Cabin Flow Modulation for Cockpit Noise Reduction on a Fighter Platform

A. Arunachaleswaran[1], S. Gunasekaran[2], K S Chowhan[3],
Rahul Agrawal[4], Sankaraiah Mada[5], S. Elangovan[6], M. Sundararaj[7]
[1]Aeronautical Development Agency, Ministry of Defence, Government of India, Bangalore and Research Scholar, Department of Aeronautical Engineering, Bharath Institute of Higher Education and Research (BIHER), Selaiyur, Chennai
[2]Aeronautical Development Agency, Ministry of Defence, Government of India, Bangalore
[3]Research Scholar, Department of Aerospace Engineering, IIT Bombay, Mumbai
[4]Aeronautical Development Agency, Ministry of Defence, Government of India, Bangalore
[5]Aeronautical Development Agency, Ministry of Defence, Government of India, Bangalore
[6]Department of Aeronautical Engineering, Bharath Institute of Higher Education and Research (BIHER), Selaiyur, Chennai
[7]Department of Aeronautical Engineering, Bharath Institute of Higher Education and Research (BIHER), Selaiyur, Chennai
Email: [1]aarunachaleswaran@yahoo.com,[2]2682guna@gmail.com, [3]kishan.chowhan@gmail.com, [4]rahul@jetmail.ada.gov.in, [5]sankaraiahmada@jetmail.ada.gov.in, [6]subelango@yahoo.co.in, [7]sundar.sonic@gmail.com

***Abstract*—Bleed air from the aero-engine is used for cabin air conditioning and pressurization apart from fuel tank pressurization, canopy sealing, avionics bay cooling and demisting systems. The temperature and pressure of the bleed air depends entirely on which stage the air is bled off from the engine. The bled air is subsequently cooled using ram air turbine coolers and the pressure is modulated for providing the requisite temperature & pressure inside the cockpit. A second order closed loop Environment Control System is utilized for maintaining the temperature and pressure of air before it was fed to the cabin. The closed loop system contains pilot cockpit selections which are fed back to the controller for suitable conditioning. In order to achieve this, control laws were optimally evolved to adjust the pressure and temperature based on the aircraft operating conditions i.e., speed, altitude and ambient atmospheric conditions. A developmental prototype fighter platform had high noise issues which were reported during the flight trials. In order to address the issue, trial modifications were carried out which comprised of three pilot selectable control laws incorporated in to the computer which controlled the Cabin Shut-Off Valve. The aircraft was suitably instrumented to capture critical data in terms of cabin noise, cabin temperature, pilot's ear level noise and cabin shut-off valve position. Qualitative inputs from experienced test pilots were used for correlation of obtained data. Based on the results of the flight trials a suitable control law was selected for implementation.**

KeyWords: Cabin Flow, Noise Reduction, Environment Control System, Control Law, Ram Air Turbine Cooler, Cockpit Pressurization, Pilot Comfort and Pilot Fatigue.

I. Introduction

Noise in a fighter cockpit can cause pilot fatigue and may lead to loss of critical Radio Transmitted information. High noise levels are more critical especially in a single cockpit fighter. Though the noise cannot be fully eliminated, it can be reduced by employing various noise reduction techniques. In high speed jet aircraft, the internal cockpit noise spectrum is random in nature with high noise levels spread over a broad frequency band. Noise Induced Hearing Loss (NIHL) in military pilots have been brought out by various physiological reports and is well documented[1]. Audiometric tests are carried out for military aircrew for conventional test frequencies (0.25-8 kHz) and extended high frequencies (10 & 12.5 kHz). Wang En-tong et al. have brought out in their study that fighter pilots are generally exposed to high levels of noise in their which range from 108-110 dBA in a fighter cockpit [2,3].Miyakitaet al. has proved that NIHL can be identified by elevated hearing thresholds in high frequency rangeand by a decrease in the difference between Acoustic Reflex Threshold (ART) to white noise [4]. Fighter pilots are required to perform multiple activities in a complex environment that may affect mission accomplishment, aircraft safety and aircrew safety. The parameters which may interfere with successful mission completion are noiseLevels, mental workload, communication requirements and individual hearing levels[6]. The modern engines are powerful and more efficient but however, they produce high noise levels 110 dB to 150 dB which results in NIHL in aircrew[1,3,7].

The sources of noise have been studied in detail by Renu Rajguru et al. in 2013. As brought out in the study, the major source of noise is the fast jet noise which includes noise generated by the external airflow around the aircraft canopy & front structure of the aircraft and the other is the internally generated noise from the

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airflow from the cockpit conditioning and pressurization systems[5,8]. The fast jet noise have been reported to be highest while operating at low level and high speed[5,9,10]. In the present study, the noise generated due to air conditioning and pressurization systems have been studied on one of the developmental aircraft. The source of air for air-conditioning is the ram air from the air intakes compressed through the engine and bled off from specific ports. This air is further cooled in different stages using ram air turbine coolers and pressure modulated for use in cockpit for environmental control. In the developmental prototype aircraft, high noise levels were reported and study was carried out in order to reduce the noise levels without affecting the environmental control in the cockpit. For undertaking this study, three control law options selectable by the pilot in the cockpit (which can differently modulate the amount of air flowing to the cockpit and hence the noise) were designed and flight tested. This paper presents the methodology adopted for the flight tests, results of the flight trials along with the qualitative comments by the test pilot.

In service Dash-V fighter helmet enabled with standard fighter noise cancellation was used for the developmental aircraft for the flight trials[11]. Noise in the cockpit can adversely affect the psychomotor skills of a pilot[11] and therefore, needs to be given due importance during the prototype developmental stage itself.

II. Methodology of the Study

The following steps were adopted in order to carry out the study:

A. Instrumentation of Critical Parameters in the ECS System

The aircraft ECS system was instrumented for the measurement of Cabin pressure, pilot temperature selection, pilot control law selection, cabin mean temperature, Cabin Shut-off Valve (CBSOV) position, pressure altitude, air speed (CAS, TAS and Mach) and ambient conditions. The data was available in the MIL STD 1553B Bus which was recorded in the on-board aircraft solid state recorder and also transmitted real-time through an on-board telemetry system to the test director conducting the flight test.

B. Instrumentation of the Test Pilot with Audio Sensor and Recording System

The pilot helmet was instrumented with an audiometric sensor and a noise meter was safely secured to the pilot's thigh strap. The photographs of the pilot wearing the helmet along with the recording equipment is shown below in Figure 1.

C. Initial Study to Ascertain Existing Noise Levels

In order to ascertain the base level noise levels, the flight trials were carried out with the existing control law and the noise levels were measured. The control law of the ECS system was embedded in a computer called the ECFM EU (ECS and Fuel Monitoring Electronic Unit). The control law was managing the opening of CBSOV based on altitude, ambient conditions and Mach number with respect to the pilot selected cabin temperature.

D. Design Modification in Control Laws

The control laws in the ECS Electronic Control Unit (ECS ECU) system were modified for various positions of CBSOV based on different flight conditions (pressure altitude and air speed). It is pertinent to note that noise and temperature comfort of the pilot are trade-offs in tropical climatic conditions like India. In case the CBSOV is biased towards better temperature comfort then the noise levels will be higher and vice versa. In order to arrive at an optimized setting of CBSOV such that environment (in terms of temperature) is also achieved at the same time noise levels are also reasonably adequate for the pilot comfort, three control laws were designed with varying levels of CBSOV controls. Based on the rig tests on ground, these three laws were ported to the ECFM EU on a prototype aircraft and flight trials were undertaken for these different control laws as per the exact profile followed for the baseline/ existing control law.

Fig. 1: Photograph of Test Pilot Wearing Helmet along with Recording Equipment

Fig. 2: Photograph of the EFI Display in the Cockpit for Control Law Selection by the Pilot

E. Provision of Suitable Controls in the Cockpit for Invoking a Specific Control Law

The modification in the prototype aircraft was carried out such that the control laws in the ECFM EU could be activated by the pilot. The pilot input panel Multi-Function Up Front Control Panel (MF-UFCP) and Engine Flight Instrument (EFI) display system were suitably incorporated with software modification to accept pilot's input for different control laws for CBSOV. The photograph of the EFI were the controls could be selected in the cockpit is shown in Figure 2

F. Ground Tests and Certification for Flight Trials

After implementation of the necessary modifications on the aircraft, requisite documents required for issue of flight clearance were submitted. The flight clearance for carrying out flight trials was obtained from the certification agency.

G. Flight Test Plan and Flight Test Schedules

A detailed flight test plan was evolved based on the initial study as brought out in Para 2.1. The flight test plan included selection of cabin mean temperature of 25 degrees, flying the aircraft above 5000ft at 350 Knots Calibrated Air Speed (KCAS) and 0.95 M, repeat the profile at above 8500 ft and repeat the profile above 15000ft. The profile was flown for baseline control law i,e., existing CBSOV setting and with different control law settings (CL_A, CL_B and CL_C). Three different control laws, CL_A, CL_B and CL_C based on the pressure altitude, Mach Number/ air speed variations and ambient conditions for controlling the CBSOV position were designed after careful planning and study. Based on the flight test plan, flight test schedules were prepared before each flight. The flight trials were progressed based on the broader plan and the results obtained in the previously obtained flight test data.

H. Flight Trials at Different Flight Conditions with Different Control Laws

Three experienced test pilots were chosen to fly the planned profiles and their independent qualitative comments were captured. The data specified in Para 2.1 along with the test pilot's comments were recorded. The cabin mean temperature was also monitored real time using on-board telemetry system.

I. Analysis of Test Results and Selection of Appropriate Control Law

The results obtained from the flight tests were analyzed and deliberated for finalizing the CBSOV control law which could give optimum noise comfort and temperature comfort to the pilot.

III. Results & Discussions

Cockpit Noise, Ear Level Noise, Cabin Mean Temperature and Pilot's Qualitative Comments forZp=3000ft

A cabin temperature of 25°C was selected by the pilot for all the flight trials. All the readings were obtained for a stabilized soaking time of 300 seconds. The mean cockpit noise recorded on ground (Bangalore, Pressure altitude Zp=3000ft) during the flight trials conducted is shown in Figure 3.

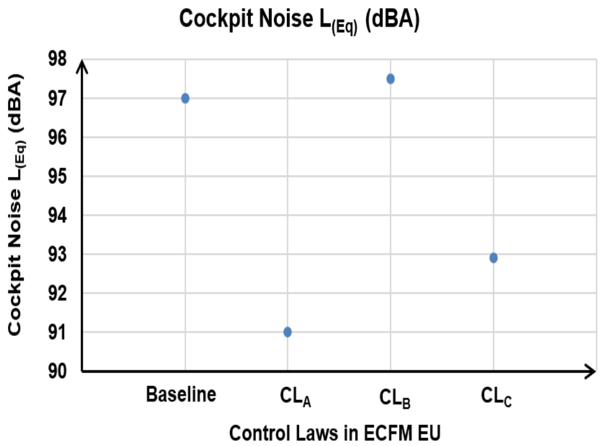

Fig.3: Cockpit Noise Recorded at Zp=3000ft

Typical continuous flight duration of LCA class of aircraft is around 3.0hrs. MIL STD 1474E specifies sound pressure levelsLeq(dBA) with respect to exposure

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duration with hearing protection is 89 dBA. The qualitative comments from the experienced test pilots were taken as the base line reference and the corresponding sound pressure levels measured using the noise measuring equipment carried on-board. The mean ear level noise measured on ground for baseline and other control laws are given in Figure 4.

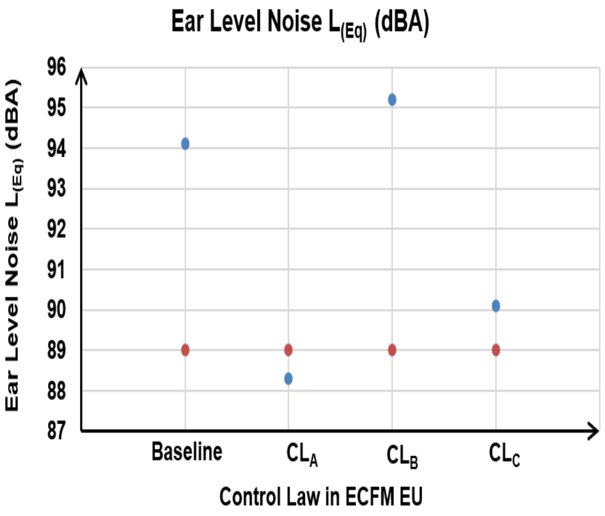

Fig. 4; Ear Level Noise Recorded at Zp=3000ft

The mean cabin temperature recorded against the selected cabin temperature of 25 °C is shown in Figure 5.

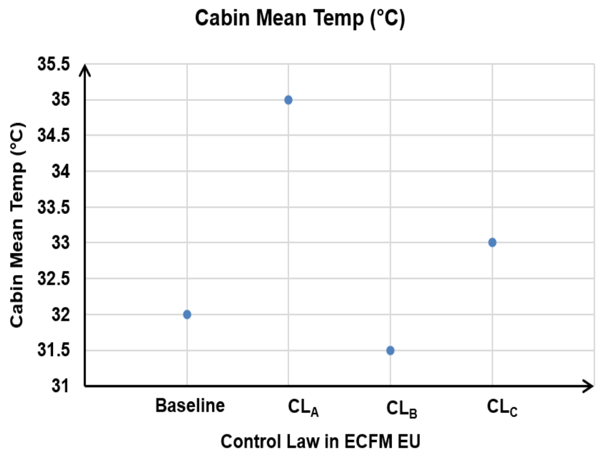

Fig.5: Mean Cabin Temperature Recorded at Zp=3000ft

As seen in Figures 3, 4 and 5, on ground the baseline control law produced an earlevel noise corresponding to 94 dBA which was 5 dBA higher than the MIL STD 1474 E recommended values. Planned Radio transmission calls were given from the Air Traffic Control tower simulating actual mission scenario. High noise levels were reported by the experienced test pilots. The qualitative comments provided by the test pilots have been tabulated in Table 1 below.

Table 1: Qualitative Comments by Test Pilot at Zp=3000ft (On ground)

Sl No	Control Law	Noise Comfort	Temperature Comfort
1.	Baseline	Very High	Comfortable
2.	CLA	Very Comfortable	Very High
3.	CLB	Very High	Very Comfortable
4.	CLC	Comfortable	Comfortable

As seen from the results, the baseline control law had very high ear level noise with comfortable temperature. This indicated that the ECS ram air flowing in to the cockpit was more and had scope for reduction. The Control Law 'A' (CL_A) reduced the ECS air a lot which resulted in a very comfortable noise level in the cockpit but led to very high temperatures. The Control Law 'B' (CL_B) increased the ECS air from the baseline which resulted in a very comfortable temperature but led to very high noise levels in the cockpit. The Control Law 'C' (CL_C) optimally reduced the ECS air where the noise was reduced to comfortable limits and the temperature comfort was also adequate. The results obtained using flight test instrumentation were corroborating with the pilot's qualitative comments.

Cockpit Noise, Ear Level Noise, Cabin Mean Temperature and Pilot's Qualitative Comments for Zp=5100ft

After take-off, the aircraft was stabilized at a pressure altitude (Zp) of 5100 ft. The measurement of cockpit noise, ear level noise and cabin temperature was recorded at two stabilized flight conditions i.e., 350 Knots Calibrated Air Speed (KCAS) and 0.95M. The aircraft was stabilized in level flight of 5100 ft for 300 seconds. The mean cockpit noise recorded at a Pressure altitude (Zp) of 5100ft during the flight trials conducted is shown in Figure 6.

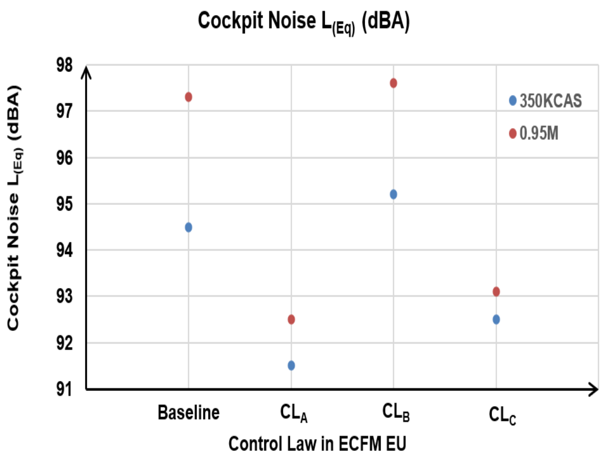

Fig. 6: Cockpit Noise Recorded at Zp=5100ft at 350 KCAS and 0.95M

The ear level noise recorded at 350 KCAS and 0.95M at Zp=5100ft is shown in Figure 7. The cabin mean

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temperature recorded at 350 KCAS and 0.95M at Zp=5100ft is shown in Figure 8. The qualitative comments from the test pilots have been summarized in Table 2.

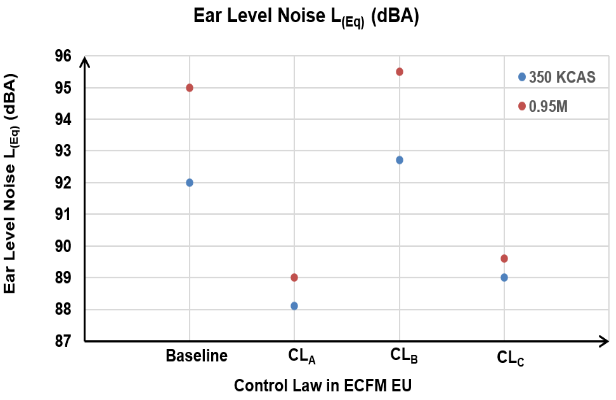

Fig. 7: Ear Level Noise Recorded at Zp=5100ft at 350 KCAS and 0.95M

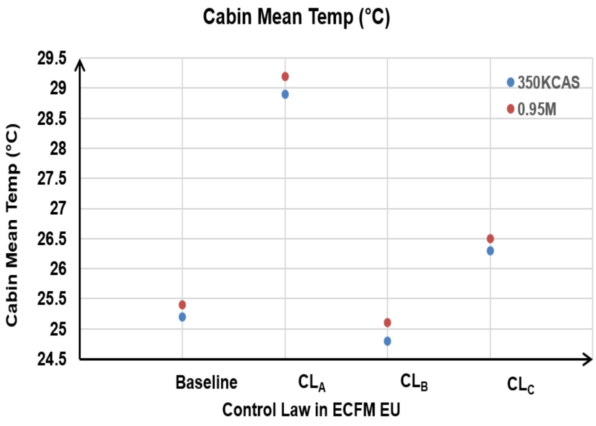

Fig. 8: Cabin Mean Temperature Recorded at Zp=5100ft at 350 KCAS and 0.95M

TABLE 2: QUALITATIVE COMMENTS BY TEST PILOT AT ZP=5100FT

KCAS/ M	Noise Comfort	Temperature Comfort
Baseline		
350 KCAS	Very High	Comfortable
0.95M	Very High	Comfortable
CLA		
350 KCAS	Very Comfortable	Very High
0.95M	Very Comfortable	Very High
CLB		
350 KCAS	Very High	Very Comfortable
0.95M	Very High	Very Comfortable
CLC		
350 KCAS	Comfortable	Comfortable
0.95M	Comfortable	Comfortable

As seen from the results at Zp=5100ft, the noise levels reported by pilots for the baseline control law was higher than the specified MIL STD 1474E limits. The Control Law 'C' had optimum levels of noise comfort and temperature comfort as it optimized the ECS air adequately to maintain the correct balance.

Cockpit Noise, Ear Level Noise, Cabin Mean Temperature and Pilot's Qualitative Comments for Zp=8600ft

In order to capture the noise and temperature data where change in control law was expected, the aircraft was stabilized at a pressure altitude (Zp) of 8600 ft. The measurements of cockpit noise, ear level noise and cabin temperature were recorded at two stabilized flight conditions i.e., 350 Knots Calibrated Air Speed (KCAS) and 0.95M. The results obtained for cockpit noise at 350 KCAS and 0.95M for baseline and other control laws are given in Figure 9.

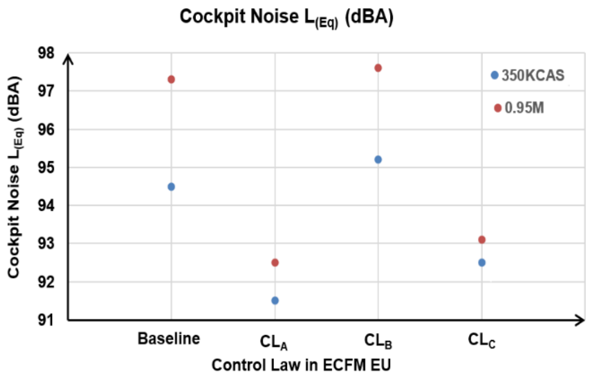

Fig. 9: Cockpit Noise Recorded at Zp=8600ft at 350 KCAS and 0.95M

The ear level noise recorded at 350 KCAS and 0.95M at Zp=8600ft is shown in Figure 10. The cabin mean temperature recorded at 350 KCAS and 0.95M at Zp=8600ft is shown in Figure 11. The qualitative comments from the test pilots have been summarized in Table 3.

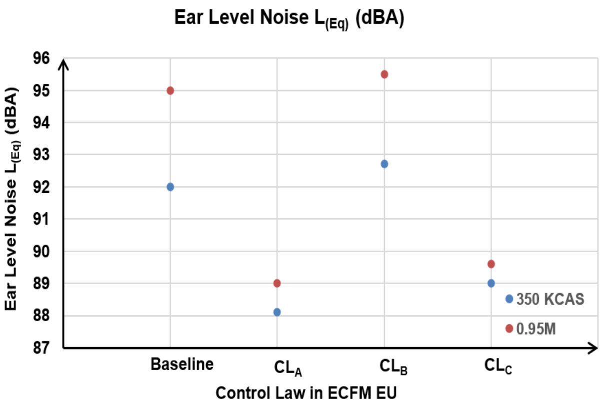

Fig. 10: Ear Level Noise Recorded at Zp=8600ft at 350 KCAS and 0.95M

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Table 3 Qualitative Comments by Test Pilot at Zp=8600ft

KCAS/ M	Noise Comfort	Temperature Comfort
Baseline		
350 KCAS	Very High	Comfortable
0.95M	Very High	Comfortable
CLA		
350 KCAS	Very Comfortable	Very High
0.95M	Very Comfortable	Very High
CLB		
350 KCAS	Very High	Very Comfortable
0.95M	Very High	Very Comfortable
CLC		
350 KCAS	Comfortable	Comfortable
0.95M	Comfortable	Comfortable

As seen from the results at Zp=8600ft, the noise levels reported by pilots for the baseline control law was higher than the specified MIL STD 1474E limits. The Control Law 'C' had optimum levels of noise comfort and temperature comfort as was observed at 5100ft.

Cockpit Noise, Ear Level Noise, Cabin Mean Temperature and Pilot's Qualitative Comments for Zp=15100ft

To capture the noise and temperature data where the second change in control law was expected, the aircraft was stabilized at a pressure altitude (Zp) of 15100 ft. The measurements of cockpit noise, ear level noise and cabin temperature were recorded at two stabilized flight conditions i.e., 350 Knots Calibrated Air Speed (KCAS) and 0.95M. The results obtained for cockpit noise at 350 KCAS and 0.95M for baseline and other control laws are given in Figure 12.

The ear level noise recorded at 350 KCAS and 0.95M at Zp=15100ft is shown in Figure 12. The cabin mean temperature recorded at 350 KCAS and 0.95M at Zp=8600ft is shown in Figure 13. The qualitative comments from the test pilots have been summarized in Table 4.

As seen from the results it is evident that the results for Zp=15100ft were similar to the one obtained at Zp=5100ft and Zp=8600ft. The optimal comfort in terms of both noise and temperature was seen in Control Law 'C' (CL_C). It was seen from the flight trials that the source of pilot reported noise was mainly contributed by the ECS system. In case the air flow was optimized based on the ambient conditions then the noise could be controlled effectively. Using trial variants of control laws, a little compromise in temperature maintained in the cockpit could result in a better comfort in terms of noise levels. As noise plays a vital role in pilot's fatigue, combat

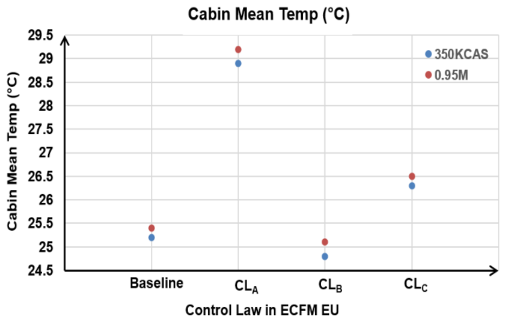

Fig.11: Cabin Mean Temperature Recorded at Zp=8600ft at 350 KCAS and 0.95M

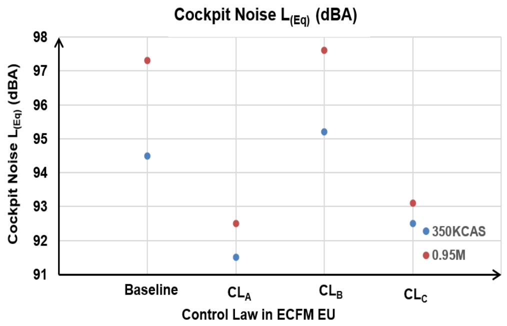

Fig. 12: Cockpit Noise Recorded at Zp=15100ft at 350 KCAS and 0.95M

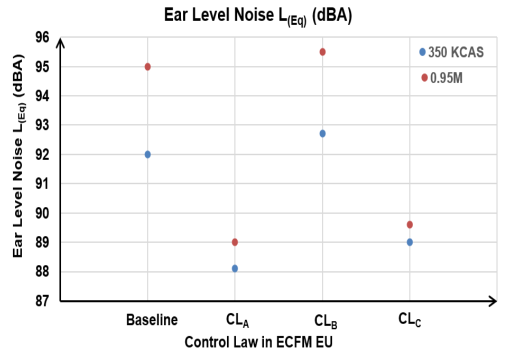

Fig. 13: Cockpit Noise Recorded at Zp=15100ft at 350 KCAS and 0.95M

Table 4: Qualitative Comments by Test Pilot at Zp=15100ft

KCAS/ M	Noise Comfort	Temperature Comfort
Baseline		
350 KCAS	Very High	Comfortable
0.95M	Very High	Comfortable
CLA		
350 KCAS	Very Comfortable	Very High
0.95M	Very Comfortable	Very High
CLB		
350 KCAS	Very High	Very Comfortable
0.95M	Very High	Very Comfortable
CLC		
350 KCAS	Comfortable	Comfortable
0.95M	Comfortable	Comfortable

preparedness and psychomotor skills, it was important to control the noise and bring it in to acceptable/ comfortable levels. For a fighter platform pilot's alertness is a key factor which may change the entire dimension of the aircraft for which it was designed. Noise Induced Hearing Loss (NHIL) and loss of certain frequencies amongst pilot's population have were a common phenomenon for which the root cause has been attributed to cockpit noise and environmental conditions. Pilot's health and his/ her specialized training is paramount in terms of mission accomplishment. Aspects which affect pilot's alertness/ health should be considered in entirety in the fabric of aircraft design otherwise the objectives of the design may be defeated. Therefore, optimization of cockpit noise is very critical at design stage itself before it is too late in the developmental program. The flight trials were repeated with three experienced test pilot's and few operational pilots. The comments were consistent and supported the study. Therefore, the control law for CBSOV opening as controlled by CL_C was recommended for implementation.

IV. Conclusion

Noise inside the cockpit has been a cause of concern in modern jet fighter platforms. Fast jet noise attributed to the environmental control system of the aircraft has been found to be a big contributor for the elevated noise levels. Cockpit comfort and ECS noise are both trade-offs. The present work has attempted to study, compare and contrast the three control law designs with respect to the baseline design in order to optimize the noise without affecting the cockpit comfort. Based on the study and analysis of flight test results, the optimal control law was finalized for the ECS system.

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