OPEN ACCESS

International
Journal
Of Modern Engineering Research (IJMER)

Position Determination of an Aircraft Using Acoustics Signal Processing

D. Lakshmanan[1], P Anand[2], P. Manmathakrishnan[3]

[1,2,3]*Department of Aeronautical Engineering, Bannari Amman institute of technology, Sathyamangalam, India*

Abstract: *This paper deals with the determination of an aircraft position using the acoustic source emitted from it. As per the experimental setup, sound energy emitted from the aircraft is captured with the help of microphones and processed further using MATLAB toolbox and LABVIEW software. Localization algorithm is sub divided into two categories, in which the first method involves time delay estimation of acoustic source through simulation process and the second method is analyzing the Doppler frequency shift from the aircraft sound. Using the above methods the navigation parameters such as velocity, Height, Mach number, RPM of the propeller, Elevation angle and slant range will be determined.*

Keywords: *frequency shift, time delay, Acoustic signal processing simulation, Aircraft velocity and Altitude.*

I. Introduction

1.1 Acoustic Source and Sensor

The ground sensors are mostly used in remote areas for surveillance and early instruction about the target for identification purposes. The maximum amount of acoustic energy emitted by the engine systems of aircraft or vehicles will be taken for position determination. It can be possible to detect the aircraft sound source using highly sensitive acoustic sensors mounted closed to the ground. The presence of an acoustic source can be detected automatically when the aircraft is nearing to fixed position with different distance. Data from acoustic sensors can also be processed for source classification, localization, and tracking. When an aircraft travels at constant velocity and constant altitude, the path is completely specified by a set of flight parameters. The retardation effect, which arises when the speed of the source is comparable with the speed of sound propagation in the medium, enables the estimation of some or all of the aircraft flight parameters using passive acoustic methods.

1.2 Acoustic Technology Overview

As the acoustic wave propagates through the surface of the material, any changes to the characteristics of the propagation path affect the velocity and/or amplitude of the wave. Changes in velocity can be monitored by measuring the frequency or phase characteristics of the sensor and can then be correlated to the corresponding physical quantity being measured.

Hardware section of an all acoustic wave devices and sensors use a piezoelectric material to generate the acoustic wave. Piezoelectricity refers to the production of electrical charges by the imposition of mechanical stress. When the certain amount of electrical field is applied to a piezoelectric material, it creates a mechanical stress. Piezoelectric acoustic wave sensors will generate an oscillating electric field to create a mechanical wave, which propagates through the substrate and is then converted back to an electric field for measurement.

1.3 Techniques Involved

The Doppler Effect is used when the aircraft is moving with respect to the fixed sensors on the ground. This can be described as the effect produced by a moving source of waves in which there is an apparent upward shift in frequency at sensors towards whom the source is approaching and an apparent downward shift in frequency at sensors from whom the source is receding.

II. Microphone Specifications (Sensor)

2.1 A Typical 4190 ½” Inch Free Field Microphone

Capacitance	16 Pf
Diameter	1/2 inch
Range	15 - 147 dB
Freq. Range	3.15 - 20000 Hz

Polarization Voltage	200 V
Pressure Coefficient	– 0.01 dB/kPa
Sensitivity	50 mV/Pa
Temperature Coefficient	-0.012 dB/ºC
Temperature Range	- 30 - 150 ºC

III. Field Works That Were Carried Out

A field experiment is conducted near to Chennai airport in which three microphones are located above the ground level. Data are collected for varies time period. After the initial setup has been made, free field microphone is switched on. When the aircraft is moving away or towards the sensor is noted and the corresponding frequency is captured for the initial time t. After a particular time period again the sensor is switched on, at which the aircraft is flying exactly over the sensor and frequency is captured for the corresponding time t_c.The output of the sensor is sampled at 1 kHz through MATLAB simulation process.

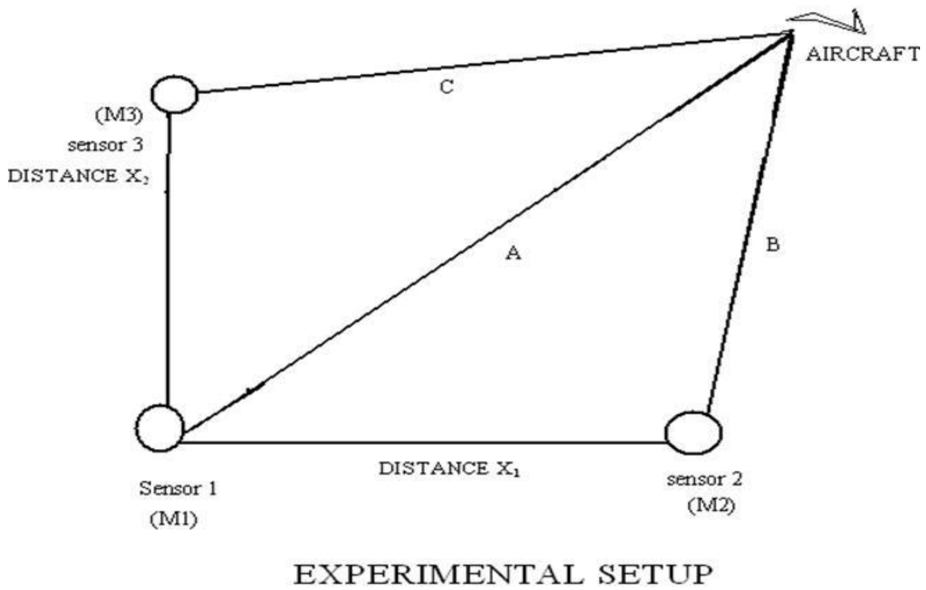

Fig 1: Sensors arrangements with equally separated Distance

IV. Matlab Simulation Process With Acoustic Source Input

4.1 Aircraft Acoustic Simulation

Simulation blocks which shows that how input wave signal is given to blocks and further signal processing is done through it. Recorded aircraft sound file is given to the block through wave file simulation setup and it is connected with cross correlation block and time vector scope. Time delay between the sensors can be analyzed by simulation setup and the results will be displayed.

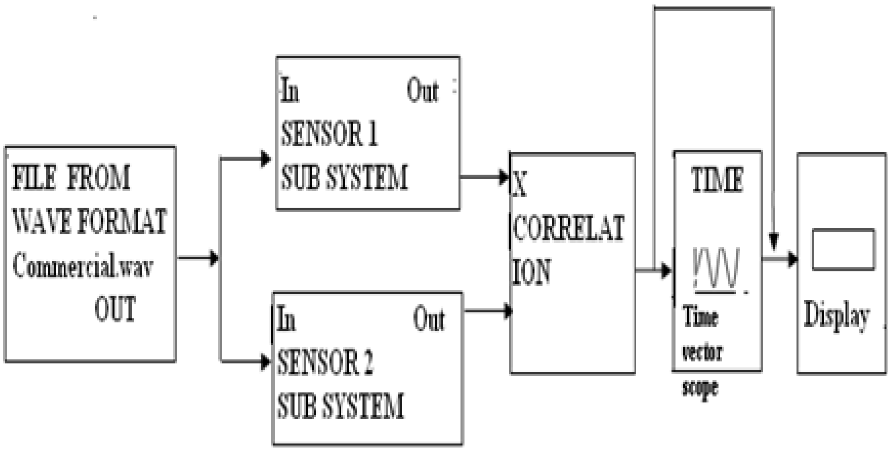

Fig 2: Simulation blocks contain aircraft sound source

Fig 2 shows that the wave file form of converted aircraft sound from three different microphones are given to the MATLAB blockset for cross correlation signal processing in which time delay between each sensor is measured. Time delay values are subjected to least square mathematical algorithm to estimate the final results.

4.1 Time - Frequency Estimation

When the aircraft is moving along a constant path at a constant speed at time at a separation distance or slant range of R_c. The aircraft emits an acoustic tone of constant frequency f_o and the speed of sound in air is *c*. The frequency of the signal, as received by the sensor, changes with time due to the acoustical Doppler Effect. The acoustic signal received by the sensor at time t is given by

$X(t) = a + b\,B(t, t_c, s)$ ...(1)

t_c the time at which aircraft moving near to sensors
B is constant parameter
a,b are relative parameters to source frequency and velocity
f_o – constant frequency (KHZ)
s – Acoustic lines from software simulation from MATLAB
$a = f_o c^2 / c^2 - v^2$
$b = -f_o c v / c^2 - v^2$
$c = R_c (c^2 - v^2)^{1/2} / (v c)$
v is the velocity of aircraft km/hr

V. Mathematical Approach

Calculation of the initial estimate of T(initial) ($\tau_c = t_c$) time at which when the aircraft is moving near to sensors

$T = \arg \mathrm{Min} \{ f(t_k) - ½\{ f(t_1) + f(t_k) \} \}$ sec ...(2)

$f(t_1)$, $f(t_k)$ are the initial and final estimate of time varying frequencies observed by the sensors and estimated in MATLAB simulation.

Estimates the source velocity V_0 is given by
$V = c * \{f(t_1) - f(t_k) / f(t_1) + f(t_k)\}$ km/hr ...(3)
C is the velocity of sound (330 m/sec)

Estimates the source range at ground mounted sensors R is given by
$R = f_0 (c\,v_0)^2 / \{[(c^2 - v_0^2)]^{3/2} * g_{max}\}$ m ...(4)
Here $V = v_0$
G_{max} = Maximum magnitude obtained from signal processing graph.

Elevation angle (θ)
$\theta = \tan^{-1} (h / t - t_0)$ Deg ...(5)

RPM of the propeller(s) ...(6)
$S = (f_0 * 60) / 2$
h is the height of the aircraft from the microphones
f_0 is estimated constant source frequency of an aircraft.

VI. Power Spectrum Analysis

The acoustic source emitted from the aircraft is captured and it is further processed through LABVIEW and MATLAB software to estimate the source properties accurately.

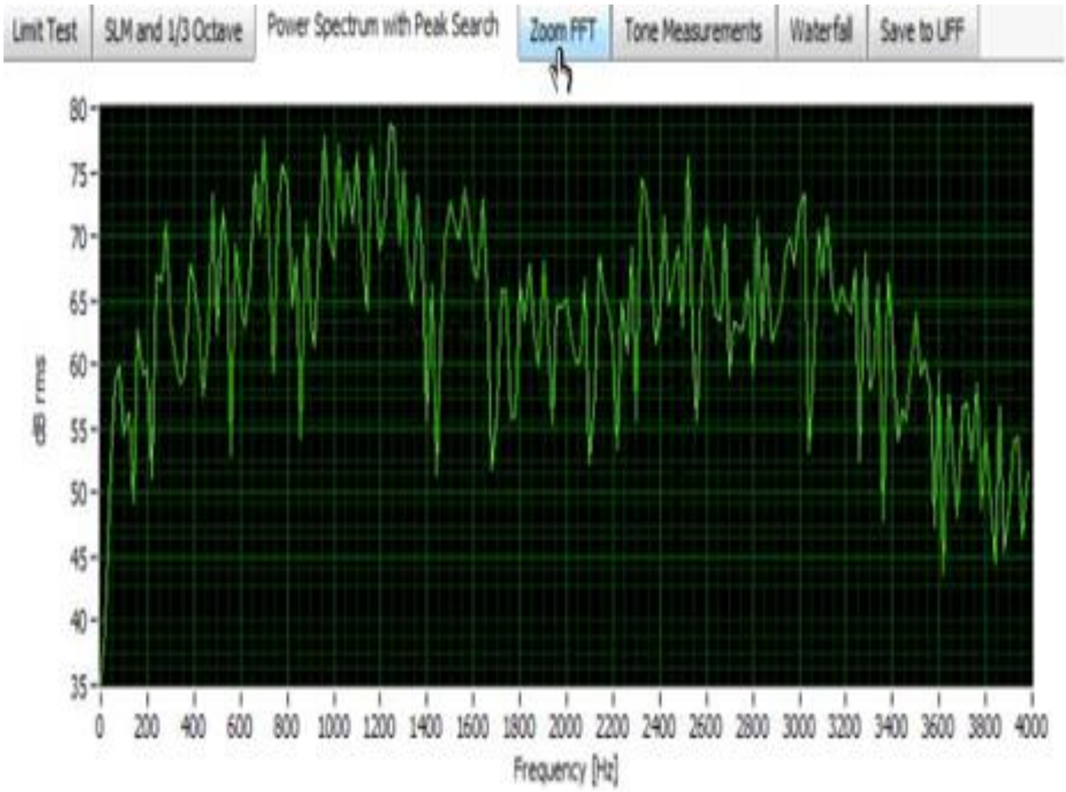

Fig 3: Spectrum lines of Aircraft sound

The Fig(3) depicts the simulation results of an aircraft sound source for frequency versus decibel properties. At 2000 to 2800 Hz, the frequencies are received little bit uniformly with small variation in decibels.

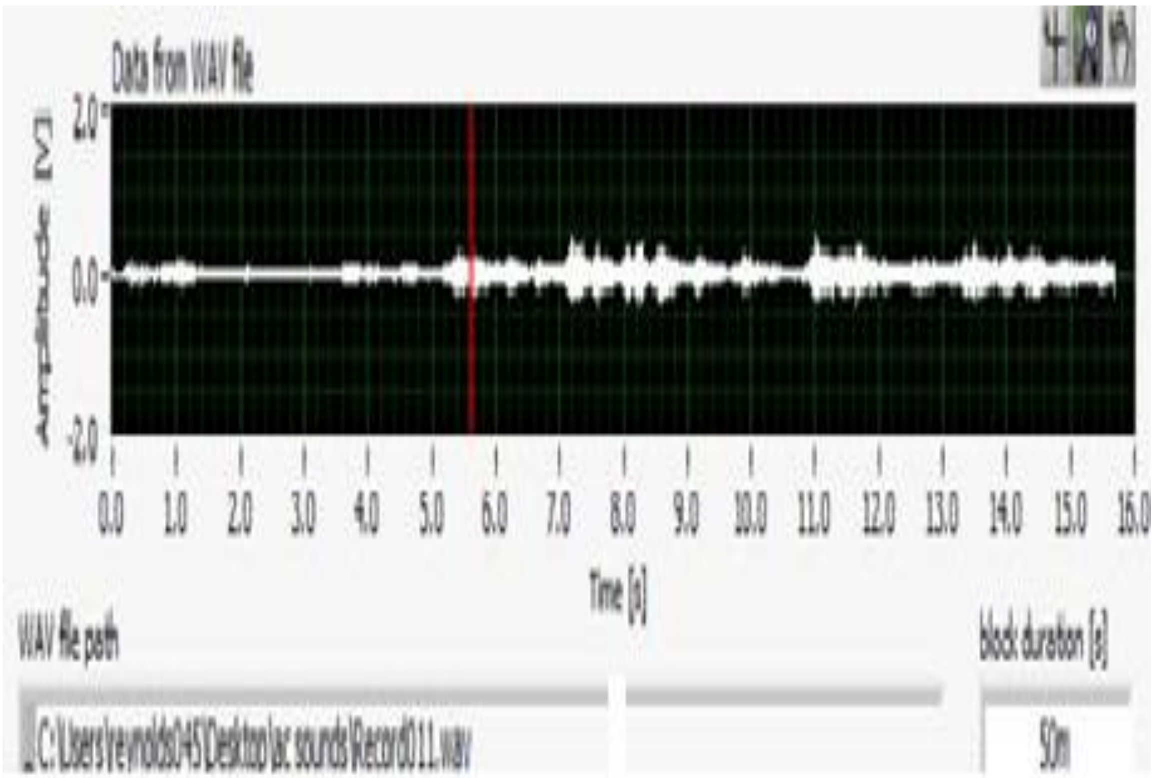

Fig 4: Aircraft sound source from first Microphone

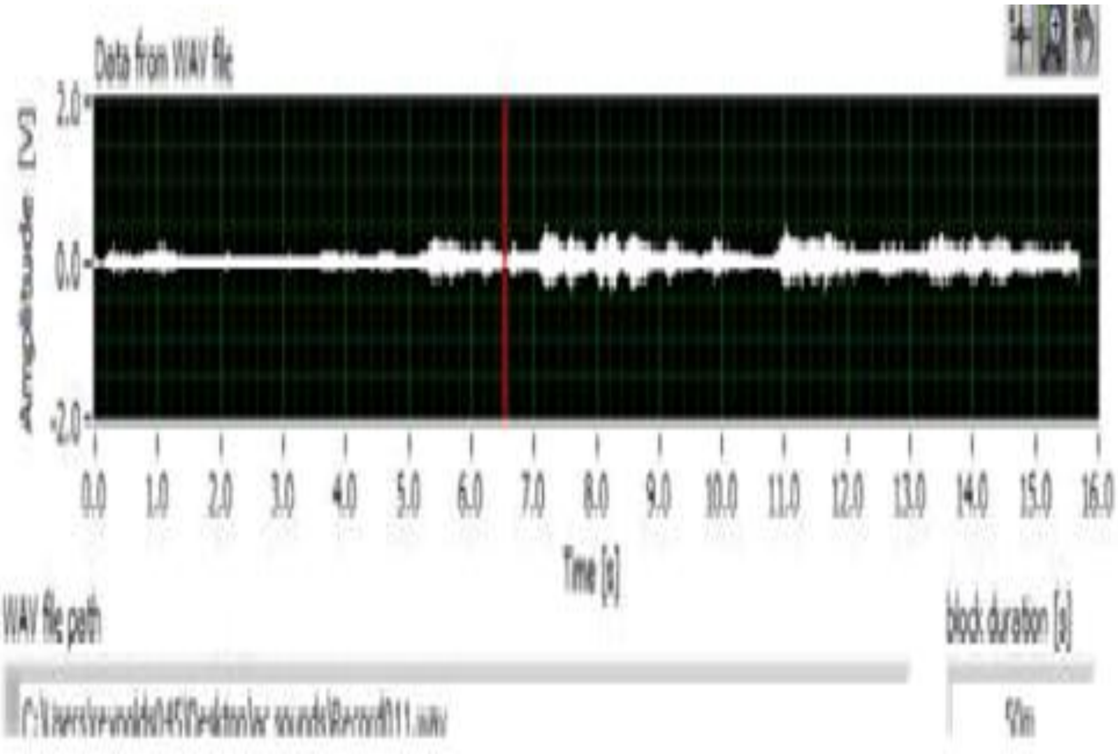

Fig 5: Aircraft sound source from second Microphone

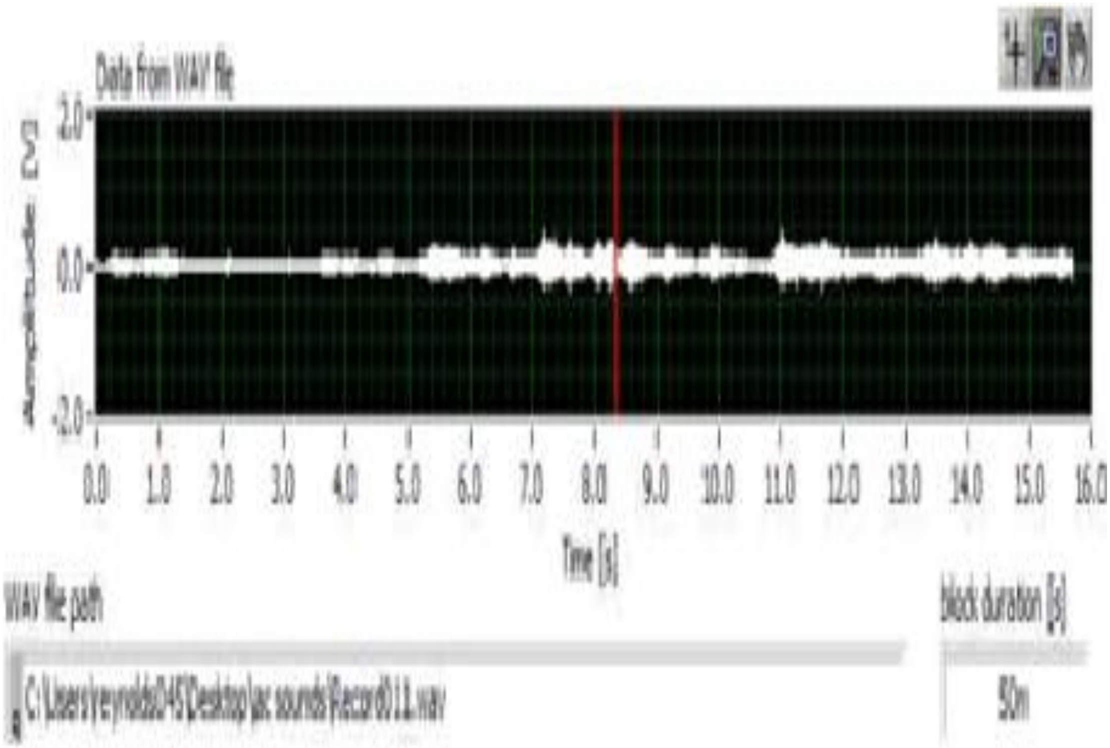

Fig 6: Aircraft sound source from Third Microphone

Fig. 4, 5 and 6 depicts the simulation results of time delay with respect to amplitude of sound source recorded by each sensor mounted over the ground. By simulation data, clearly it shows that the time delays between the sensors are like as 0.5sec, 1sec and 1.8 sec. The amplitude of the signal, which also changes due to the variation in distance between the aircraft and microphones.

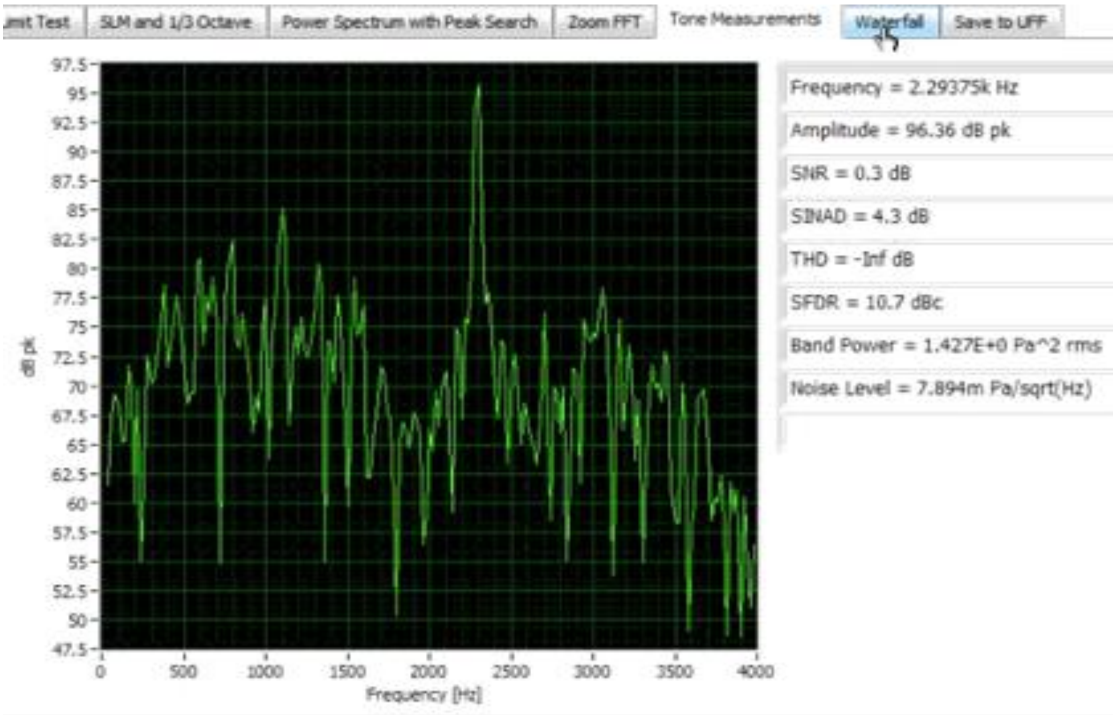

Fig 7: Tone measurements through LABVIEW

The Fig (7) depicts the simulation results to determine the exact initial frequency. Initial frequency is shown at the right of the graph with other tone properties. Accurately, Initial frequency is 2.93 KHz, Signal to Noise ratio also determined as 0.3 db.

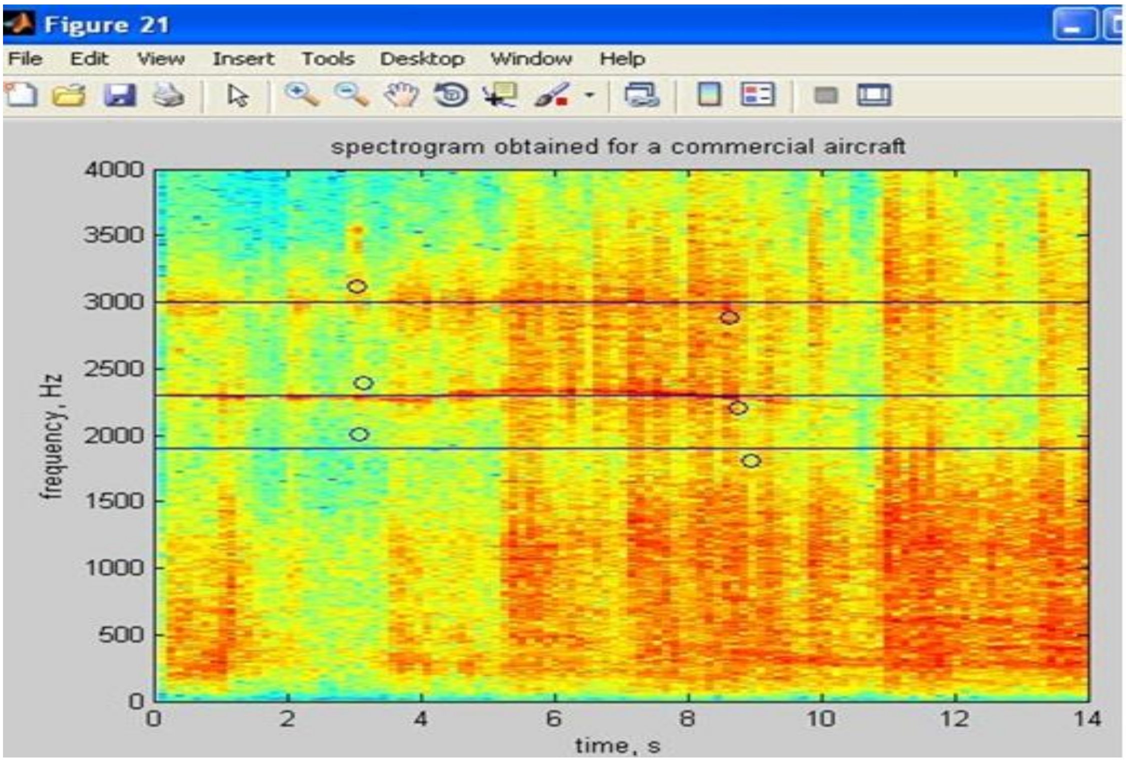

Fig 8: Spectrogram process for Aircraft Sound

Fig 8 is observed that the constant tone of Doppler frequency f_0 is lies between the range of 2000 Hz to 3000 Hz. The above three horizontal lines which are exactly gives the values of f (t_1) and f(t_2) to calculate the navigational parameters such as velocity and Range from the microphones.

VII. Results

Observed datas from the simulation process are analysed mathematically with least square approach. From the analysis of Doppler shifting frequency, the initial and final time varying Frequencies are taken as f (t_1) = 2 KHz, $f(t_2)$ = 3.5 KHz.

Velocity of the aircraft V = 1224 * (3.5 - 2) / 5.5 = 333.81 km/ hr
Constant frequency source emitted from the aircraft F_0 = 2.5428 kHz
Slant Range of an aircraft near the ground mounted sensors R = 267 m
RPM of the propeller = 75000/m
Elevation angle = 0.8753*10^-3 Deg
Height from the microphone = 325.27 m
Mach number = 0.2721(subsonic)

VIII. Conclusion

The process of aircraft position determination method provides reliable estimates of the aircraft speed during takeoff, height from the microphones, slant range distance between the aircraft to the microphone, elevation angle, RPM of the propeller and Mach number of a transiting aircraft. In this work sound of a commercial aircraft is recorded by free field microphones which are fixed on the ground. From the recorded sound, spectrogram and tone properties are obtained using MATLAB and LABVIEW toolbox.

REFERENCE

[1]. Barry D Bullard," Pulse Doppler signature of Rotary wing aircraft," Georgia tech research institute Atlanta
[2]. B.G. Quinn, 1996, "Application of short time Fourier transform and Winger – Ville to the acoustic localization of Aircraft," Journal of Acoustic society of America.
[3]. Kam W.Lo and Brain G. Ferguson,1996,"Passive emission of aircraft motive parameters using destructive interference between direct and ground reflected sound waves," Journal of Acoustic society of America.
[4]. Severino, A. Zaccaron and R. Ardoino, 2002, "Performances of Doppler based direct passive localization techniques," University of California.
[5]. Giovanni and Gaetano Scarano, 2000, "Discrete time techniques for time delay estimation," IEEE transactions on digital signal processing.
[6]. Debadeepta Dey, Christopher geyer, Sanjiv singh, Matt digioia, 2009, "Passive, long range detection of aircraft: Towards a field deployable sense and avoid systems," In.proc field & service robotics.
[7]. B.Friendlander, 1987,"Passive localization algorithm and its accuracy analysis,"IEEE Journal of Ocean Engineering.