promotes:

- Reduce jet noise at the source: chevron s on engine nozzle.
- Minor change in nozzle configuration not major re-designs.

8.3.2 Variable Cycle:

It is a type of gas turbine jet engine whose cycle parameters, such as pressure ratio, temperature, gas flow paths, and air-handling characteristics, can be varied between those of a turbojet and a turbofan, enabling it to combine the advantages of both.

Fig 5: Variable Cycle Engine



Variable cycle system worked by varying the bypass ratio of engine for different flight regimes, allowing the engine act like either a low bypass turbofan or nearly a turbojet. As a low bypass turbofan, the engine performed similar to comparable engines. When needed, however, the engine could direct more airflow through the hot core of the engine (like a turbojet), increasing the specific thrust of the engine. This made the engine more efficient at high altitude, high thrust levels than a traditional low bypass turbofan. An expected disadvantage of this variable cycle system would be increased complexity and weight.

8.4 Total Optimization:

Desired aircraft performance, signature control and noise levels are only possible through system integration and total system optimization, not individual component optimization, which merits a special consideration at every stage of design process.

8.5 Lean Combustion Technology - Clean Operation:

The procedure entails reduction of SFC by advanced design viz swept fan and associated wake reduction and use of advanced fuel injectors for pre--mixing leading to NOx reduction also the method aims at extended operating range using advanced cooling and materials.

9. Conclusion:

Jet aircraft noise is a combined effect of aircraft noise and the jet engine. Degree of aircraft noise menace is comparatively smaller related to jet engine noise . This paper focuses on this major problem. Jet engine technology is getting sophisticated than ever, building on decades of learning and growth in the field. However, even the latest advances in jet engine design and technology have not been able to counter an age-old challenge – noise. Noise issues persist and adversely impact both ground maintenance personnel and surrounding communities. There is continued research to combat this issue, but for these emerging tools to achieve their full potential, innovative measurement and analysis methods are necessary to characterize the jet noise source region. There will be no single solution for the jet engine noise problem it will require a combination of: Reducing jet engine noise source, which requires a long term research program, developing a requirement for noise in future tactical jet aircraft, continuing to make improvements to hearing protection, finding ways to limit exposure to excessive noise levels, developing better methods to monitor noise exposure and hearing loss of our personnel. It is certain that new technologies, smart materials and practically optimized operational cycles would undoubtedly control the menace of jet noise which probably would prove as a future relief from the *“unwanted menace”*.

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