

## **ANNEX B**

# **SONIC BOOM CHARACTERISTICS AND ITS IMPACTS<sup>1</sup>**

---

### **Table of Contents**

- 1.0 Introduction
- 2.0 Sonic Boom Characteristics
  - 2.1 Focused Sonic Booms
- 3.0 Environmental Issues and Concerns
  - 3.1 Noise Environment
- 4.0 Brief Overview of D Air CFG (DND) Supersonic Field Measurement Program
  - 4.1 The Supersonic Field Measurement Program
  - 4.2 Field Measurement Program – Human Observers
  - 4.3 Field Measurement Program – Biological Observations
    - 4.3.1 Waterfowl Observations
    - 4.3.2 Osprey Observations
    - 4.3.3 D Air CFG Seismic Study
- 5.0 PCBoom Sonic Boom Computer Model
  - 5.1 PCBoom3 Computer Model Validation
- 6.0 Assessment of Sonic Boom Impacts
  - 6.1 Supersonic Training in 5 Wing Goose Bay Air Range CYA 732
  - 6.2 Modelling of Single Boom Events Using PCBoom
  - 6.3 Modelling of Air Combat Training Areas
    - 6.3.1 Risk Assessment
- 7.0 Assessment of Environmental Impacts
  - 7.1 Environmental Impact on People
  - 7.2 Environmental Impact on Wildlife
  - 7.3 Damage to Structures (Conventional and Unconventional)
    - 7.3.1 Conventional Structures – Review of Existing Damage Data
    - 7.3.2 Unconventional Structures – Review of Existing Damage Data
  - 7.4 Conclusions (Assessment of Environmental Impacts)
- 8.0 Conclusions
- Appendix 1 Sonic Boom Environment in CYA 732

---

## **1.0 Introduction**

Military flight training in the 5 Wing Goose Bay Air Ranges is restricted to the subsonic regime. At present, supersonic flight is not authorized below 30,000 ft MSL (in accordance with 1 Canadian Air Division Orders). Because of changes in military tactics,

---

<sup>1</sup> Prepared by Dr. Vijay Singh

technology and training requirements, Department of National Defence is seeking release under the Newfoundland and Labrador Environmental Assessment Act for the supersonic training in the Labrador portion of 5 Wing Goose Bay Air Range CYA 732. During a typical training mission, the aircrews generally achieve supersonic speeds (wherever permitted) for brief periods to engage other aircraft, deliver a weapon, or evade enemy threat systems. Further, with the current generation of aircraft, the aircrews have to use their engines' afterburners to achieve supersonic speeds, and that imposes a tremendous fuel-burn penalty on the aircrews. Therefore supersonic speeds can be maintained only for a small portion of the sortie. Thus, during a typical training mission there could be several of these supersonic events, each lasting a few seconds.

During aircraft operations, the main source of environmental impact is the noise that is generated during these activities. During subsonic operations, the only concern is aircraft noise that emanates from the aircraft engines and airframe. The effects of noise from subsonic aircraft activity were evaluated in the EIS (DND, 1994). With supersonic aircraft operations, there is a source of noise referred to as the "sonic boom" in addition to aircraft noise that is associated with the airframe and the engines. It must be emphasized that because of airframe/ engine limitations, supersonic activity generally takes place at higher altitudes (Annex E, Table 1), and therefore the noise on the ground from the engines and the airframe is going to be much less than what the area currently experiences. However, from the environmental perspective, the noise resulting from a sonic boom can be treated as the additional noise, similar to subsonic noise; thus, its environmental effects have to be mitigated.

Historically, an average of 5,000 low-level (altitude less than 1,000 ft AGL), subsonic sorties has been flown annually in the 5 Wing Goose Bay Air Ranges. For the purpose of this Environmental Assessment, two separate scenarios have been envisaged:

- (a) Conventional Night Strike, and
- (b) Ongoing training.

**Conventional Night Strike** training activity takes advantage weather and day-light hours to conduct large scale, intensive training during the night time for approximately two weeks period. It should be pointed out, due to the logistics and resources involved in this type of training, these activities cannot be sustained for long periods of time. Under this type scenario, training activity may be possible only for one or two training events during the year.

**Ongoing training activity**, in this scenario, it assumed that the total number of sorties would remain the same (~5,000 sorties), and of these about one-quarter (~1,250) may be flown at supersonic speeds. However, because of the current lack of allied training activity, the actual number of supersonic flights may be considerably less than the annually projected 1,250 sorties<sup>2</sup>.

All aircraft travelling at supersonic speeds generate sonic booms, but due to atmospheric refraction some of these booms never reach the ground. Consequently, for the same number of sorties in the 5 Wing Air Ranges and when both subsonic and supersonic activity is conducted simultaneously, it is expected that the noise impact on the ground is

---

<sup>2</sup> Due to lack of interest from the Allies, DND expects that only Conventional Night Strike exercise may be possible for the CYA 732. The Ongoing training activity scenario assumes if the historical estimates can be carried forward, but at this stage, it appears highly unlikely.

going to be less than that of subsonic flying training activity only. This is because, with the supersonic component added, some portion of subsonic activity would also shift up to the higher altitudes (into Air Range CYA 732) from the lower Air Range (CYA 731, referred to as the LLTA). Because CYA 731 is capped at 5,000 ft AGL, all low-level subsonic flight activity takes place below 5,000 ft AGL, and quite often it is lower than 1,000 ft AGL. Furthermore, because of the higher altitudes associated with supersonic activity, there is no visual stimulus to impact the wildlife and human activity on the ground.

In this Annex, consequences of sonic booms resulting from the supersonic activity have been assessed, and comparisons have been made to noise levels generated from the subsonic aircraft activity. The information presented here has been derived from a number of publicly available documents; a list of the pertinent documents is given in Annex A.

## **2.0 Sonic Boom Characteristics**

As an aircraft flies at supersonic speeds (i.e. exceeds 1 Mach, which is the ratio of aircraft speed and speed of sound), it is continuously generating shock waves due to compression and rarefaction of air in the atmosphere. The sound that is heard on the ground as a “sonic boom” is due to the sudden onset and release of pressure after the build-up by the shock wave or “peak overpressure”. The speed of sound at any altitude is a function of air temperature. A decrease or increase in temperature results in a corresponding decrease or increase in sound speed. Under standard atmospheric conditions, air temperature decreases with increased altitude. Therefore, depending on the aircraft speed and altitude some shock waves are refracted by the atmosphere and never reach the ground. This phenomenon is referred to as “cut off”, and it limits the width of the area affected by a sonic boom that reaches the ground. For a sustained supersonic event, the impacted ground area is referred to as a “footprint” or “carpet”.

In general, a sonic boom is an impulsive noise similar to thunder, and its magnitude is defined by the peak overpressure, measured in pounds per square foot (psf). The duration of a sonic boom is quite brief: approximately 100 milliseconds for most fighter sized aircraft; and, most of the energy is concentrated in the 0.1-100 Hz frequency ranges. By and large, depending on the aircraft's altitude, sonic booms can reach the ground 2 – 60 seconds after flyover.

The size of the footprint depends on the physical characteristics of the aircraft, the supersonic flight path characteristics (i.e. how the aircraft is being operated), and on atmospheric conditions. For a steady state supersonic event (the aircraft maintains constant speed and altitude) the shock wave moves with the aircraft, resulting in a “carpet boom” (Figure 1). Peak overpressures in the sonic boom impact area are not uniform, as the boom intensity is greatest directly under the flight path (i.e., sonic booms are loudest near the centre of the footprint, with a sharp “bang-bang” sound). The boom progressively weakens with an increase in horizontal distance from the aircraft ground track. Near the edges, they are weak and have a rumbling sound like a distant thunder. Ground width of the boom exposure area is approximately one mile for each 1,000 feet of altitude. However, when the aircraft is performing rapid manoeuvres such as accelerating, turning or diving, the shock wave (or sonic boom) does not move with the aircraft, and thus it is confined to a much smaller area. The sonic boom in this case is of greater magnitude, and is commonly referred as a “focused boom”.

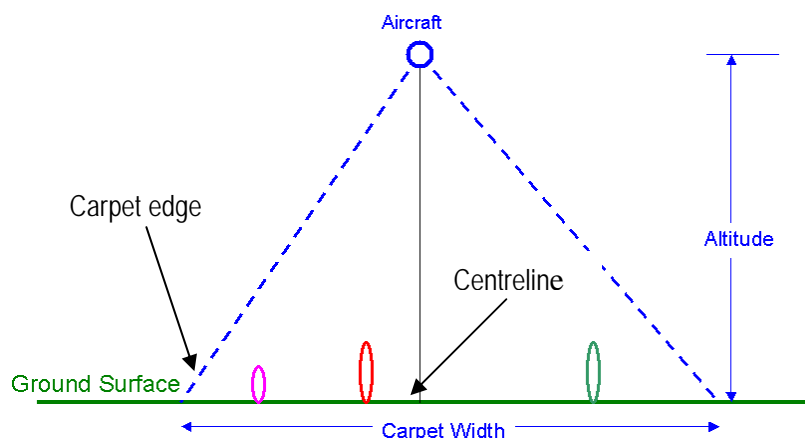


Figure 1. Relationship between an aircraft's altitude and the carpet width. For steady state flight, the maximum boom intensity is along the centreline, and the intensity decreases gradually away from the centreline. Consequently, for the same flight profile, sensitive species located at varying distance from the centreline would be subjected to different boom intensities.

The sonic boom amplitude depends on a number of parameters including, the aircraft size, weight, and geometry, Mach number, and flight altitude. Table 1 shows the sonic boom peak overpressures for several fighter aircraft in level flight at various altitudes; and it is graphically depicted in Figure 2. Thus, the peak overpressure largely depends on the aircraft altitude and its speed has lesser influence (Figure 3). The peak overpressure on the ground increases as the altitude of the aircraft decreases; this change in peak overpressure is more pronounced at lower altitudes. However, when the aircraft is at higher altitudes, the boom's lateral spread increases, thus exposing a wider area to the boom.

Table 1. Sonic boom peak overpressures (psf) on ground for various aircraft types at Mach 1.2 in straight and level flight.

Aircraft	Altitude (feet, AGL)				
	5,000	10,000	20,000	30,000	40,000
15-C	9.4	5.4	2.9	1.9	1.5
F/A-18	8.8	5.0	2.7	1.7	1.3
F-16	7.6	4.4	2.3	1.5	1.2
Tornado	8.9	5.1	2.7	1.7	1.3
F/A-22	9.9	5.7	3.0	2.0	1.5

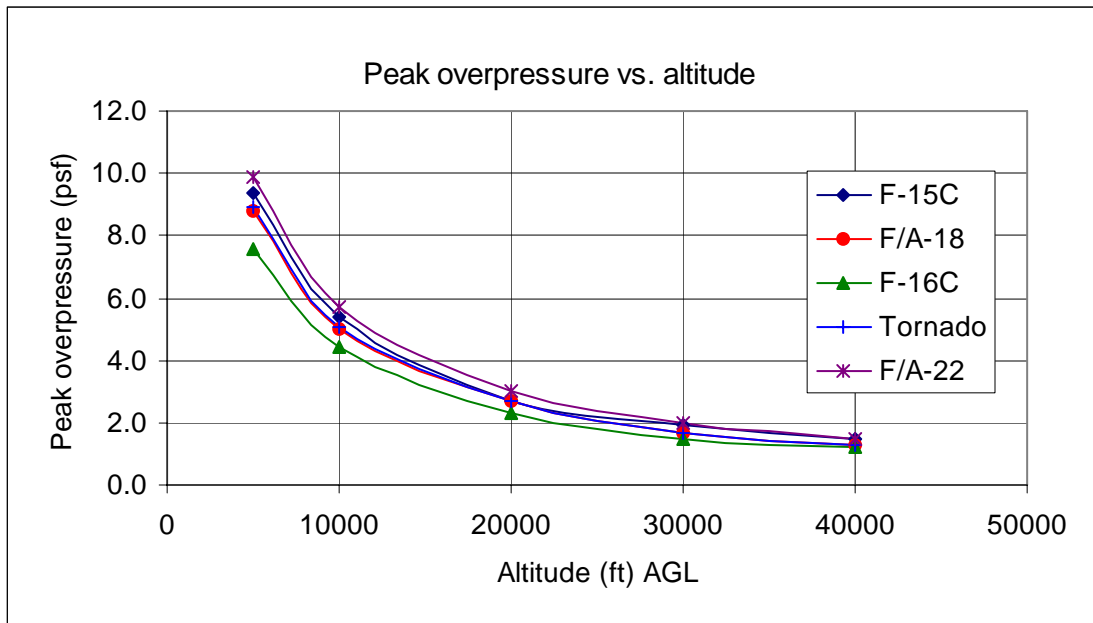


Figure 2. Graphic relationship of an aircraft's altitude and peak overpressure (psf) on the ground for different types of fighters. Since most of these aircraft have similar characteristics (namely shape factor and weight), peak overpressure values on the ground are very similar, except for the lighter F-16C aircraft.

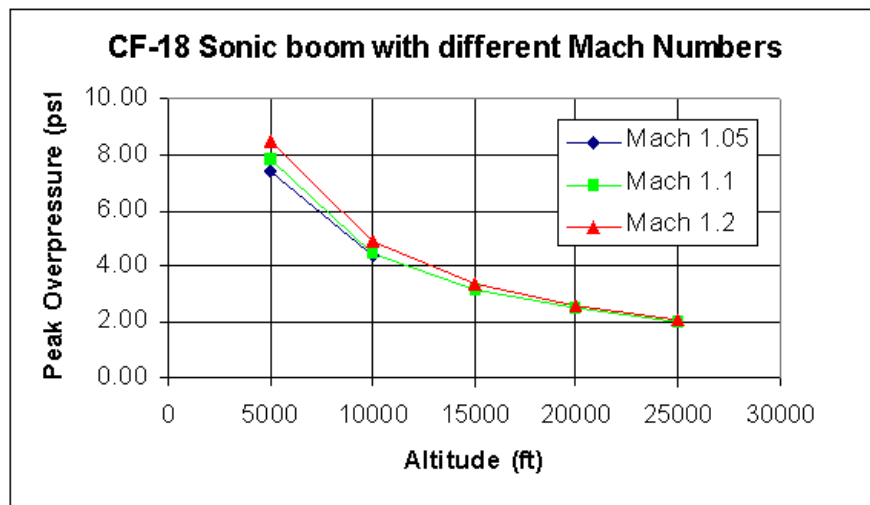


Figure 3. Showing the relationship of an aircraft's altitude and peak overpressure with different Mach numbers. Altitude has a greater influence on the peak overpressure experienced on the ground; Mach number has less influence.

## 2.1 Focused Sonic Booms

Aircraft manoeuvres at supersonic speeds such as dives, accelerations, or turns can cause a concentration of the peak overpressure referred to as focusing the sonic boom. In general, the peak overpressures for a “focused boom” are amplified 2-5 times, but this focused boom impacts a much smaller area as compared to a non-focused sonic boom. Other manoeuvres, such as decelerations and climbs, can reduce the strength of the shock, which results in “defocusing”. In some instances, weather conditions can also distort sonic booms. It must be emphasized that unlike the carpet boom, the focus boom does not move with the aircraft, and it is generally confined to a very small region.

As stated earlier, atmospheric conditions have significant impact as to whether or not the sonic booms reach the ground. This is particularly true for focus booms, where the number of booms reaching the ground is lower still. This is because the conditions have to be just right for a focus boom to reach the ground. Table 2 shows the relationship between the rate of acceleration and altitude of an aircraft for focus boom to occur on the ground. Based on the aircraft’s altitude and acceleration rate, the focusing (convergence) of the rays may occur above or below the ground, as depicted in Figure 4. The peak overpressure is greater in the focus region than in the pre-focus or post-focus regions.

Table 2. Showing relationship between rate of acceleration and altitude of the aircraft for focus boom.

	Small Acceleration	Large Acceleration
Low Altitude	Focus Below Ground	Focus at Ground
High Altitude	Focus at Ground	Focus Above Ground

The relationship can be graphically depicted as follows:

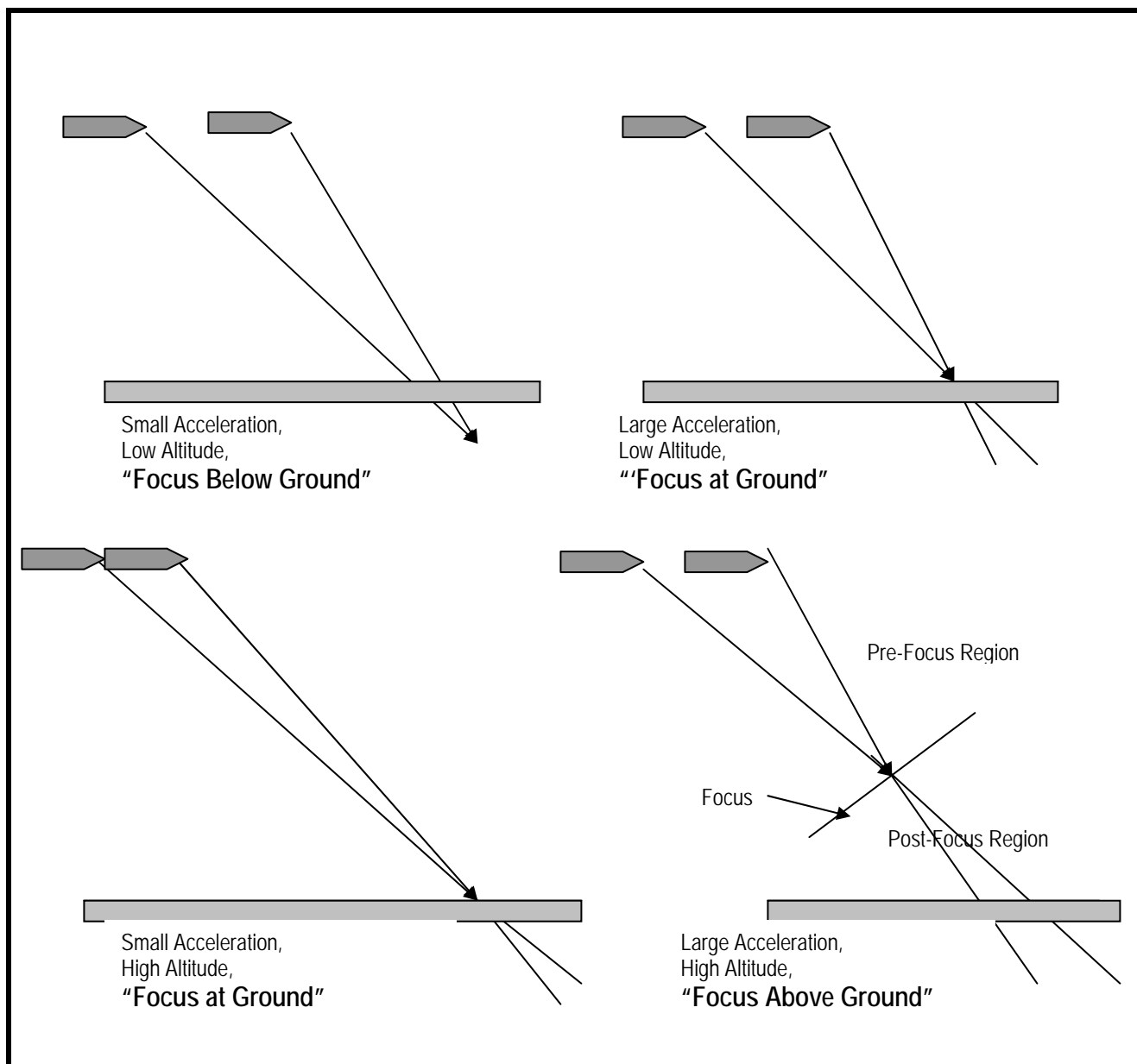


Figure 4. Showing the relationship between the aircraft's acceleration and altitude, and the associated likelihood of a focus boom at ground level (modified after, Sutherland et. al., 1990).

### 3.0 Environmental Issues and Concerns

From an environmental perspective, there are two issues related to the magnitude of the peak overpressures when shock waves (sonic booms) reach the ground,

1. When shock waves impinge upon the surface of objects, they may create vibrations in the object which may result in structural damage; and
2. The loud noise that is associated with shock waves due to the sudden rise and fall of the peak overpressures. These loud noises may cause disturbance to wildlife and human activity, generally in the form of startle reactions.

It should be noted that the sonic boom event lasts only a fraction of second (generally approximately 0.1 second) and, unlike the noise from subsonic aircraft, there is no build up of the noise. During a supersonic event, the sonic boom is heard on the ground about 2-60 seconds after the aircraft has flown overhead. Figure 5 graphically illustrates the noise level time history of a supersonic and a subsonic event.

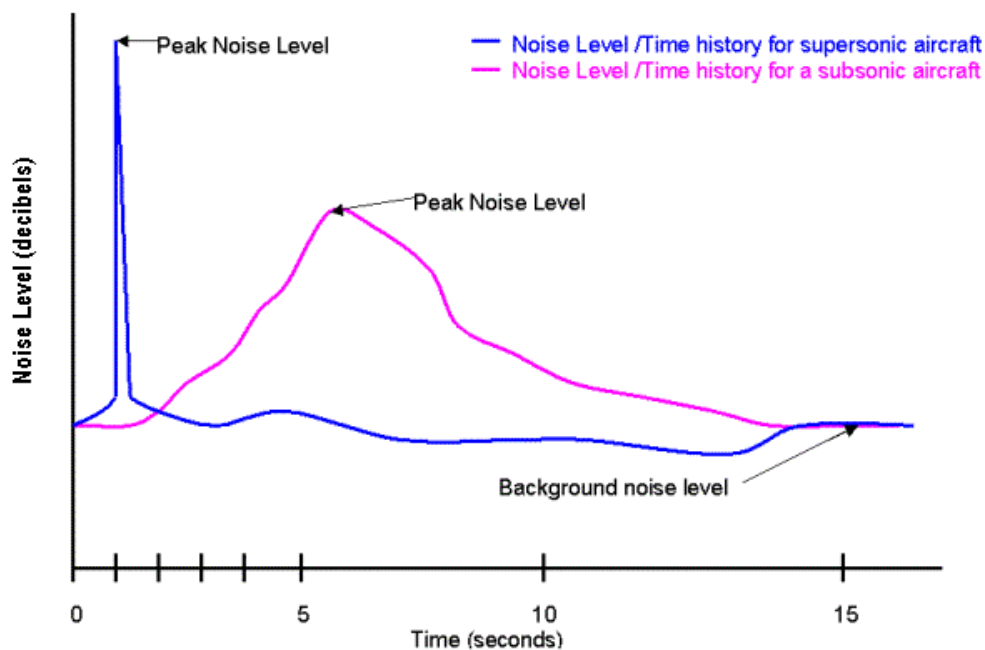


Figure 5. Graphic illustration of a noise level – time history for a subsonic and supersonic (sonic boom) aircraft event. Subsonic noise is generated from the aircraft's engines and airframe. At low altitude, the entire sub-noise event lasts about 10-15 seconds, whereas the noise from a sonic boom is like a spike lasting about 0.1 second, and it reaches the ground 2-60 seconds after the aircraft has passed overhead.

### 3.1 Noise Environment

Measurement and perception of sound involves two basic physical characteristics: amplitude and frequency. Amplitude is a measure of the strength of the sound and is directly



measured in terms of the pressure of a sound wave. Because sound pressure varies with time, various types of pressure averages are commonly used. Frequency, commonly perceived as pitch, is the number of times per second the sound causes air molecules to oscillate. Frequency is measured in units of cycles per second, or Hertz (Hz).

Attempts to represent sound amplitude by pressure are generally unwieldy. Therefore, sound is generally represented on a logarithmic scale with a unit called the decibel (dB). Sound on the decibel scale is referred to as a sound level. Due to the logarithmic nature of the decibel scale, sound levels do not add and subtract directly and are somewhat cumbersome to handle mathematically. However, a simple rule of thumb is useful in dealing with sound levels: if a sound's intensity is doubled, the sound level increases by 3 dB, regardless of the initial sound level.

It should be noted that under laboratory conditions, the human ear could detect differences in sound level of 1 dB. However, in the community, the smallest change in average noise level that can be detected is about 3 dB. A change in sound level of about 10 dB is usually perceived by the average person as a doubling (or halving) of the sound's loudness, and this relation holds true for loud sounds and for quieter sounds.

Moreover, the human ear (and the ear of various animal species) is more sensitive to high frequencies of sound (or noise) than to low frequencies. Furthermore, the sensitivity of the human ear to sound of varying frequencies changes with the sound magnitude. Thus, "a technique for relating physical noise properties and measurements to the subjective response of various species is desirable, but rarely attainable. The introduction of noise frequency weighting on sound-level meters is one attempt to solve this problem for human noise impact assessment. However, no such device has been developed for a species of wildlife or domestic animal" (Manci, et. al., 1988).

Depending on the noise metric used to quantify a noise event (e.g. a sonic boom), different numerical decibel values can be obtained. For example, Figure 6 shows modelled supersonic flights by a Tornado aircraft at Mach 1.2 at different altitudes. In order to obtain numeric decibel values, one selects the altitude of the aircraft on the horizontal axis, and then on the vertical axis reads the corresponding decibel levels. A brief description of commonly used noise metrics is given in the following paragraphs.

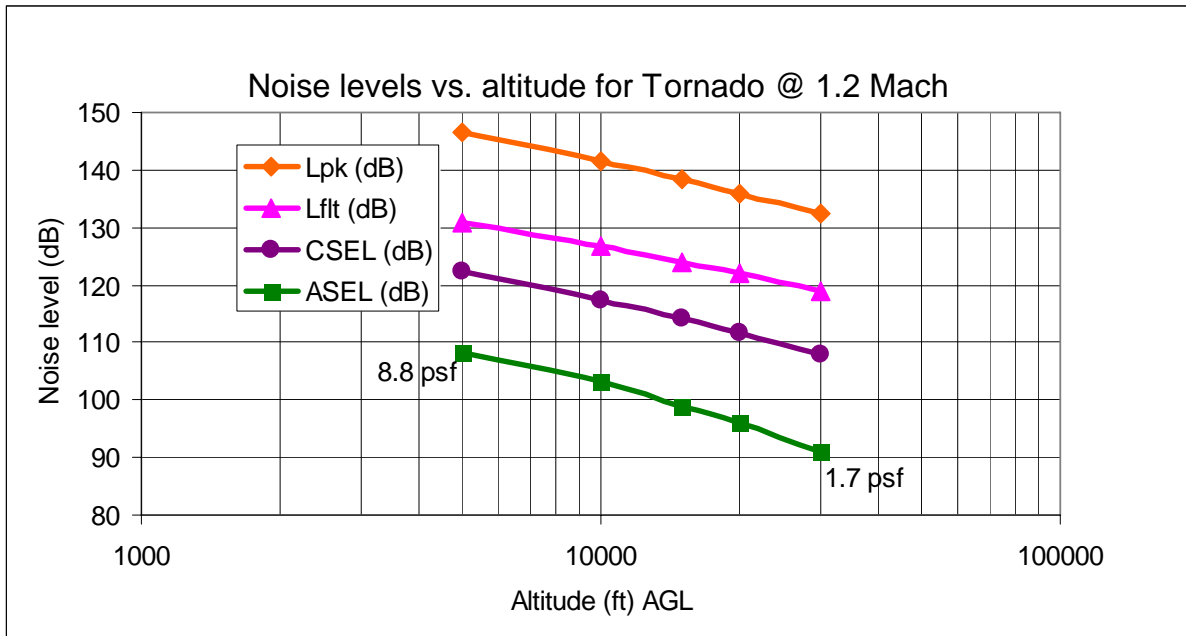


Figure 6. Showing relationship between various noise metrics and the altitude of a Tornado flying at 1.2 Mach. The peak overpressure generated by an aircraft flying at 5,000 ft AGL is 8.8 psf; at 30,000 ft AGL, it is 1.7 psf. This sudden change in pressure results in a sonic boom and, depending on the weighting functions, a number of noise metrics can be used to quantify this noise.

- (a) Lpk – Peak noise, or instantaneous noise, lasts only a fraction of a second, and in this case no weighting function is used. Since it is a true instantaneous sound pressure, it is usually presented in physical units of pounds per square foot (psf), but it can be represented on a decibel scale (dB);
- (b) Lflt – Flat-weighted noise level. It takes into account the duration of the noise, and all the frequencies of the noise are weighted equally. Thus, this represents a sound averaged over one second duration;
- (c) CSEL – C-weighted noise level where the low-frequencies are less attenuated, and the noise is averaged over one second duration. C-weighting is generally used to quantify impulsive noise, such as noise from blasting operations, artillery firing, and sonic booms;
- (d) ASEL – A-weighted noise level, where the low-frequencies noise is attenuated more, and it is averaged over duration of one second. This noise metric corresponds well to the response of human ear, and thus it is commonly used to quantify the noise disturbance.

The instantaneous peak sound level or Lpk (dB) can easily be converted to peak overpressures (psf), and vice versa. Since the instantaneous peak level does not take into account the duration, it does not describe the complete noise event; often, the human ear may not respond to a noise of such short duration (nor, possibly, the ear of many species).

Table 3 shows the comparison of sound levels (both units of pressure and decibel scales) from typical sources. Note that the overpressure from firing a rifle close to the ear is more than 40 psf (which is likely to be experienced by hunters); whereas overpressure from a jet aircraft taking off at approximately 25 meters is about 4 psf. The peak overpressure, as an un-weighted noise level (Lpk in dB), from a rifle is considerably greater than what would be experienced below the 5 Wing Air Ranges from supersonic noise events.

Table 3. Comparison of sound pressures and sound levels from typical sources (after, Mancini et. al., 1988).

Sound Pressure Levels		Sound Level (dB)	Typical Source
N/m <sup>2</sup>	psf		
2000	41.77	160	Peak level at ear of 0.303 calibre rifle
200	4.17	140	Jet aircraft taking off at 25 m
20	0.41	120	Human pain threshold
2	0.04	100	Very noisy factory
0.2	0.004	80	Ringing alarm clock at 1m
0.02	0.0004	60	Ordinary conversation at 1m

The Sound Exposure Level (SEL) accounts for both the maximum sound level and the length of time a sound lasts. However, the SEL does not directly represent the sound level heard at any given instance; rather it provides a measure of the total sound exposure for an entire event averaged over 1 second. Due to the weighting functions that are applied to various frequencies, Lpk (dB) can be empirically related to the C-weighted sound levels CSEL (dB). However, if the raw sound (noise) level data is recorded, then it can be converted to any other type by passing it through the weighting networks of a sound level meter. The sonic boom modelling program available to DND (PCBoom3) that will be used for the environmental assessment provides all of these noise parameters (Lpk, Lft, CSEL, ASEL etc) both as a single event (i.e. to determine impact at a specific location), and in the form of contour maps.

A-weighted noise metric (ASEL) is the most commonly used noise parameter for many types of noise disturbance, such as vehicle traffic, railroads, airport, and other types of human activities. This noise metric has also been used for subsonic noise monitoring studies of low-level fixed wing and rotary wing aircraft in the Goose Bay Air Ranges and noise measurements at the Goose Bay airport (EIS, DND, 1994). The A-weighted noise correlates well with human response to noise, as it assigns high weights to the typically more audible high-frequency tones; and low weights to the low-frequency tones, to which the human ear (and the ears of some other animals) is less sensitive. The A-weighting function has been standardized in many of the current sound-level meter specifications. A drawback to its use is that a simple sound level measure usually does not adequately account for wide ranging tonal variations. It is the most commonly used noise metric in biological studies where disturbance to wildlife is correlated with human activity.

The C-weighted noise metric (CSEL) is used to quantify impulsive noise such as sonic booms, as it accounts for low-frequency components. Due to the subjective sensitivity of the human ear, the low-frequency components in noise are not heard. CSEL is the

common noise metric used to describe the amplitude of impulsive noise, because this correlates well with annoyance. The annoyance is not only due to the sudden loud noise, but also may be due to vibrations and rattling of the fixed structures that are occupied by people. It should be noted that for noise assessment and prediction of long-term community response, a single event high-energy impulsive sounds measured on C-weighted metric ( $L_{CE}$ ) could be related to A-weighted metric ( $L_{NE}$ ), using the following formulation (ANSI S12.9-1996-Part 4):

$$L_{NE} = 2(L_{CE}) - 103$$

The relation in this equation suggests that 1 dB change in C-weighted exposure level produces a 2 dB change in adjusted sound exposure level; and the two descriptors are numerically equal at 103 dB.

In order to quantify environmental impacts due to sonic booms, the US Air Force uses a cumulative C-weighted noise metric CDNL (C-weighted day and night averages). This is because of the large number of sonic booms produced during their training activity. The CDNL is usually computed as a monthly or annual average, but may be computed for a period as short as one day. Since CDNL accounts for both the number of sonic booms and their amplitude, it correlates well with community annoyance (noise disturbance). Furthermore, the cumulative noise metric CDNL values can be displayed as contour maps that show the affected areas (see Appendix 1 to this Annex for the graphics).

#### **4.0 Brief Overview of D Air CFG (DND) Supersonic Field Measurement Program<sup>2</sup>**

D Air CFG (DND) conducted field measurement programs in Goose Bay during April and July of 2004 to collect independent data about the impact of sonic booms on the environment. In order to accomplish the objectives, predetermined supersonic flights were conducted at specific altitudes, speeds (Mach number), segment lengths, and directions. Measurement and observation stations were setup in the Naskaupi Valley, Labrador to collect data. The field program was designed with three distinct objectives, as follows:

1. Measurement of physical parameters: To collect data about the sonic boom characteristics, i.e. sonic boom magnitude (peak overpressures and carpet widths, etc.). In addition to making the field measurements, DND compared the data obtained from field measurements with the modelled values. Sonic booms were modelled using PCBoom3 computer program by:
  - a. Inputting the flight profile information that was obtained from the Air Combat Manoeuvre Instrumentation (ACMI) pod mounted on the aircraft, and
  - b. Inputting the Goose Bay weather profile information that was obtained from balloon launches.
2. Biological Component: To determine the biological impacts of sonic booms on the wildlife, particularly on the osprey and waterfowl.

---

<sup>2</sup> A copy of complete report on the field measurement program can be obtained from the Principal Contact Person for this EA.

3. Seismic Component: To determine the seismic impact of sonic booms on land; specifically, the impacts on the slopes due to vibrations caused by the sonic booms.

#### 4.1 The Supersonic Field Measurement Program

The Canadian Forces made two CF-18 aircraft available for the July 2004 field measurement program. Table 4 provides information about the dates, number of sorties and the tracks flown during each sortie along with the attitude of flight profiles. A total of 10 sorties (resulting in 39 tracks) were flown at different altitudes. Five measurement stations along the Nasakupi valley were set up to record the sonic booms. The flight profiles (altitude, speed, and direction, etc.) were designed such that the generated sonic booms would reach the measurement stations on the ground so that the results could be compared with the modelled values.

Table 4. Summary of Supersonic field measurement program in the Naskaupi valley, Labrador.

Date	Sortie Number	Number of Tracks Flown in an individual Sortie	Attitude of Flight Profiles	Main Objectives: Peak overpressure measurement/ seismic measurement and observation of wildlife behaviour
19 July 2004	1	4	Straight and Level	Measurement and Waterfowl
	2	3	Straight and Level	Measurement and Waterfowl
20 July 2004	1	5	Straight and Level	Measurement and Seismic/ Osprey
	2	4	Straight and Level	Measurement and Seismic/ Osprey
	3	4	Straight and Level	Measurement and Seismic/ Osprey
	4	3	Straight and Level	Measurement and Seismic/ Osprey
21 July 2004	1	3	Straight and Level	Measurement and Seismic
	2	3	Straight and Level	Measurement and Seismic
22 July 2004	1	6	Acceleration and Dive	Measurement and Seismic
	2	4	Acceleration and Dive	Measurement and Seismic
<b>Total</b>	<b>10</b>	<b>39</b>		

During this field measurement program most of the flight profiles were straight and level flights, ranging in altitude from 10,000 ft to about 25,000 ft (AGL), with Mach numbers of 1.2 to 1.35. These are extremely high speeds, and during Air Combat Manoeuvre (ACM) the aircraft rarely reach these speeds. However, these speeds represent extreme levels that the aircraft could fly in the Goose Bay area because of the associated fuel penalty (in order to

achieve higher Mach number, the pilot has to use afterburners, and that consumes a lot of fuel).

During this field measurement program, the lowest altitude of the aircraft was about 10,000 ft AGL. An analysis of the field data resulted in a total of 62 recorded sonic boom events, and the maximum peak overpressure measured was approximately 3.25 psf. Further, the predicted value for the peak overpressure for aircraft flown at 1.26 Mach at an altitude of 16,000 ft is around 3.3 psf. A comparison of the measured peak overpressure values and those predicted using the PCBoom computer model is given in Section 5.1 of this Annex.

Attempts were made to capture focus booms during the field trials. For this measurement, stations were setup within a one square mile area. However, due to the difficulty of placing the focus booms at the pre-positioned measurement stations, and the small area covered by focus booms, only a few stations recorded the boom. During the high-speed manoeuvres, particularly dives, the maximum peak overpressure was calculated to be about 18.0 psf. The area affected by focused booms (sonic booms of high amplitude values) is extremely small; and typically, areas with more than 5.0 psf values are less than a few square miles.

As stated earlier, all supersonic flights result in sonic booms, but only a few reach the ground. This is particularly true for supersonic events at higher altitudes. This is because of the refraction of the shock wave resulting from atmospheric conditions; specifically, the change in temperature with altitude. Furthermore, as the aircraft's altitude increases, there is a corresponding drop in the amplitude of the sonic boom. Thus, the areas affected by high amplitude sonic booms are small, and a carefully designed environmental mitigation program should be able to protect the sensitive areas.

## **4.2 Field Measurement Program – Human Observers**

In addition to the Measurement Teams and Field Observers to the biological responses to sonic booms, representatives attended the field measurements from the Scientific and Review Committee (SRC) of the IEMR, the Innu Nations, the Government of Newfoundland and Labrador, the Canadian Wildlife Services (CWS), Churchill Falls (Labrador) Corporation, and the Director General Environment of the DND.

## **4.3 Field Measurement Program – Biological Observations**

In order to observe the reactions of wildlife to sonic booms, field teams were placed at suitable locations prior to the supersonic flights. However, due to the location of the measurement sites, the only available wildlife in the vicinity were the waterfowl and osprey; thus, only reactions of these wildlife species to sonic booms were observed.

### **4.3.1 Waterfowl Observations**

The Institute for Environmental Monitoring and Research (IEMR) sponsored this study, and three observation sites were set up. Two sorties were flown with straight and

level profiles, resulting in total of seven tracks. Sonic booms were generated along each of the seven tracks. Since there were three observation sites, this resulted in total of about 21 observations. The lowest altitude for one of tracks was approximately 10,000 ft AGL, and it produced a sonic boom of about 3.25 psf on the ground.

The seven sonic booms at a single location during the morning of 19 July were created over a 2 hour-period, representing an extreme situation in terms of future operational requirements in the Goose Bay Air Range CYA 732, or for that matter, anywhere else. The following is the excerpt from an IEMR report that offered general points for consideration should supersonic training activities are implemented at 5 Wing Goose Bay.

“The findings of this single-day investigation of supersonic flight and the associated sonic booms indicated a strong response amongst the species of waterfowl present. The immediate reaction of the majority of waterfowl under observation during a sonic boom was an escape response such as flushing, flying and/ or diving. Following a series of successive booms, waterfowl often departed from the field of view, indicating a sensitization (heightened or increased response), versus habituation to these events. It was the opinion of the study team that Mergansers exhibited the most overt reactions. Regardless of the response, individual avifauna that remained visible following a boom event appeared to return to pre-exposure behaviours usually within 1 minute and certainly within 5 minutes.”

#### **4.3.2 Osprey Observations**

In order to observe the reactions of osprey to sonic booms, four nest sites were selected during the reconnaissance period; but only three sites could be monitored, because at the fourth nest site the pairs were absent when the study team arrived. The osprey monitoring was done on July 20, 2005; a total of 16 boom events were generated, and with three monitoring sites, it provided an opportunity for a total of 48 observations.

All of these nests had the young chicks when the supersonic flights were conducted. As expected, the adults were startled and they flushed from the nest when the first sonic boom reached the nest location. At all of the observed sites, adults were back at the respective nest site well before any significant effect may have had a chance to manifest (generally within 1-2 minutes after the sonic boom). Since each nest location was subjected to several sonic booms during each sortie, when the second boom reached the nest site the adults did not flush from the nest. However, they were seen turning their heads and sometimes seen to be ducking down. Thus, it can be said that the startle effect lessened with successive sonic booms. By the third or fourth sonic boom, it appeared that the adults had habituated and were not even turning their heads to see what had happened.

As stated earlier, this field measurement program represented an extreme case. Yet, the study team managed to observe startle response with habituation occurring within 1-2 hrs and 3-5 events in a single morning. However, during actual supersonic training, the occasional sonic boom that reaches the ground would definitely startle the osprey, resulting in the flushing of the birds. But this is not expected to cause a loss of chicks nor consequent population level damage, as the chicks did not appear to respond negatively to the events.

#### **4.3.3 D Air CFG Seismic Study**

The field study commissioned by D Air CFG illustrated that, due to inefficient transfer of energy from the atmosphere to the ground, there is very little ground coupling. The ineffective transfer of energy is due to large differences in the acoustic impedance of the atmosphere and the ground. Consequently, for the operational altitudes for the proposed training, it would not have any impact on the unconventional structures present below the Air Range CYA 732. A complete report of this study is provided as Annex D.

### **5.0 PCBoom Sonic Boom Computer Model**

The USAF has gathered large amounts of sonic boom data (peak overpressures and other noise parameters) from field measurements using different types of aircraft and a variety of manoeuvres. Wyle Laboratories, in conjunction with the USAF, has developed computer programs to model the characteristics of the sonic boom. The most commonly used computer program to model a single boom event is the PCBoom.

PCBoom3 can be used to model individual flight segments (manoeuvre segments – straight level flights, linear acceleration, dives, and g-turns, etc.), by entering flight parameters (such as Mach number, altitude, flight direction, etc.). It also provides an option to choose from a variety of aircraft types (since amplitude of the sonic boom is dependent on the aircraft shape factor and its weight). The program allows for the input of atmospheric parameters (i.e., temperature gradient and wind speed/ direction), and calculates peak overpressures at target locations (measurement sites). Therefore, to some extent, the variations expected in peak overpressure and carpet width because of wind direction can be modelled. Sonic boom spectra (the type of shock wave its duration and amplitude) at different locations can also be determined. Finally, all of these results (e.g., Lpk, Lft, CSEL, and ASEL etc.) can be plotted as contour maps.

PCBoom3 sonic boom computer modelling program was obtained from the Wyle Laboratories, and it has been used to determine impacts of the sonic boom (i.e. the peak overpressure, and carpet widths, etc.) for each of the flight profiles flown during the field measurement program. The US Air Force has used different versions of this program for a long time, for environmental mitigation purposes, including the development of Environmental Impact Statements (EIS) for many of their military operating areas (MOAs) where supersonic flight activities take place today. The results obtained from various versions of the PCBoom program have been widely published in peer-reviewed journal articles and graduate theses.

#### **5.1 PCBoom3 Computer Model Validation**

In order to validate the PCBoom3 computer model (using the aircraft flight profile information and atmospheric conditions at that time), sonic boom values were calculated at the locations corresponding to the measurement stations during the field measurement program. Figure 7 shows the relationship between the predicted values and the field measurement values. The lowest flight altitude during the field measurement program was about 10,000 ft AGL. From this figure, it is obvious that all of the measured peak



overpressure values are less than 3.25 psf and all of the predicted values are less than 5.0 psf. The predictions of the PCBoom3 computer model tend to agree with the field measurement values along the centreline, whereas it over predicts at the carpet edge. Similar observations about the PCBoom3 over predictions have also been reported in literature. Alternatively, it can be said that the predictions of peak overpressures made using the PCBoom3 computer model are on the conservative side, and all the variations that may result from atmospheric conditions can be accounted for the mitigation purpose.

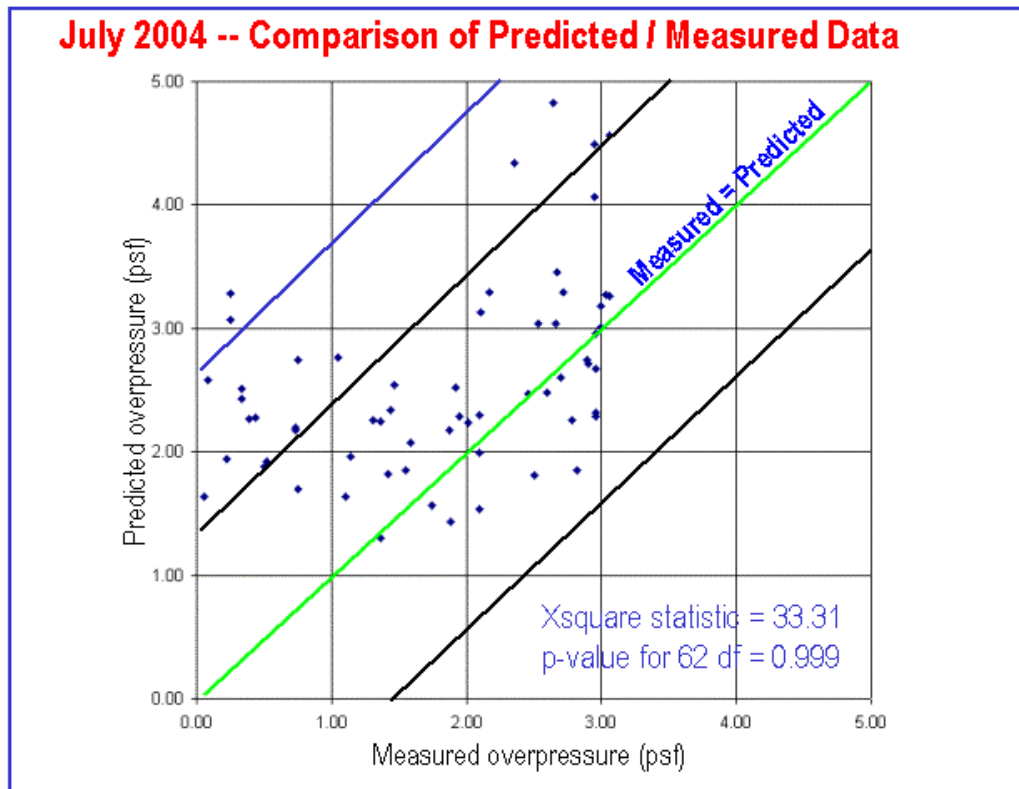


Figure 7. Showing the relationship between the measured and predicted peak overpressure values. The peak overpressure values were measured during the July 2004 field trials, and the corresponding values were predicted using the PCBoom3 computer program. In this case 62 data points are shown. The green diagonal line represents where the measured and predicted values are the same. This demonstrates that the PCBoom3 predicted values are on the conservative side, as it tends to over predict the magnitude of the overpressure (particularly at the carpet edges). The other diagonal lines are 1 psf apart.

DND presented the data<sup>3</sup> collected during the field measurement programs and the corresponding modelled values to the SRC (IEMR) in November 2004. The objective was to determine the effectiveness of PCBoom3 computer program for monitoring the impacts of sonic boom on the environment. It was agreed by the participants that the results obtained from PCBoom3 are on the conservative side; that is, the model tends to over-predict (with slightly higher magnitude values than measured in the field), particularly at the edges of the carpet. At this meeting, it was agreed by all of the participants that the PCBoom3 is a valid model. It can be effectively used to make tentative prediction of environmental impacts of sonic boom events (such as peak overpressures, noise levels, and carpet widths, etc.) that are likely to be generated in the 5 Wing Goose Bay Air Range.

The predicted sonic boom values suggest that these are within acceptable limits when compared with the published literature. At these peak overpressures, and associated noise levels, no significant environmental impact is expected with the proposed supersonic flight activity. If environmental impact because of sonic boom activity (of similar magnitude) is observed during the field monitoring studies (see Section 1.6 of the Registration document), it can be mitigated by practicing avoidance of sensitive species and by maintaining an active environmental mitigation program.

## **6.0 Assessment of Sonic Boom Impacts**

Supersonic flight for fighter aircraft is primarily associated with air combat training (ACT). Modern combat tactics and advanced weaponry also require supersonic speeds to launch a variety of munitions at optimum levels and within desired employment envelopes. These activities will occur above 5,000 ft AGL within the CYA 732 Air Range, and the assessment of impact is the objective of this environmental assessment.

### **6.1 Supersonic Training in 5 Wing Goose Bay Range CYA 732**

Since, at present, there is no allied commitment to supersonic training activity, DND is proposing to approve this activity in the Labrador portion of the CYA 732 Air Range. As stated in Section 1.0, DND envisages two separate scenarios, that is, the Conventional Night Strike, and the Ongoing training activity. The Night Strike Training requires a large-scale deployment for short time, generally two weeks only; and due to the logistics and resources needed, this type of exercise can be conducted only a few times a year. With the Ongoing Training requirements, although this Environmental Assessment stipulates 1,250 sorties during a training season (all impacts are predicted based on 1,250 sorties in CYA 732), initially the number of sorties will likely be considerably less. Nonetheless, subsequent to approval, DND will gain experience in monitoring and mitigation of sonic boom impacts in air range CYA 732; and if the adverse effects on sensitive wildlife species are observed that cannot be mitigated, DND would recommend the termination of supersonic flight training activity in the Goose Bay area.

---

<sup>3</sup> Copy of the complete presentation can be obtained from the Principal Contact Person for this EA.

The details of fighter tactics are given in Annex E. Table 5 provides a comparison of minimum altitudes for supersonic events. In this table, data for the F-16 and other fighter aircraft are from long-term monitoring studies by the U.S. Air Force; whereas, the CF-18 data is from one squadron's training phase in June-August 2004. With modern aircraft such as the CF-18, most supersonic activity is above 20,000 ft. However, since these are long-term averages, supersonic events in the Goose Bay Air Range are likely to follow the similar altitude bands as depicted in Table 5. It should be noted that in Air Combat Training (ACT) there are no set patterns and it is common knowledge that "pilots who follow set patterns in air combat do not survive", because their reactions can be predicted with accuracy. Furthermore, with the deployment of modern aircraft, the altitude for supersonic training activity is gradually shifting to higher altitudes.

Table 5 Comparison of minimum altitudes for supersonic events by percentage during F-16, CF-18 and other Fighter aircraft in Air-to-Air Combat Training.

Altitude (feet)	F-16 (%)	CF-18 (%)	Other Fighter Aircraft (%)	Average number of sorties in different altitude bands for all types of aircraft (based on 1,250 sorties)
> 40,000	0	0	6	25
30,000-40,000	15	29	28	300
20,000-30,000	44	56	53	638
15,000-20,000	28	13	12	220
10,000-15,000	12	2	1	62
05,000-10,000	1	0	0	4

Table 6 provides a comparison of the ACM (Air Combat Manoeuvres) activity levels that take place in some of the U.S. Military Operating Areas (MOAs) and the expected activity levels in the Goose Bay Air Ranges. The size of the MOA, in many cases, is much smaller than the size of the Goose Bay Air Ranges, and they tend to experience a much higher level of activity. Further, in some of these MOAs, there are permanent human settlements, which include communities of ranchers and native peoples. Below the Goose Bay Air Ranges, there are no permanent human communities. There are a few fishing camps (which include fixed structures) that are occupied on an annual basis during the summer months. There are traditional Innu Camps below the Goose Bay Air Ranges that could become occupied during part of the training season. The locations and timings of these occupancy areas are communicated to the MCCO, who is responsible for placing environmental closures so that they can be avoided from low-level subsonic aircraft flights. Similarly, the locations of sensitive species are also protected from low-level over flights.

Table 6. Comparison of the Air Combat Manoeuvre (ACM) activity levels between the selected American Military Operating Areas (MOAs) and the predicted activity level in Goose Bay Air Range.

Air Range	Aircraft Types	Area (sq. mi.)	ACM Sorties
Elgin MOA (Subsection of Nellis Range Complex, NV)	F-15 and F-16	2,400	6,225 (during six months)
Lava/ Mesa MOA (White Sands Missiles Range, NM)	Primarily F-15 (72%)	2,600	4,600 (during six months)
Air Range CYA 732 (5 Wing Goose Bay)	All	17,100	~160 (during Night Strike exercise) <b>OR</b> ~1,250 (during training season)

## 6.2 Modelling of Single Boom Events Using PCBoom

Supersonic single event booms can be modelled using the PCBoom software developed by the USAF. This program requires specific input: specifically the aircraft information (i.e., size and weight), flight profile, and the weather information. PCBoom is more likely to be used for modelling impacts in the Goose Bay area, and its applicability for supersonic training has been validated using the field measurement data.

In order to assess the environmental impacts, a series of steady state supersonic flights were modelled using the PCBoom3 and US standard atmosphere (for temperature gradient, and a no-wind condition). Table 7 has some of the modelled values for a Tornado aircraft in a straight and level flight at a speed of 1.2 Mach and various altitudes. These are given as the peak overpressures (psf), C-weighted sound exposure levels (dB), and carpet width (in thousands of feet). The factors that are likely to affect the environment are the peak overpressures and the noise levels at the earth's surface. Both are given in the table below, along the centreline and at the edge of the carpet; this information is further depicted in Figure 8 and Figure 9.

Table 7. Estimated Carpet boom characteristics for a Tornado flying at a constant speed of 1.2 Mach and at different altitudes.

Aircraft altitude (ft) AGL	Peak Overpressure (psf)		Noise Level CSEL (dB)		Carpet Width (k ft)
	Pressure at carpet edge	Pressure along centreline	Noise at carpet edge	Noise along centreline	
5,000	3.20	8.80	113.4	122.5	38.48
10,000	2.10	5.00	109.9	117.5	59.60
15,000	1.80	3.40	108.6	114.2	63.86
20,000	1.50	2.60	106.9	111.7	74.22
30,000	1.30	1.70	105.4	107.9	74.24

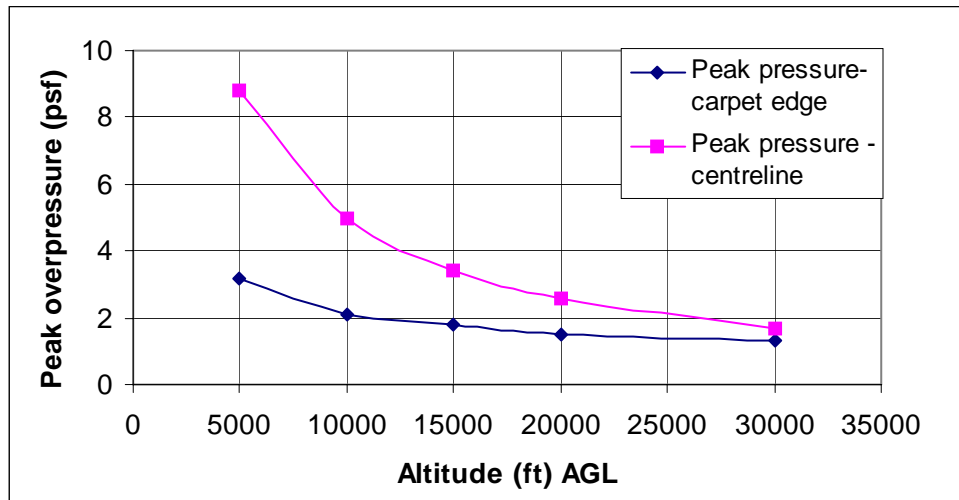


Figure 8. Showing the relationship between aircraft altitudes above ground level (AGL) with the predicted minimum and maximum peak overpressures (psf) for the Tornado in level flight at a constant speed of Mach 1.2. The maximum overpressure will be along the centreline, whereas the minimum is expected along the carpet edge.

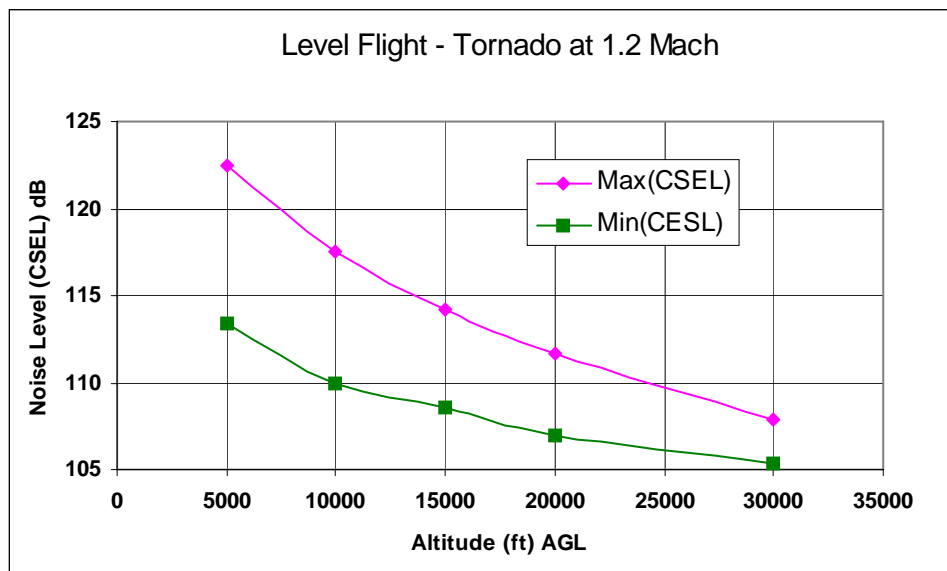


Figure 9. Showing the relationship between aircraft altitudes above ground level (AGL) with the predicted C-weighted sound exposure levels both along the centreline and the carpet edge for a Tornado in level flight at a constant speed of Mach 1.2.

### 6.3 Modelling of Air Combat Training Area

The US Air Force conducts supersonic training in designated areas referred to as Military Operating Areas (MOAs), where the floor of training activity is generally 5,000 ft AGL, similar to what is being proposed in this undertaking for the Goose Bay Air Range. Quite

often, small communities of ranchers, farmers (including dairy farmers), and native people occupy the lands covered by many of these MOAs. Thus it is not only the wildlife present in the military operating areas (MOAs) that are subjected to sonic booms, but also human populations (permanent residents) and domesticated animals. It should be emphasized that the Goose Bay Air Range CYA 732 is much larger in size than many of the American Military Operating Areas (see Table 6) and the land below the Goose Bay Air Ranges do not have permanent human settlements.

The USAF has developed computer models (such as BooMap) to determine the noise impact on the ground below a supersonic training area. BooMap is an empirical model, based on the long-term monitoring projects in four airspace units, namely: (a) White Sands Missiles Range, New Mexico, (b) Eastern portion of the Goldwater, Arizona, (c) Elgin MOA at Nellis AFB, Nevada, and (d) Western portion of the Goldwater Range. Some of these measurement projects were conducted by deploying more than 30 measurement stations in each training area for more than six months. Because BooMap is directly based on long-term measurements, it implicitly accounts for such variables as manoeuvres, statistical variations in operations, atmospheric effects, and other factors.

The long-term measurements in the MOAs have shown that the supersonic tracks from air combat training (ACT) activity tend to fall into an elliptical pattern aligned with preferred engagement directions in the airspace. Consequently the long-term averages of sonic boom patterns also tend to be elliptical. This elliptical pattern of sonic booms is centered on the manoeuvre ellipse. Further, the area potentially exposed to sonic booms does not depend on the number of supersonic sorties. The area is described by the presence of supersonic flights and the boundaries of the airspace. The population exposed to sonic booms will generally be the same as the baseline or existing conditions, but the number of booms will increase with a corresponding increase in supersonic activity. Due to the nature of this training activity, there are a higher number of sonic booms in the centre of the manoeuvre ellipse (i.e. training airspace), and the number of booms decreases away from the centre.

### 6.3.1 Risk Assessment

D Air CFG (Department of National Defence) contracted Wyle Laboratories to conduct the risk assessment, using BooMap computer model (see Appendix 1 to this Annex for a complete report). Once the manoeuvre ellipse is defined and the sortie rate is specified, BooMap computes two quantities that describe the boom environment, namely: the number of sonic booms that are expected to be heard at a given point on the ground within the airspace, and the C-weighted day night level (CDNL). CDNL is a cumulative noise metric that accounts for the number and amplitude of the booms over some period of time.

The BooMap analysis has been conducted using the area of CYA 732 Air Range under two distinct scenarios (see Appendix 1 to this Annex for a complete report): (a) Conventional Night Strike, and (b) Ongoing Training.

**Conventional Night Strike**, under this scenario, a maximum of 12-16 aircraft (sorties) may participate on a given night (as it is a large scale exercise), and the exercise may last up to two weeks period. In this case, the Air Range CA 732 is divided into three supersonic manoeuvre ellipses. With this type of operation, the CDNL would be slightly

above 45 dB in the centre of the manoeuvre ellipse and lower on the edges. The noise impact in the centre of the air space is not expected to cause any significant damage to any of the wildlife species present. Further, the centre of the air space may expect about 0.25 per day; whereas the on the edges of the air space there may be one boom every 20 days or so (i.e. one boom during the training event). However, it should be emphasized that by moving the training into different manoeuvre ellipses, the impact on the ground can be minimized.

**Ongoing Training**, under this scenario, 1,250 sorties are used to model to the noise impacts in the area, which is the maximum number of air-to-air sorties that DND can expect (or, the worst case scenario). However, supersonic training is rarely conducted in such a large airspace in monolithic fashion (see Table 6, for the comparison of airspace size). Quite often, depending on the various training scenarios, this large airspace is subdivided into several sections (i.e., the manoeuvre ellipses). For analysis under three separate training scenarios, CYA 732 has been divided into six, four, and two supersonic manoeuvre ellipses respectively:

- (a) **Six Supersonic Manoeuvre Ellipses:** In this scenario, the CYA is divided into six supersonic manoeuvre ellipses and the total numbers of sorties (1,250 sorties annually) are assumed to be divided equally among these ellipses. In this case, the results of the BooMap analysis indicate that there will be about 0.02 booms per day (one boom every 50 days) in the centre of each ellipse, and a CDNL between 30-40 dB; whereas near the edge of the each ellipse, there will be about 0.005 booms per day (one every 200 days) and a CDNL of approximately 25 dB (see Figure 5-7, Appendix 1 of this Annex). These ellipses can be used simultaneously on busy days, or in rotation when full capacity is not used.
- (b) **Two Supersonic Manoeuvre Ellipses:** In this scenario, the CYA 732 is divided into two supersonic manoeuvre ellipses, and the sorties are assumed to be divided equally between these two areas. The results of the BooMap analysis indicate that in the centre of each ellipse there will be about 0.06 booms per day (one boom every 15 days), and a CDNL of slightly over 40 dB. Near the edge of this portion of airspace, the CDNL will be 30 to 35 dB, and approximately 0.01 booms per day (one every 100 days). (See Figure 11-13, Appendix 1 of this Annex.). In this case the expected number of booms at the centre and edge of each ellipse will be about three times that expected for each ellipse in the six-ellipse scenario. This is because the same number of sorties is considered, but they are concentrated into two ellipses, rather than spread over six areas.
- (c) **Single Supersonic Manoeuvre Ellipse:** In this scenario, the entire CYA 732 Air Range is a considered a single supersonic manoeuvre ellipse (an unlikely scenario). In the centre of the airspace, there will be about 0.12 booms per day (about one every 8 days) and a CDNL value of slightly over 45 dB. Near the edges of the airspace, the CDNL will be about 35 dB and there will be about 0.03 booms per day (about one every 30 days). (See Figures 14-15, Appendix 1 of this Annex.)

Thus, even under the worst case situation with 1,250 sorties when the entire CYA 732 Air Range is used as a single training airspace (i.e., single supersonic manoeuvre ellipse), the predicted CDNL will be slightly over 45 dB in the centre, and on average one boom will be heard every 8 days.

Note the impact area is considerably smaller when compared to the total area of the airspace. This level of noise and boom intensity would not cause significant environmental impact (either to wildlife or human activity). As stated earlier, the size of the impact area is independent of the number of supersonic sorties; however, the number of sonic booms reaching the ground and consequent noise level is related to the number of supersonic sorties.

Given the state of allied forces training in the Goose Bay area, only the *Conventional Night Strike* exercise may materialize; and the *Ongoing Training* with the expected number of 1,250 supersonic sorties may or may not materialize in a training season. The conventional night exercise may be over in two weeks, and the DND does not expects more one or two exercises in a year. Accordingly, the impact may be less than what is predicted in this EA for the worst-case scenario. Alternatively, assuming that once the supersonic flight training activity is approved for the Goose Bay Air Range CYA 732 under either scenarios, then the Adaptive Management strategy proposed in this EA (see Section 1.6 of the Registration document) should be adequate to mitigate environmental impacts. Nonetheless, in order to further reduce impact on the ground, the airspace (CYA 732) will be divided into multiple supersonic manoeuvre ellipses, thereby dividing the total number of sorties into individual manoeuvre airspaces. The same strategy will be employed to provide spatial separation of sensitive species, if required.

Figure 10, resulting from BooMap analysis (see Appendix 1, Table 1) shows the distribution of sonic boom overpressures under this type of supersonic airspace. The average peak overpressure is under 1 psf<sup>4</sup>; and only about 2 percent of booms will exceed 4 psf. There is a very small probability of booms exceeding 5 or 6 psf. Sonic boom overpressure of such a magnitude can cause vibration in structures resulting in adverse effects to delicate and balanced items. However, damage to structures in good condition (including windows) is not expected with booms under about 10 psf. Structures that are not in good condition could be susceptible to damage (their probability of damage is discussed in Section 7.3).

---

<sup>4</sup> For example, a sonic boom of 1 psf is equivalent to 101.6 CSEL (dB) noise. Using the expression  $L_{NE} = 2(L_{CE}) - 103$  (as defined in ANSI S12.9-1996-Part 4), this is equivalent to 100.2 ASEL (dB). At present, DND does not mitigate single noise events of this level.



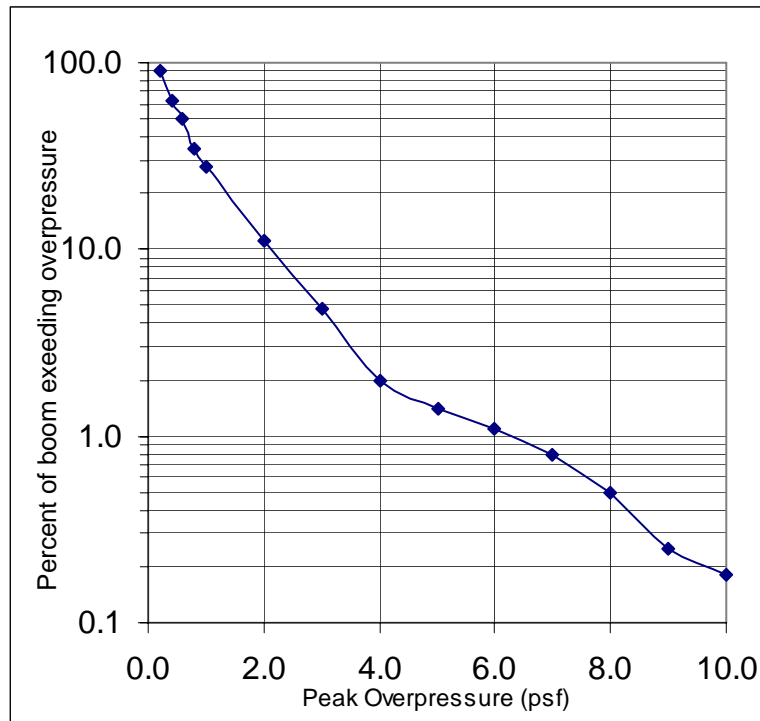


Figure 10. Percent of sonic booms exceeding certain peak overpressure.

## 7.0 Assessment of Environmental Impacts

Most of the information that is available in literature (Annex A) is from the studies conducted by the US Air Force. These studies have been limited to assessing the environmental damage caused to structures and wildlife that can be expected from supersonic flight training under realistic situations, rather than simply to determine the threshold levels that can cause the potential damage to various wildlife species. This is because, from a practical point of view, it is more convenient to assess the reaction of wildlife species and/ or damage to structures through observation following actual supersonic events rather than conducting controlled studies for individual species with various levels of offset to determine the threshold levels. Alternatively, comparison of some type of “before and after” study could be made during supersonic flight activities.

This Environmental Assessment does not study low-level supersonic issues because DND will not allow supersonic flight below 5,000 ft AGL. Notwithstanding, reaction and behaviour of various wildlife species under extreme pressure and loud noise from a supersonic event at low-level is completely unknown, with the exception of some extrapolation of observations and/ or results. Under normal operating conditions, sonic booms of extreme peak overpressures are rare. For example, BooMap analysis (Figure 10) indicates that only 2% of sonic booms may exceed 4 psf, and sonic booms of greater magnitude are extremely rare. Further, the area impacted by large overpressures is quite small (see the graphics in Appendix 1); thus, it would not result in significant environmental impact on the wildlife species.

## 7.1 Environmental Impacts on People

The greatest impact of sonic booms on humans is that of annoyance, which results from being startled by the boom. The annoyance factor can be caused by a variety of means including house rattle/ vibration, and interruption of activities. Further, startling is also responsible for creating fear in some individuals because of the unexpected loud sound associated with the overpressure, although some adaptation may be expected with repeated sonic boom exposures. With the proposed 'Supersonic Flight Training' activity, the CDNL in the centre of the airspace (single manoeuvre ellipse) is slightly above 45 dB. This is a modest value, and in ordinary lightly populated areas would be expected to annoy about one percent of the population. It is worth noting that unlike the MOAs of the USAF, below the Goose Bay Air Ranges there are no permanent settlements that are occupied throughout the entire year. Accordingly, the annoyance from this activity in the Air Range CYA 732 would be less than what is currently experienced on the ground with the low-level flights in the LLTA (CYA 731).

Figure 11 shows the relationship between the noise levels and altitudes for different types subsonic of aircraft. Under the current avoidance criteria, the DND mitigates the noise disturbance by providing a vertical separation of over 1,000 ft between the source of the noise (i.e., the aircraft) and the receptor on the ground. The subsonic low-level flight activity, which is already approved for the LLTA, is practiced below 1,000 ft AGL, and most of this would shift to higher altitudes. As stated earlier, the average sonic boom would be less than 1 psf, and the resulting noise level is insignificant when compared to some sources of noise related to human activity (such as rifle fire, etc), and natural noise events (such as thunder). Furthermore, with this proposed activity, only a small area is subjected to overpressure and the impacted area is considerably smaller when compared to the total area of CYA 732. Sonic boom tests have been conducted at overpressures ranging from 50 to 144 psf without causing injury to people.

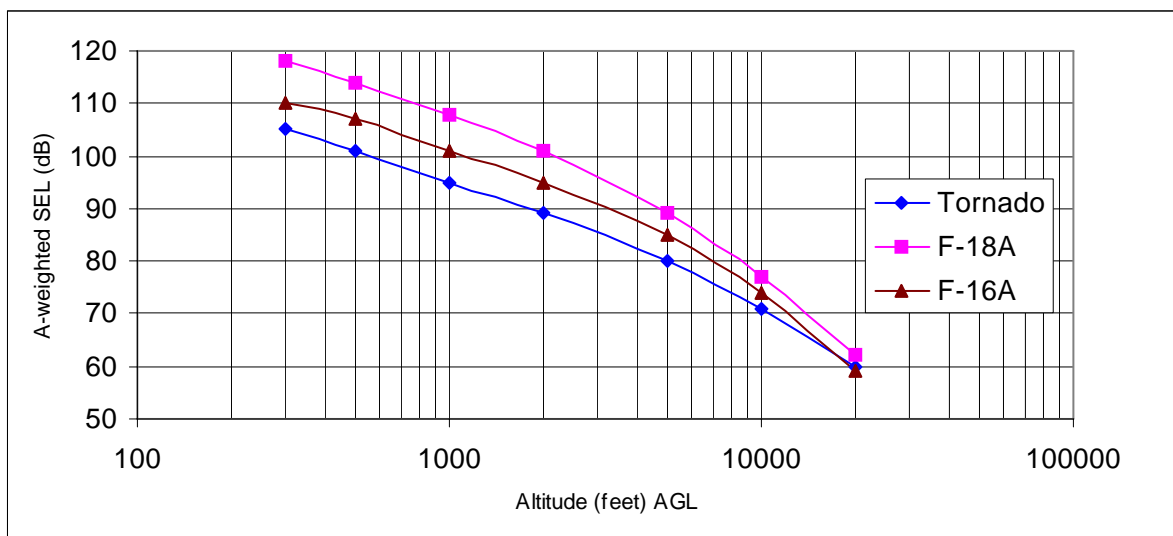


Figure 11. Shows the relationship between fighter aircraft altitudes (AGL) and predicted noise levels from subsonic aircraft. Disturbance resulting from these noise levels in the LLTA has been accepted in the Environmental Impact Assessment of 1994.

## 7.2 Environmental Impacts on Wildlife

The effects of noise and sonic booms on animals vary due to the animals' hearing ability, which varies considerably among animal species. Each species has physically and behaviourally adapted to fill an ecological role within a community, and an animal's hearing ability often reflects this role. Animals rely on hearing to avoid predators, to obtain food, and to communicate with members of their own species.

Behavioural experiments have demonstrated that high-magnitude noise is mildly aversive to animals; this is because of the apparent physiological effects resulting from a stimulating noise that is short lived (e.g. muscular flinch and vasoconstriction, etc). However, the high level noise of short duration may not be aversive enough to result in an effective conditioning stimulus over the long term. This explains the failure of most acoustic harassment devices to deter wildlife, such as deer, from a favoured area.

It is likely that animal species differ greatly in their response to noise of various characteristics and duration. Similarly, the response of an individual animal to a given noise event or series of events can also vary widely, due to a variety of factors including the time of day and year, the physical condition of the animal, the physical environment (such as whether the animal is restrained or unrestrained), the experience of the individual animal, and whether or not other physical stressors are present (e.g. weather conditions, and lack of food etc.).

Potential environmental impacts on wildlife may be due to the sudden change in peak overpressure levels (psf) and/ or the noise that is associated with sonic booms. A detailed description of wildlife species that are common below the 5 Wing Goose Bay Air Ranges is given in Annex C. However, a review of the literature (as listed in Annex A) and some anecdotal references suggest that a loud noise of short duration (e.g. sonic booms) may startle and cause injury to animals; and it could also result in birds flushing from the nest that results in temporary abandonment of the young.

The USAF has conducted several studies both on domestic animals and wildlife species. The research indicates that individual wild and domestic animals exhibit different reactions to sonic booms according to the species involved. These reactions will also differ depending on whether the animal is alone and, in some cases, whether there has been previous exposure. Common reactions are the raising of the head, stampeding, jumping, or running. Avian species may run, fly, or crowd. Animal reactions tend to vary from boom to boom; but the general reactions tend to be similar to low-level subsonic flights, helicopter noise, and other sudden aural disturbances. In many instances, the animal responses are either unrecognizable or consist of an apparent altering accompanied by trotting off a short distance. The results of numerous studies conducted by the USAF both on domestic animals and wildlife, can be summarized as:

- knowledge concerning the effects of sonic boom on wildlife is limited, but it appears that sonic booms do not pose a significant threat;
- available data indicates limited response by wildlife and no nestling death or abandonment;
- all experimental evidence to date indicates that the exposure of mink to sonic booms does not affect reproduction;

- all experimental evidence to date indicates that the exposure of chicken eggs to sonic booms does not affect their hatchability;
- sonic booms do not appear to pose a threat to fish and fish eggs;
- a study on raptorial birds made the following observations: (a) small nestlings do not respond noticeably, (b) large nestlings are alerted or alarmed and, less often, the young will cower, (c) occasionally adults respond minimally (if at all) to loud booms, and (d) adult behaviour indicative of site abandonment was not observed. The report summarized that, although the birds were alarmed/ startled by the subject stimuli, the negative responses were brief and were not productivity limiting. Note, that similar reactions were also observed during field measurement program in the Goose Bay area (see Section 4.3 of this Annex).

### **7.3 Damage to Structures (Conventional and Unconventional)**

When a sonic boom strikes any type of structure (including the ground), a certain amount of energy is transferred that propagates as acoustic or seismic waves. Normally, this energy transfer is very inefficient across the interface that exists between the atmosphere and the structure because of the large differences in the acoustic impedance. Depending on the amount of energy transferred, the structures may vibrate and these vibrations may result in damage.

The degree of vibration in the structure is dependent upon the distribution of mass, the stiffness within the structure and the degree of damping. Damage to structures will only occur when the peak stress induced by the sonic boom loading exceeds the strength of the particular material involved.

#### **7.3.1 Conventional Structures – Review of Existing Damage Data**

Existing data and prediction models for minor damage to conventional structures from sonic booms emphasize window damage. Information on major building damage from sonic booms is generally limited to qualitative observations from a few accidents (Table 9). However, considerable data exist on structural response and relatively major damage from conventional and nuclear blast studies. Using this data, statistical models can be used to assess the damage to the conventional structures (buildings) because of the following reasons:

1. Nature of the building materials – due to the uncertainty of the construction materials used in buildings (brittle and non-brittle materials, i.e. elastic--plastic) that have different load-response behaviours; and
2. Other factors – these are difficult to define, but could include such effects as age/ moisture/ fatigue, and density of the building, etc.

The statistical models can be used to assess damage to conventional structures. These models are based on an empirical fit over a wide range of the measured responses to sonic booms, including the damage data from blast loads on given structural elements such as a wall or roof. The nature and extent of damage to conventional buildings from sonic

booms for nominal overpressures of up to approximately 30 psf, and the status of prediction models for such damage, has been summarized in a USAF report (by Sutherland et. al. 1986, p. 58; see Annex A, section 7) as follows:

1. Most of the damage will be minor, i.e. plaster cracks, broken windows, broken bric-a-brac, and masonry and tile cracks. The actual damage can only be predicted within, perhaps, several orders of magnitude (e.g.  $10^{-5}$  to  $10^{-2}$  broken windows per window-boom exposure for 6 psf nominal booms, Figure 12). This damage rate will increase by about 2 to 3 orders of magnitude for each doubling of sonic boom pressures up to approximately 30 psf.
2. The probability of more significant failures appears to be very small based on over flight results and theoretical analyses relating sonic boom loadings to other natural or man-made loadings.
3. These failures could be “triggered” by sonic booms if the structures were already deteriorated or damaged by other causes so that incipient failures were imminent.
4. Cumulative minor damage effects from prolonged exposures to low amplitude (approximately 2 psf) repeated booms was not evident from results of the few extended sonic boom tests. Data, albeit very limited, is available that suggests that cumulative damage effects may result from repeated exposure to more intense sonic booms – booms greater than 10 to 15 psf.
5. Considerable knowledge exists on natural forces and mechanisms that cause structural damage (e.g. “differential settlement” of soils, lumber shrinkage and swelling from humidity changes, etc.), and is useful for damage claims. This knowledge can be used to provide support for pre-existence of the damage, or to show it was obviously caused by something other than sonic booms.
6. The extensive series of over flight tests have provided valuable data on the order of magnitude of responses to be expected. These tests show that building structures in good repair should not be damaged at boom overpressures less than about 11 psf (Sutherland et. al. 1986, p. 59; see Annex A, section 7). However, it is recognized that considerable loading variability occurs, owing to atmospheric effects, and that the residual strength of structures varies according to usage and natural causes. Thus, there is a small probability that some damage will be produced by the sonic boom intensities that are expected in the training area.
7. The cumulative damage problem is considered less important relative to individual supersonic events. The Sutherland Report raises the issue of primary structural damage: the report details that 2 or 3 low/ moderate intensity booms per day may result in some damage. It should be noted that no more than 4 sonic booms per month are expected in CYA 732; however, this does not preclude minor cumulative damage to primary structures that may result from one sonic event.

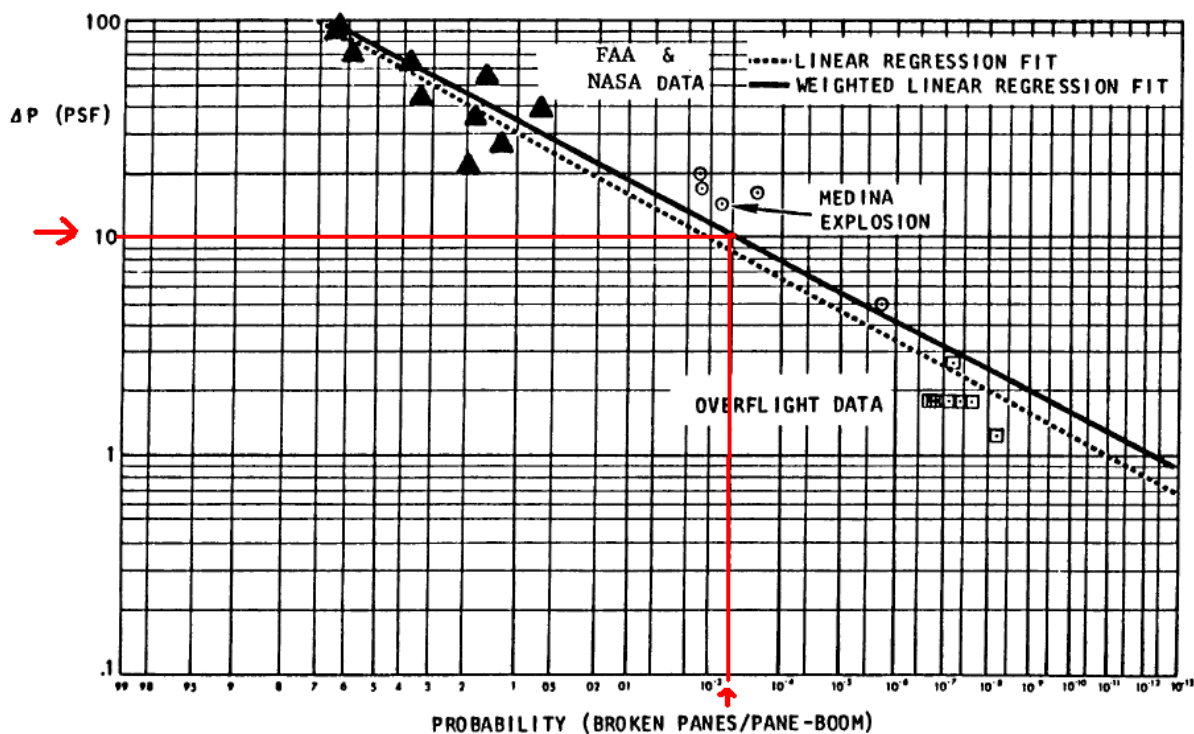


Figure 12. Regression curves showing the relationship between the probabilities of glass being broken and the change in pressure (psf). Note that the probability of a broken pane is one in ~3000 at about 10 psf.

Table 9. Possible damage to structures from sonic booms. The table illustrates the variation in the range of damage that can result from different peak overpressures.

<b>Possible Damage to Structures From Sonic Booms</b>		
<i>Sonic Boom Overpressure Nominal (psf)</i>	<i>Type of Damage</i>	<i>Item Affected</i>
0.5 - 2	Cracks in plaster	Fine cracks; extension of existing cracks; more in ceilings; over door frames; between some plaster boards.
	Cracks in glass	Rarely shattered; either partial or extension of existing.
	Damage to roof	Slippage of existing loose tiles/slates; sometimes new cracking of old slates at nail hole.
	Damage to outside walls	Existing cracks in stucco extended.
	Bric-a-brac	Those carefully balanced or on edges can fall; fine glass, e.g., large goblets, can fall and break.
	Other	Dust falls in chimneys.
2 - 4	Glass, plaster, roofs, ceilings	Failures show that would have been difficult to forecast in terms of their existing localized condition. Nominally in good condition.
4 - 10	Glass	Regular failures within a population of well-installed glass; industrial as well as domestic greenhouses.
	Plaster	Partial ceiling collapse of good plaster; complete collapse of very new, incompletely cured, or very old plaster.
	Roofs	High probability rate of failure in nominally good state, slurry-wash; some chance of failures in tiles on modern roofs; light roofs (bungalow) or large area can move bodily.
	Walls (out)	Old, free standing, in fairly good condition can collapse.
	Walls (in)	Inside ("Party") walls known to move at 10 psf.
Greater than 10	Glass	Some good glass will fail regularly to sonic booms from the same direction. Glass with existing faults could shatter and fly. Large window frames move.
	Plaster	Most plaster affected.
	Ceilings	Plaster boards displaced by nail popping.
	Roofs	Most slate/slurry roofs affected, some badly; large roofs having good tile can be affected; some roofs bodily displaced causing gale-end and will-plate cracks; domestic chimneys dislodged if not in good condition.
	Walls	Internal party walls can move even if carrying fittings such as hand basins or taps; secondary damage due to water leakage.
	Bric-a-brac	Some nominally secure items can fall; e.g., large pictures, especially if fixed to party walls.

Source: Haber and Nakaki 1989

### 7.3.2 Unconventional Structures – Review of Exiting Damage Data

In this document, unconventional structures have been defined as large structures resting on the ground. These include the dykes along the Churchill Falls Reservoir, hydro transmission towers, and steep slopes where the potential for landslides may exist.

The general seismic response of the terrain due to sonic booms is well defined: for very low altitude supersonic flights that produce a high peak overpressures (e.g. 30-50 psf) the resultant overpressure remains well within blast damage limits. The damage threshold limits established by the U.S. Bureau of Mines for blast-induced ground vibration is about 1 inch per second.

The energy that is imparted to the ground usually dissipates within a relatively short distance. In certain situations, surface (Rayleigh) waves may be generated by an interaction of the sonic boom with the ground. Structures may be subject to damage from acoustically excited seismic vibration, since they rest on, or are part of, the local terrain. However, based on the nature of the supersonic flights (i.e. mismatch of the sonic boom carpet velocity and propagation velocity of surface waves over a sufficient distance), and the variability in geological conditions, the ideal conditions for coupling of the sonic booms and the surface waves rarely exist. Thus, surface waves are likely to introduce relatively minor variations in effective loading, beyond that accounted for by peak overpressures.

#### **7.4 Conclusions (Assessment of Environmental Impacts)**

The Department of National Defence is proposing supersonic training activity for the Goose Bay Air Range CYA 732. With the proposed level of supersonic activity and the flight altitude bands where the supersonic events would take place, DND predicts that: even in a worst case scenario (i.e., using the entire air range as one manoeuvre ellipse) there would be no more than one sonic boom heard on the ground every 4 days, if the *Conventional Night Strike* training is conducted (note, that there may be one or two night strike exercise events in an year). On the other hand, with the *Ongoing Training* activity, there may be one sonic boom on the ground every 8 days for the training season. In both of these situations, the frequency of booms would be less towards the edges of the manoeuvre ellipse. The average overpressure of the sonic boom would be less than 1 psf, and in the centre of the manoeuvre ellipse the CDNL would be slightly above 45 dB. This is not enough to cause significant annoyance to humans. Therefore, DND predicts that, with the proposed supersonic training activity, there will be no significant environmental impact on humans, wildlife and/ or structures. However, if there are any unforeseen events that result in significant impact, they should be discovered through the proposed adaptive monitoring and mitigation options as discussed in Section 1.6 of the main document.

#### **8.0 Conclusions**

The field measurements and modelling results indicate that the altitude of the aircraft has greater impact on the magnitude of the sonic boom than the speed of the aircraft. From Figure 8, it is obvious that for a constant Mach number (speed), there is a rapid drop in peak overpressure with an increase in aircraft altitude. This rapid change in peak overpressure is more pronounced when the aircraft is at lower altitudes, such as when the altitude changes from 5,000 ft AGL to 10,000 ft AGL. Also, at lower altitudes (e.g. 5,000 -10,000 ft AGL), the difference between the maximum and minimum peak overpressure is very large. However, at higher altitudes (e.g. 20,000 ft AGL), the difference between the maximum and minimum pressures is not that pronounced (i.e. pressure along the centre line and at the edge of the carpet). Furthermore, Table 7 indicates that for a constant speed supersonic aircraft (no change in Mach number), the carpet width is much narrower at low altitudes, and the carpet is much wider at higher altitudes. It should be noted here that supersonic flights are permitted throughout Canada, except over southern domestic “built up areas”, without any restriction above 30,000 ft MSL. At these overpressure levels, no environmental damage has been reported to biological components (i.e. wildlife species and human activity), or physical structures, be they conventional or unconventional.



Because of changes in military tactics, and associated deployed fighter aircraft and weapon systems, the allies have expressed interest in supersonic flight training at 5 Wing Goose Bay. In order to make the 5 Wing Goose Bay Air Ranges a viable training option, DND would like to approve this training activity for the Labrador portion of CYA 732 Air Range. It is believed that this proposed supersonic flight training activity would have an insignificant effect from an environmental perspective. Further, the minor affects that may occur because of this activity can be mitigated with effective monitoring and mitigation programs.