PROJECT NO. NFS10202

SEISMIC EFFECTS
SUPERSONIC TESTING
NASKAUPI RIVER, LABRADOR

OCTOBER 2004

Jacques Whitford

PROJECT NO. NFS10202

REPORT TO

DEFENCE CONSTRUCTION CANADA
PLACE DE VILLE, TOWER B
112 KENT STREET, 17TH FLOOR
OTTAWA, ONTARIO
K1A 0K3

ON

SEISMIC EFFECTS SUPERSONIC TESTING NASKAUPI RIVER, LABRADOR

PREPARED BY

JACQUES WHITFORD LIMITED
607 TORBAY ROAD
ST. JOHN'S, NL A1A 4Y6
TEL: (709) 576-1458
FAX: (709) 576-2126

OCTOBER 28, 2004

Jacques Whitford

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1.0 INTRODUCTION

In accordance with the work being completed by Minaskuat in the Low Level Training Area (LLTA) for Defence Construction Canada, this report represents the component study to evaluate the potential of seismic effects and slope stability during supersonic flight testing at Naskaupi River, Labrador. This component of the work was carried out by one of Minaskuat's parent companies, Jacques Whitford.

The purpose of the work was to gather field vibration measurements during the supersonic flight testing trials, and by comparison with a review of other soil vibration data from construction-type blasting activities, to help understand whether supersonic activity in the LLTA could pose an issue for hydro-electric impoundments or structures in the vicinity of Smallwood Reservoir.

A literature review of the study topic yielded little information on the subject of seismic effects associated with supersonic flight. Most of the information gathered was sourced from several US military documents obtained via the internet and these are discussed and referenced within this report.

The seismic effects – supersonic testing project was conducted from July 20 to 22, 2004. A senior geologist from Jacques Whitford's St. John's office supervised the setting up and monitoring of seismographs along the sandy slopes of the Naskaupi River, in order to detect any measurable ground vibrations induced by sonic booms. A total of six seismograph units were used for this study, attempting to measure the effects of sonic booms created by a CAF F-18A Hornet, flying at MACH 1.1 to 1.2.

2.0 SITE AND GEOLOGY

The site of the seismic investigation was approximately 105 km northwest of the town of Happy Valley-Goose Bay, Newfoundland and Labrador. The seismograph set-up area was situated along the southern side of the Naskaupi River, at an approximate elevation of 85 m above sea level. The vegetation in the area comprises dominantly spruce, fir and alder. Photo 1 below illustrates the general topography and vegetation along the Naskaupi River in the vicinity of the seismograph set-up, and Figure 1 shows the general location and orientation of the slopes.

Photo 1: Physiography Along the Naskaupi River; Seismograph Set-up Locations

Slope 1 is located along the south side of the Naskaupi River, and has a slope height of 16.7 metres (top of slope to river level), and an inclination of approximately 33°. Slope 2, located approximately 750 metres to the southeast of Slope 1, has a slope height of 15.3 metres, and an inclination of 30°. Both slopes comprise similar materials, consisting of medium to coarse-grained sand with occasional to frequent cobbles and boulders.

3.0 FIELD PROCEDURES

The fieldwork consisted of the collection of seismograph measurements during supersonic flight trials. Twenty-eight (28) sonic booms were recorded during the period from July 20 to 22, 2004. Six Instantel digital seismographs were employed during the field measurements. The units consisted of two Minimate, two Minimate Plus, one Blastmate II, and one Blastmate III. The Blastmate and Minimate series seismographs are full-featured, advanced vibration and overpressure monitors that offer manual, single-shot, continuous, and programmed record modes. The Minimate Plus units were equipped with high frequency geophones, and the Minimate and Blastmate seismographs were equipped with standard geophones.

On Day 1 (July 20, 2004) all geophones were buried to a depth of 15 cm, and each covered with an approximate 10 kg bag of sand. To measure the potential variation in the vibration measurements, on Days 2 and 3 (July 21 and 22, 2004), the Blastmate II and III geophones were buried to a depth of 40 cm, and each covered with an approximate 10 kg bag of sand.

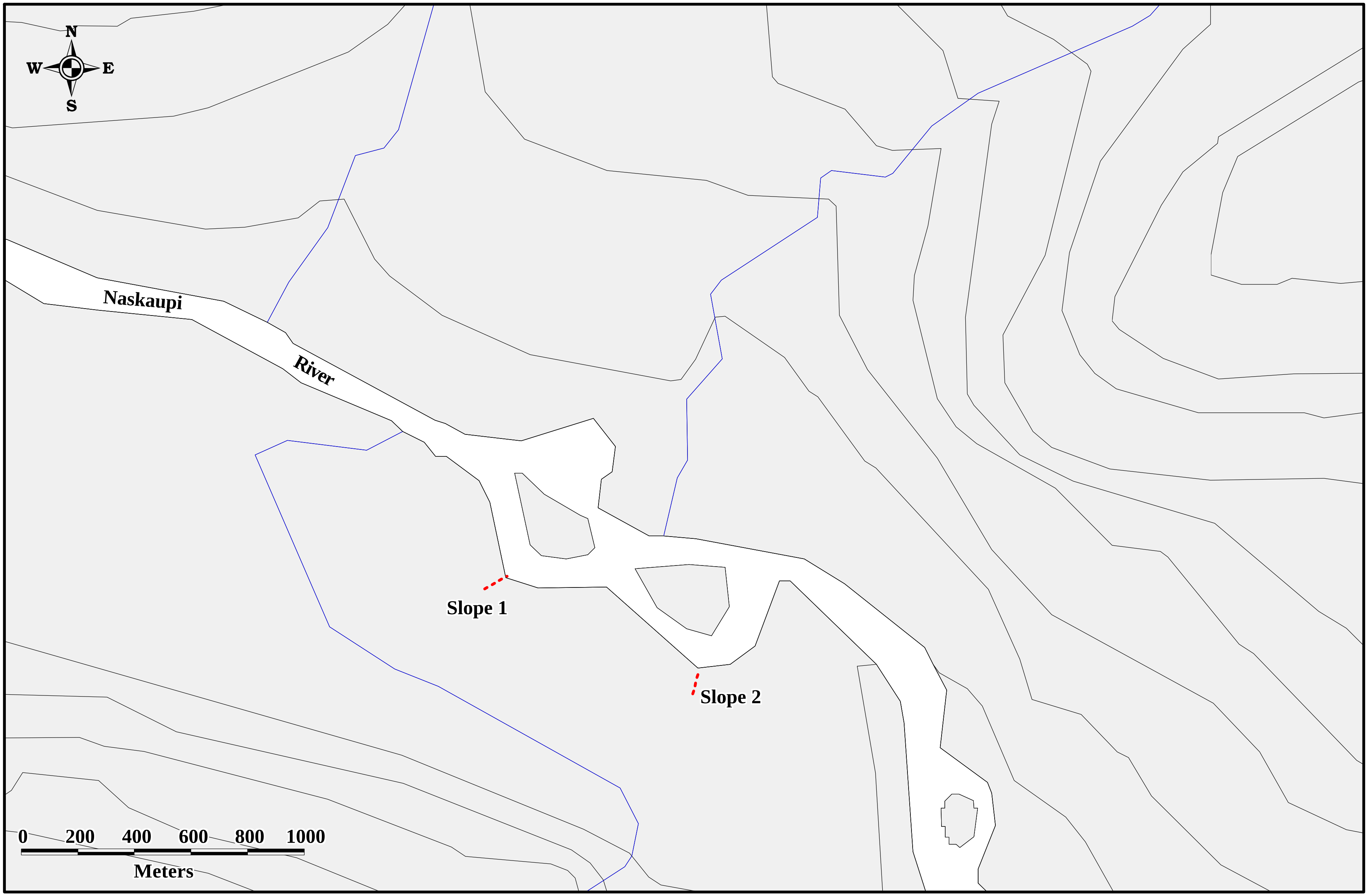

FIGURE 1 - LOCATION OF SEISMOGRAPHS

SEISMIC EFFECTS - SUPERSONIC TESTING
NASKAUPI RIVER, LABRADOR

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All of the seismograph instruments are manufactured by Instantel. Since 1982, Instantel has established a leadership position with best of class vibration monitoring equipment for the mining, construction and geotechnical markets. Technical specifications for each of the seismograph models used are included in Appendix A.

The fieldwork was conducted and inspected by a senior geologist from Jacques Whitford who kept detailed records of sonic booms and vibration data. Details of the sonic booms and vibration recordings can be found in Appendix B. The configuration for the seismographs with respect to geophone orientation and burial depth is provided in Table 1 below and in Figures 2 and 3.

Table 1: Seismograph Set-up and Location

Date	Slope	Upper Slope	Mid Slope	Lower Slope
July 20, 2004	Slope 1	Minimate Plus - 7369	Minimate Plus - 7186	Blastemate III - 5037
	Slope 2	Blastmate II - 1796	Minimate - 4419	Minimate - 4418
July 21, 2004	Slope 1 - east	Minimate - 4419	Minimate - 4418	Blastemate III - 5037
	Slope 1 - west	Minimate Plus - 7369	Minimate Plus - 7186	Blastmate II - 1796
July 22, 2004	Slope 1 - east	Minimate - 4419	Minimate - 4418	Blastemate III - 5037
	Slope 1 - west	Minimate Plus - 7369	Minimate Plus - 7186	Blastmate II - 1796

4.0 SEISMOGRAPH RESULTS

Ground vibrations were detected from twenty-four (24) of twenty-eight (28) recorded passes of the CAF F-18A Hornet. We note that four of the passes were not directly overhead, causing the sonic boom to miss our target set-up locations. Ground vibration measurements were collected from four of the six seismographs during the testing. Two of the seismograph units were equipped with high frequency geophones and did not trigger during the testing.

A total of 75 measurements were collected from the four seismographs, and the results are presented in Appendix B of this report. The average peak vector sum (PVS) value calculated from the data collected during testing was 0.775 mm/s (millimetres per second). Other statistical data are tabulated below in Tables 2 and 3.

Table 2: Summary of Peak Vector Sum (PVS – mm/s) and Peak Particle Velocity (PPV – mm/s)

	All Data PVS (mm/s)	**All Data PPV (mm/s)**	**Blastmate II 1796 PVS (mm/s)**	**Minimate 4418 PVS (mm/s)**	**Minimate 4419 PVS (mm/s)**	**Blastmate III 5037 PVS (mm/s)**
Mean	0.7749	0.5414	0.8220	0.7463	0.8549	0.6832
Standard Deviation	0.1936	0.1845	0.2444	0.1425	0.1859	0.1498
Variance	0.0375	0.0340	0.0597	0.0203	0.0346	0.0224
Maximum	1.6700	1.2700	1.6700	1.2100	1.2900	1.0800
Minimum	0.5240	0.1270	0.5400	0.5870	0.5720	0.5240

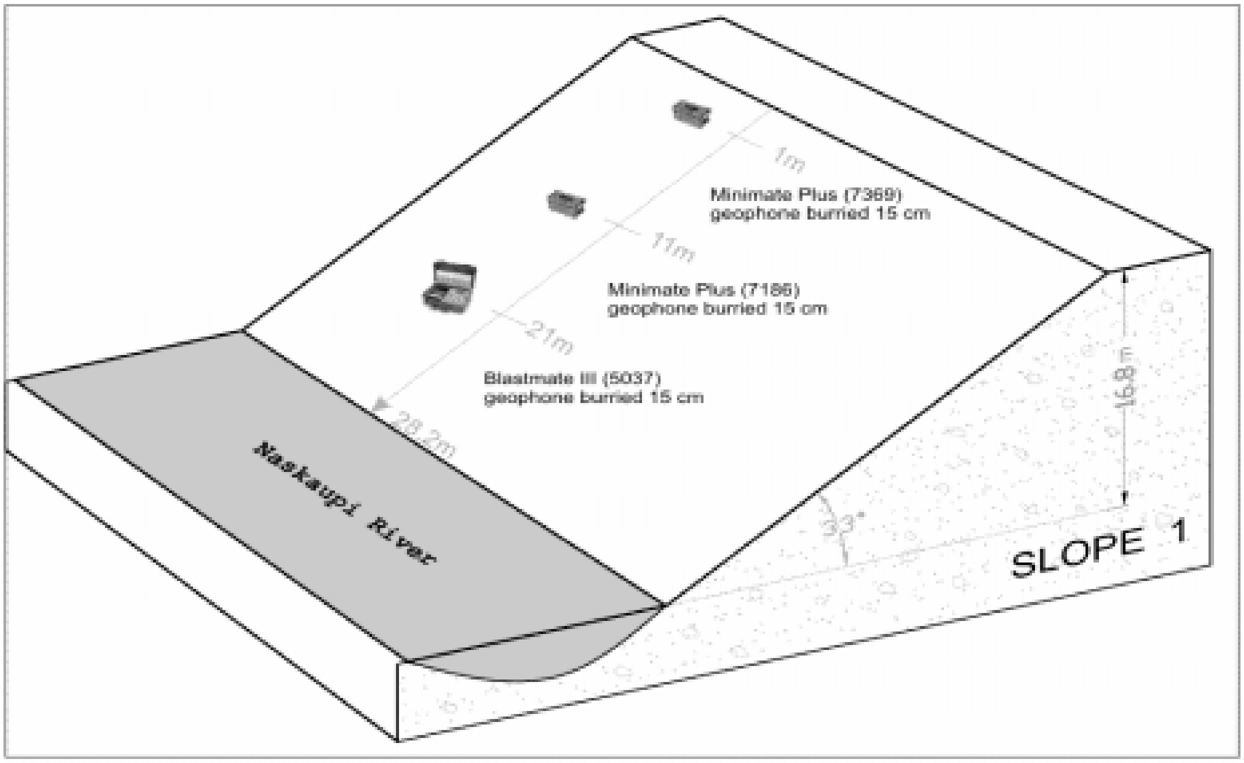
Note: PPV – Peak Particle Velocity on either transverse, vertical or longitudinal axes measured in mm/sec. PVS – Peak Vector Sum is the maximum amplitude of the sum of the vibration velocity signals.

Table 3: Summary of Peak Vector Sum (PVS – mm/s) as a Function of Geophone Burial Depth

	20-Jul-04	**21-22 July-04**	
Seismograph	Blastmate III 5037	Blastmate II 1796	Blastmate III 5037
Mean	0.6910	0.6906	0.6734
Standard Deviation	0.1604	0.1477	0.1457
Variance	0.0257	0.0218	0.0212

Note: July 20, 2004 Geophones buried 15 cm; July 21 and 22, 2004 Geophones buried 40 cm. The data is gathered from geophones buried near the toe of the slope, and used for comparison purposes of burial depth

A Summary Table of all recorded seismograph events is presented in Appendix C.



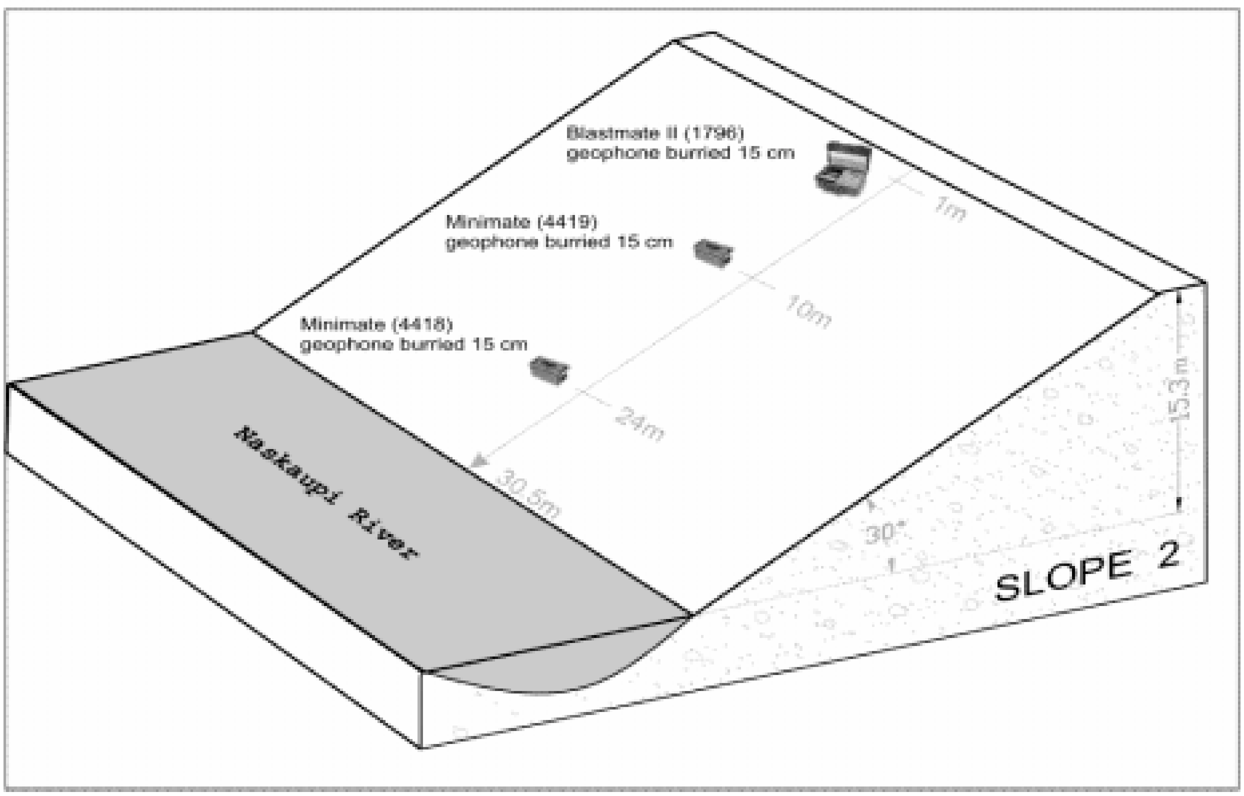


Figure 2: Seismograph Set-up on July 20, 2004

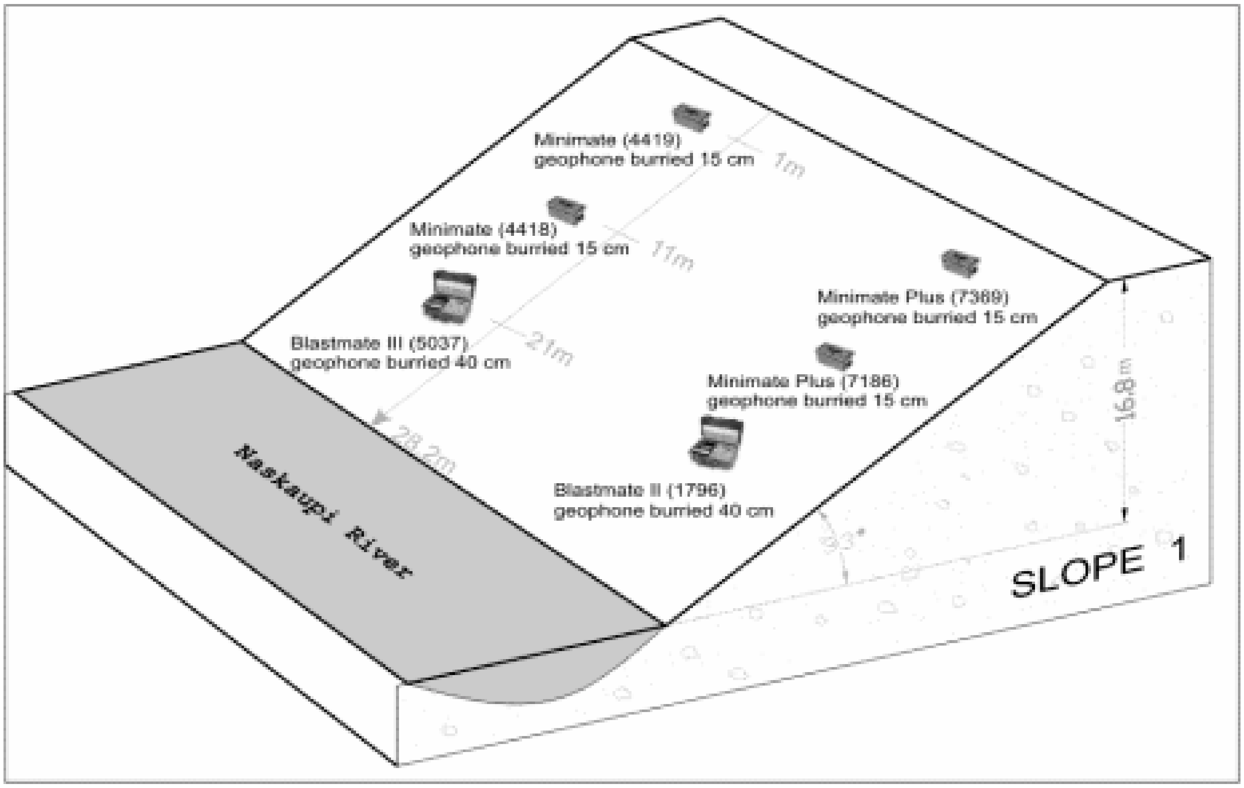


Figure 3: Seismograph Set-up on July 21 and 22, 2004

5.0 DISCUSSION

5.1 Literature Review

A review of the literature on sonic booms indicate the following (from USAF Fact Sheet 96-03 – Sonic Boom) as described below in italics:

Sonic boom is an impulsive noise similar to thunder. It is caused by an object moving faster than sound -- about 1,225 kilometers per hour at sea level. An aircraft traveling through the atmosphere continuously produces air-pressure waves similar to the water waves caused by a ship's bow. When the aircraft exceeds the speed of sound, these pressure waves combine and form shock waves which travel forward from the generation or "release" point.

As an aircraft flies at supersonic speeds it is continually generating shock waves, dropping sonic boom along its flight path, similar to someone dropping objects from a moving vehicle. From the perspective of the aircraft, the boom appears to be swept backwards as it travels away from the aircraft. If the plane makes a sharp turn or pulls up, the boom will hit the ground in front of the aircraft.

The sound heard on the ground as a "sonic boom" is the sudden onset and release of pressure after the buildup by the shock wave or "peak overpressure." The change in pressure caused by sonic boom is only a few pounds per square foot -- about the same pressure change we experience on an elevator as it descends two or three floors -- in a much shorter time period. It is the magnitude of this peak overpressure that describes a sonic boom.

There are two types of booms: N-waves and U-waves. The N-wave is generated from steady flight conditions, and its pressure wave is shaped like the letter "N." N-waves have a front shock to a positive peak overpressure which is followed by a linear decrease in the pressure until the rear shock returns to ambient pressure. The U-wave, or focused boom, is generated from maneuvering flights, and its pressure wave is shaped like the letter "U." U-waves have positive shocks at the front and rear of the boom in which the peak overpressures are increased compared to the N-wave.

For today's supersonic aircraft in normal operating conditions, the peak overpressure varies from less than one pound to about 10 pounds per square foot for a N-wave boom. Peak overpressures for U-waves are amplified two to five times the N-wave, but this amplified overpressure impacts only a very small area when compared to the area exposed to the rest of the sonic boom.

The strongest sonic boom ever recorded was 144 pounds per square foot and it did not cause injury to the researchers who were exposed to it. The boom was produced by a F-4 flying just above the speed of sound at an altitude of 100 feet.

In recent tests, the maximum boom measured during more realistic flight conditions was 21 pounds per square foot. There is a probability that some damage -- shattered glass, for example, will result from a sonic boom. Buildings in good repair should suffer no damage by pressures of less than 16 pounds per square foot. And, typically, community exposure to sonic boom is below two pounds per square foot. Ground motion resulting from sonic boom is rare and is well below structural damage thresholds accepted by the U.S. Bureau of Mines and other agencies.

Characteristics

The energy range of sonic boom is concentrated in the 0.1 - 100 hertz frequency range that is considerably below that of subsonic aircraft, gunfire and most industrial noise. Duration of sonic boom is brief; less than a second -- 100 milliseconds (.100 seconds) for most fighter-sized aircraft and 500 milliseconds for the space shuttle or Concorde jetliner .

The intensity and width of a sonic boom path depends on the physical characteristics of the aircraft and how it is operated. In general, the greater an aircraft's altitude, the lower the overpressure on the ground. Greater altitude also increases the boom's lateral spread, exposing a wider area to the boom. Overpressures in the sonic boom impact area, however, will not be uniform. Boom intensity *is greatest directly under the flight path, progressively weakening with greater horizontal distance away from the aircraft flight track.*

Ground width of the boom exposure area is approximately one mile for each 1,000 feet of altitude; that is, an aircraft flying supersonic at 30,000 feet will create a lateral boom spread of about 30 miles. For steady supersonic flight, the boom is described as a carpet boom since it moves with the aircraft as it maintains supersonic speed and altitude.

Some maneuvers, diving, acceleration or turning, can cause focusing of the boom. Other maneuvers, such as deceleration and climbing, can reduce the strength of the shock. In some instances weather conditions can distort sonic booms.

Sonic Boom Refraction

Depending on the aircraft's altitude, sonic booms reach the ground two to 60 seconds after flyover. However, not all booms are heard at ground level. 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. For example, when sea-level temperature is 58 degrees Fahrenheit, the temperature at 30,000 feet drops to minus 49 degrees Fahrenheit. This temperature gradient helps bend the sound waves upward. Therefore, for a boom to reach the ground, the aircraft speed relative to the ground must be greater than the speed of sound at the ground. For example, the speed of sound at 30,000 feet is about 670 miles per hour, but an aircraft must travel at least 750 miles per hour (Mach 1.12, where Mach 1 equals the speed of sound) for a boom to be heard on the ground.

5.2 Findings

As presented in Table 2, Summary of Peak Vector Sum (PVS) and Peak Particle Velocity (PPV), the mean or average PVS was 0.77 mm/s, in the range of 0.52 to 1.67 mm/s. This value is significantly lower than conventional standards of comparison for acceptable vibration levels in the construction/engineering field for construction blasting. Figure 4, below illustrates the human perception of vibration levels as a function of frequency and also indicates a conventional "limit" on PPV of 50 mm/s (2 in/s) as an acceptable limit or tolerance. This is the vibration value to which most blasting operations are conducted such that vibrations are permissible up to this limit, so that no damage would occur under normal circumstances to most buildings, based on statistical averaging of historical data.

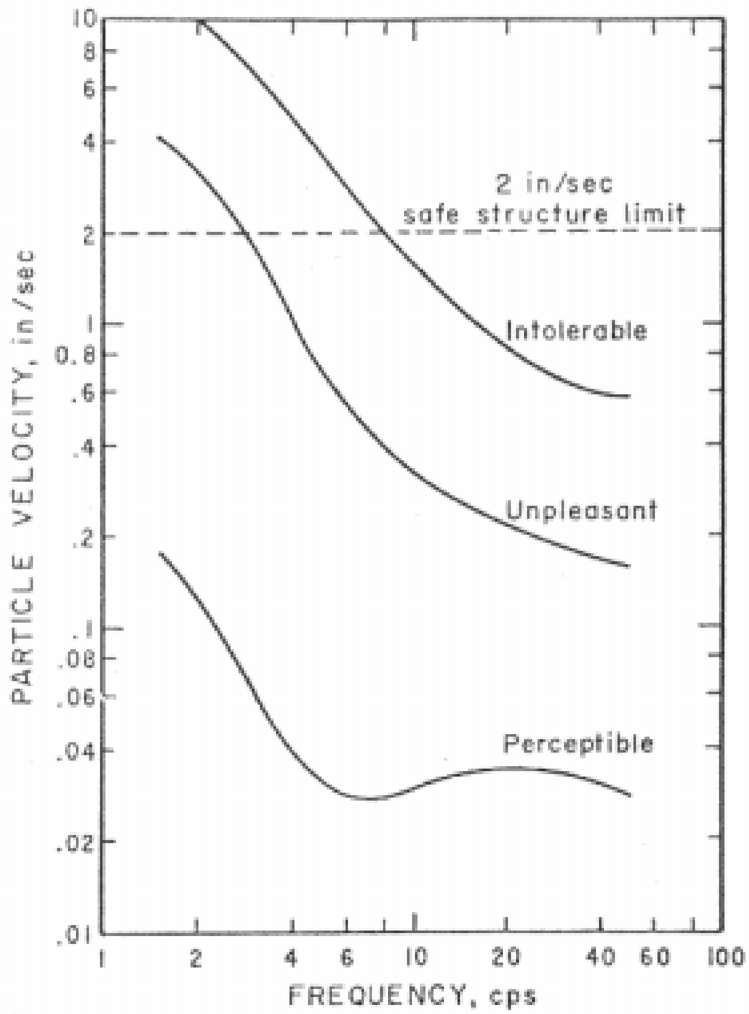


Figure 4: Subjective Response of the Human Body to Vibratory Motion (Nicholls et al., 1971)

Further discussion is provided below in italics and was obtained from Tetra Tech, Inc (2004).

Physical Effects on Buildings and Structures

Physical effects of noise on buildings and other structures occur primarily through airborne or ground vibrations. Most ground vibrations are generated by underground sources or by sources in physical contact with the ground surface. Open air noise sources rarely generate detectable ground vibrations. Although many people attribute building vibration and object shaking to ground vibrations, most such events are caused by vibrations induced by airborne sound. Direct ground vibration is important only at locations close to the vibration source. Sonic booms and blast noise *events are the major sources of airborne vibrations that can be strong enough to create detectable vibrations in buildings or structures. Vibration intensities can be measured in many different ways, but movement velocity units (such as inches per second) are commonly used. Common vibration criteria and guidelines can be summarized as follows (U.S. Army Center for Health Promotion and Preventive Medicine 1999). Most people can detect structural vibrations at an intensity of 0.08 inches per second (2 mm/s). Vibrations become noticeable at an intensity of 0.20 inches per second (5 mm/s). Many people rate a vibration intensity of 0.38 inches per second (9.7 mm/s) as unpleasant, and an intensity of 0.8 inches per second (20 mm/s) as disturbing. A vibration intensity of 0.1 inches per second (2.5 mm/s) can cause loose objects to rattle. A vibration intensity of 0.5 inches per second (12.5 mm/s) often is used as a guideline for avoiding minor cracking in poorly fitted loose glass windows or in stressed plaster. A vibration intensity limit of 2 inches per second (50 mm/s) often is used as a guideline for avoiding damage to lightweight structures. Cracking of concrete may occur at vibration intensities above 4 inches per second (100 mm/s). Minor structural damage is likely at a vibration intensity of 5.4 inches per second (137 mm/s).*

6.0 CONCLUSIONS

The purpose of this study was to assess the potential of sonic booms to create measurable seismic effects within soil or structures leading to slope instability. The findings of this study confirm that soil vibrations induced by sonic booms are measurable. The field vibration measurements obtained during supersonic flight testing identified peak particle velocities within the soil slope in the range of 0.12 to 1.27 mm/s.

Based on conventional engineering practice, and analysis of vibration data, the recorded measurements would not be considered of sufficient magnitude to support slope movement/instability, or affect structures under normal conditions. Where a slope or structure exists such that it is in a highly unstable state, or on the “verge” of failure, any disturbance such as wind, rain or snow loading would initiate failure, and these would be considered more likely factors than sonic booms. For example: where a slope is under a condition of imminent failure, such as where a river has created a natural erosion at the base of a slope, any disturbance, due to rain or snow load, would be a more significant natural factor than energy induced by a sonic boom. These conditions are not the “norm” for typical “engineered” structures or slopes which are designed with adequate factors of safety. As well, naturally occurring slopes reach long term stable angles of repose as products of erosional forces and the environment.

The vibration levels recorded during this study are insufficient to create instability in soil slopes or damage to structures under normal conditions and accepted statistical methods of engineering analysis as described above. The forces and vibrations and failure mechanisms associated with slope instability from earthquakes are significantly greater than the vibrations associated with and measured during the sonic booms events of this study.

7.0 CLOSING

This report has been prepared for the sole benefit of Defence Construction Canada and their agents, and may not be used by any third party without the express written consent of Jacques Whitford, Minaskaut and the client. Any use which a third party makes of this report is the responsibility of such third party.

The comments and recommendations presented herein are based on information gathered at specific locations only and can only be extrapolated to an undefined limited area around these locations. Variations throughout the site may differ significantly from data collected at these locations. The extent of the limited area depends on the soil, bedrock and groundwater conditions, as well as the history of the site reflecting natural, construction and other activities. Should any conditions at the site be encountered which differ from those noted herein, we require that we be notified immediately in order to permit reassessment of our comments and recommendations.

We trust this information meets your present requirements. Should any additional information be required, please do not hesitate to contact our office at your convenience.

Yours truly,

JACQUES WHITFORD LIMITED

Lorne C. Boone, M.Eng., P.Eng.

David J. Butler, P.Geo.

REGISTERED PROFESSIONAL ENGINEER
LORNE C. BOONE
Lorne Boone
SIGNATURE
October 28 04
DATE
PROVINCE OF NEWFOUNDLAND

PROVINCE OF NEWFOUNDLAND
PERMIT HOLDER
This Permit Allows
JACQUES WHITFORD ENVIRONMENT LIMITED
To practice Professional Engineering in Newfoundland and Labrador.
Permit No. as issued by APEGN N0040
which is valid for the year 2004

REFERENCES

USAF Fact Sheet 96-03: Armstrong Laboratory, 2610 Seventh St., Wright-Patterson AFB OH 45433-7201

Nicholls, Harry R, 1971: Blasting vibrations and their effects of structures, by Harry R. Nicholls, Charles F. Johnson, and Wilbur I. Duvall. Washington U.S. Dept. of the Interior, Bureau of Mines 1971.

Tetra Tech, Inc, Honolulu, Hawaii, 2004: Final Environmental Impact Statement, Transformation of the 2nd Brigade, 25th Infantry Division (L) to a Stryker Brigade Combat Team in Hawaii.

APPENDIX A

Technical Specifications for Seismographs

- **Minimate**
- **Minimate Plus**
- **Blastmate Series II**
- **Blastmate Series III**

APPENDIX B

Individual Seismograph Reports for Recorded Events

APPENDIX C

Summary Table for All Recorded Events

Serial No.	Date	Time	Trigger	Tran Peak (mm/s)	Vert Peak (mm/s)	Long Peak (mm/s)	PVS1 (mm/s)	Description	Event Info	Geophone Direction	Geophone Location
1796	Jul 20 /04	8:31:04	Long	0.810	0.619	0.667	1.000	Naskaupi River, Labrador	Sonic boom # 2; NE to SW	Pointing uphill; geophone burried ~15 cm	Top of slope 2
4419	Jul 20 /04	8:32:01	Long	0.953	0.508	0.762	1.100	Naskaupi River, Labrador	Sonic boom # 2; NE to SW	Pointing uphill; sand-bagged	Middle of slope 2
4418	Jul 20 /04	8:32:02	Tran	0.508	0.445	0.635	0.746	Naskaupi River, Labrador	Sonic boom # 2; NE to SW	Pointing uphill; sand-bagged	Bottom of slope 2
5037	Jul 20 /04	8:35:18	Vert	0.254	0.508	0.381	0.568	Naskaupi River, Labrador	Sonic boom # 3; NW to SE	Pointing uphill; geophone burried ~15 cm	Bottom of slope 1; east
1796	Jul 20 /04	8:35:42	Long	0.381	0.333	0.794	0.889	Naskaupi River, Labrador	Sonic boom # 3; NW to SE	Pointing uphill; geophone burried ~15 cm	Top of slope 2
4419	Jul 20 /04	8:36:39	Tran	0.635	0.381	0.635	0.714	Naskaupi River, Labrador	Sonic boom # 3; NW to SE	Pointing uphill; sand-bagged	Middle of slope 2
4418	Jul 20 /04	8:36:40	Tran	0.635	0.381	0.445	0.667	Naskaupi River, Labrador	Sonic boom # 3; NW to SE	Pointing uphill; sand-bagged	Bottom of slope 2
5037	Jul 20 /04	8:39:53	Long	0.254	0.381	0.508	0.539	Naskaupi River, Labrador	Sonic boom # 4; SE to NW	Pointing uphill; geophone burried ~15 cm	Bottom of slope 1; east
1796	Jul 20 /04	8:40:15	Long	0.413	0.492	0.635	0.730	Naskaupi River, Labrador	Sonic boom # 4; SE to NW	Pointing uphill; geophone burried ~15 cm	Top of slope 2
4419	Jul 20 /04	8:41:11	Tran	0.762	0.381	0.508	0.841	Naskaupi River, Labrador	Sonic boom # 4; SE to NW	Pointing uphill; sand-bagged	Middle of slope 2
5037	Jul 20 /04	9:38:14	Vert	0.381	0.635	0.508	0.660	Naskaupi River, Labrador	Sonic boom # 6; NW to SE	Pointing uphill; geophone burried ~15 cm	Bottom of slope 1; east
1796	Jul 20 /04	9:38:38	Long	0.587	0.365	0.651	0.810	Naskaupi River, Labrador	Sonic boom # 6; NW to SE	Pointing uphill; geophone burried ~15 cm	Top of slope 2
4419	Jul 20 /04	9:39:32	Vert	0.572	0.572	0.889	0.905	Naskaupi River, Labrador	Sonic boom # 6; NW to SE	Pointing uphill; sand-bagged	Middle of slope 2
4418	Jul 20 /04	9:39:34	Long	0.762	0.318	0.699	0.778	Naskaupi River, Labrador	Sonic boom # 6; NW to SE	Pointing uphill; sand-bagged	Bottom of slope 2
5037	Jul 20 /04	9:42:47	Vert	0.254	0.508	0.381	0.582	Naskaupi River, Labrador	Sonic boom # 7; NE to SW	Pointing uphill; geophone burried ~15 cm	Bottom of slope 1; east
1796	Jul 20 /04	9:43:09	Vert	0.603	0.587	0.683	0.841	Naskaupi River, Labrador	Sonic boom # 7; NE to SW	Pointing uphill; geophone burried ~15 cm	Top of slope 2
4419	Jul 20 /04	9:44:02	Vert	0.762	0.635	0.635	0.841	Naskaupi River, Labrador	Sonic boom # 7; NE to SW	Pointing uphill; sand-bagged	Middle of slope 2
4418	Jul 20 /04	9:44:05	Tran	0.572	0.572	0.699	0.857	Naskaupi River, Labrador	Sonic boom # 7; NE to SW	Pointing uphill; sand-bagged	Bottom of slope 2
5037	Jul 20 /04	9:47:23	Vert	0.381	0.508	0.635	0.696	Naskaupi River, Labrador	Sonic boom # 8; SW to NE	Pointing uphill; geophone burried ~15 cm	Bottom of slope 1; east
1796	Jul 20 /04	9:47:47	Tran	0.683	0.460	0.826	1.020	Naskaupi River, Labrador	Sonic boom # 8; SW to NE	Pointing uphill; geophone burried ~15 cm	Top of slope 2
4419	Jul 20 /04	9:48:40	Long	0.889	0.572	0.826	0.905	Naskaupi River, Labrador	Sonic boom # 8; SW to NE	Pointing uphill; sand-bagged	Middle of slope 2
4418	Jul 20 /04	9:48:42	Long	0.953	0.445	0.826	0.953	Naskaupi River, Labrador	Sonic boom # 8; SW to NE	Pointing uphill; sand-bagged	Bottom of slope 2
1796	Jul 20 /04	9:52:13	Long	0.556	0.651	0.794	0.937	Naskaupi River, Labrador	Sonic boom # 9; SW to NE	Pointing uphill; geophone burried ~15 cm	Top of slope 2
4419	Jul 20 /04	9:53:06	Vert	0.953	0.699	0.635	1.050	Naskaupi River, Labrador	Sonic boom # 9; SW to NE	Pointing uphill; sand-bagged	Middle of slope 2
4418	Jul 20 /04	9:53:08	Tran	0.572	0.572	0.699	0.857	Naskaupi River, Labrador	Sonic boom # 9; SW to NE	Pointing uphill; sand-bagged	Bottom of slope 2
1796	Jul 20 /04	10:50:07	Long	0.429	0.429	0.762	0.810	Naskaupi River, Labrador	Sonic boom # 11; NW to SE	Pointing uphill; geophone burried ~15 cm	Top of slope 2
4419	Jul 20 /04	10:50:59	Vert	0.699	0.572	0.762	0.889	Naskaupi River, Labrador	Sonic boom # 11; NW to SE	Pointing uphill; sand-bagged	Middle of slope 2
4418	Jul 20 /04	10:51:00	Vert	0.508	0.635	0.381	0.667	Naskaupi River, Labrador	Sonic boom # 11; NW to SE	Pointing uphill; sand-bagged	Bottom of slope 2
5037	Jul 20 /04	10:54:54	Tran	0.635	0.381	0.381	0.660	Naskaupi River, Labrador	Sonic boom # 12; SE to NW	Pointing uphill; geophone burried ~15 cm	Bottom of slope 1; east
1796	Jul 20 /04	10:55:16	Long	0.286	0.286	0.683	0.746	Naskaupi River, Labrador	Sonic boom # 12; SE to NW	Pointing uphill; geophone burried ~15 cm	Top of slope 2
4419	Jul 20 /04	10:56:08	Long	0.699	0.381	0.699	0.857	Naskaupi River, Labrador	Sonic boom # 12; SE to NW	Pointing uphill; sand-bagged	Middle of slope 2
4418	Jul 20 /04	10:56:09	Tran	0.572	0.381	0.445	0.667	Naskaupi River, Labrador	Sonic boom # 12; SE to NW	Pointing uphill; sand-bagged	Bottom of slope 2
5037	Jul 20 /04	10:59:56	Tran	0.762	0.381	0.635	0.813	Naskaupi River, Labrador	Sonic boom # 13; NW to SE	Pointing uphill; geophone burried ~15 cm	Bottom of slope 1; east
1796	Jul 20 /04	11:00:22	Long	0.445	0.365	0.762	0.778	Naskaupi River, Labrador	Sonic boom # 13; NW to SE	Pointing uphill; geophone burried ~15 cm	Top of slope 2
4419	Jul 20 /04	11:01:14	Tran	0.889	0.572	0.572	0.905	Naskaupi River, Labrador	Sonic boom # 13; NW to SE	Pointing uphill; sand-bagged	Middle of slope 2
4418	Jul 20 /04	11:01:15	Vert	0.445	0.635	0.254	0.683	Naskaupi River, Labrador	Sonic boom # 13; NW to SE	Pointing uphill; sand-bagged	Bottom of slope 2
5037	Jul 20 /04	11:49:47	Tran	0.508	0.508	0.381	0.582	Naskaupi River, Labrador	Sonic boom # 14; SE to NW	Pointing uphill; geophone burried ~15 cm	Bottom of slope 1; east
1796	Jul 20 /04	11:50:10	Long	0.270	0.175	0.635	0.683	Naskaupi River, Labrador	Sonic boom # 14; SE to NW	Pointing uphill; geophone burried ~15 cm	Top of slope 2
4419	Jul 20 /04	11:51:01	Long	0.318	0.191	0.572	0.587	Naskaupi River, Labrador	Sonic boom # 14; SE to NW	Pointing uphill; sand-bagged	Middle of slope 2
5037	Jul 20 /04	11:54:15	Vert	0.381	0.508	0.635	0.730	Naskaupi River, Labrador	Sonic boom # 15;	Pointing uphill; geophone burried ~15 cm	Bottom of slope 1; east
4419	Jul 20 /04	11:55:32	Tran	0.699	0.572	0.572	0.826	Naskaupi River, Labrador	Sonic boom # 15;	Pointing uphill; sand-bagged	Middle of slope 2
4418	Jul 20 /04	11:55:34	Vert	0.508	0.635	0.318	0.730	Naskaupi River, Labrador	Sonic boom # 15;	Pointing uphill; sand-bagged	Bottom of slope 2
5037	Jul 20 /04	11:59:34	Vert	1.020	0.635	0.508	1.080	Naskaupi River, Labrador	Sonic boom # 16;	Pointing uphill; geophone burried ~15 cm	Bottom of slope 1; east
4419	Jul 20 /04	12:00:46	Long	0.953	0.572	1.270	1.290	Naskaupi River, Labrador	Sonic boom # 16;	Pointing uphill; sand-bagged	Middle of slope 2
4418	Jul 20 /04	12:00:48	Tran	1.020	0.889	0.635	1.210	Naskaupi River, Labrador	Sonic boom # 16;	Pointing uphill; sand-bagged	Bottom of slope 2

Serial No.	Date	Time	Trigger	Tran Peak (mm/s)	Vert Peak (mm/s)	Long Peak (mm/s)	PVS1 (mm/s)	Description	Event Info	Geophone Direction	Geophone Location
1796	Jul 20 /04	11.59.56	Tran	0.685	0.508	1.060	1.670	Naskaupi River, Labrador	Sonic boom # 16;	Pointing uphill; geophone burried ~15 cm	Top of slope 2
5037	Jul 21 /04	13:06:33	Vert	0.381	0.508	0.508	0.539	Naskaupi River, Labrador	Sonic boom # 17; SW to NE	Pointing downhill; geophone burried ~45 cm	Bottom of slope 1; east
4418	Jul 21 /04	13:08:05	Vert	0.445	0.635	0.699	0.762	Naskaupi River, Labrador	Sonic boom # 17; SW to NE	Pointing downhill; sand-bagged	Middle of slope 1; east
5037	Jul 21 /04	13:11:48	Long	0.381	0.508	0.508	0.648	Naskaupi River, Labrador	Sonic boom # 18; NE to SW	Pointing downhill; geophone burried ~45 cm	Bottom of slope 1; east
1796	Jul 21 /04	13:12:30	Vert	0.238	0.572	0.476	0.603	Naskaupi River, Labrador	Sonic boom # 18; NE to SW	Pointing downhill; geophone burried ~15 cm	Bottom of slope 1; west
4418	Jul 21 /04	13:13:20	Vert	0.318	0.508	0.381	0.619	Naskaupi River, Labrador	Sonic boom # 18; NE to SW	Pointing downhill; sand-bagged	Middle of slope 1; east
5037	Jul 21 /04	13:16:27	Vert	0.381	0.508	0.381	0.539	Naskaupi River, Labrador	Sonic boom # 19; SW to NE	Pointing downhill; geophone burried ~45 cm	Bottom of slope 1; east
4419	Jul 21 /04	13:17:53	Long	0.381	0.445	0.508	0.572	Naskaupi River, Labrador	Sonic boom # 19; SW to NE	Pointing downhill; sand-bagged	Top of slope 1; east
4418	Jul 21 /04	13:17:58	Long	0.508	0.635	0.635	0.683	Naskaupi River, Labrador	Sonic boom # 19; SW to NE	Pointing downhill; sand-bagged	Middle of slope 1; east
4418	Jul 21 /04	14:22:48	Long	0.381	0.381	0.572	0.603	Naskaupi River, Labrador	Sonic boom # 20; SE to NW	Pointing downhill; sand-bagged	Middle of slope 1; east
5037	Jul 21 /04	14:25:21	Vert	0.254	0.635	0.381	0.648	Naskaupi River, Labrador	Sonic boom # 21; NW to SE	Pointing downhill; geophone burried ~45 cm	Bottom of slope 1; east
1796	Jul 21 /04	14:26:04	Long	0.286	0.572	0.524	0.667	Naskaupi River, Labrador	Sonic boom # 21; NW to SE	Pointing downhill; geophone burried ~15 cm	Bottom of slope 1; west
4418	Jul 21 /04	14:26:53	Long	0.318	0.445	0.572	0.587	Naskaupi River, Labrador	Sonic boom # 21; NW to SE	Pointing downhill; sand-bagged	Middle of slope 1; east
1796	Jul 21 /04	14:30:44	Long	0.238	0.286	0.492	0.540	Naskaupi River, Labrador	Sonic boom # 22; SW to NE	Pointing downhill; geophone burried ~15 cm	Bottom of slope 1; west
4418	Jul 21 /04	14:31:32	Long	0.318	0.381	0.635	0.635	Naskaupi River, Labrador	Sonic boom # 22; SW to NE	Pointing downhill; sand-bagged	Middle of slope 1; east
1796	Jul 22 /04	12:20:22	Vert	0.238	0.572	0.476	0.572	Naskaupi River, Labrador	Sonic boom # 23; NE to SW	Pointing downhill; geophone burried ~15 cm	Bottom of slope 1; west
5037	Jul 22 /04	12:31:45	Long	0.254	0.508	0.635	0.751	Naskaupi River, Labrador	Sonic boom # 25;	Pointing downhill; geophone burried ~45 cm	Bottom of slope 1; east
1796	Jul 22 /04	12:32:43	Vert	0.254	0.730	0.762	0.937	Naskaupi River, Labrador	Sonic boom # 25;	Pointing downhill; geophone burried ~15 cm	Bottom of slope 1; west
4418	Jul 22 /04	12:33:27	Long	0.191	0.635	0.699	0.730	Naskaupi River, Labrador	Sonic boom # 25;	Pointing downhill; sand-bagged	Middle of slope 1; east
5037	Jul 22 /04	13:59:48	Vert	0.381	0.508	0.508	0.524	Naskaupi River, Labrador	Focused sonic boom # 1;	Pointing downhill; geophone burried ~45 cm	Bottom of slope 1; east
1796	Jul 22 /04	14:00:46	Long	0.397	0.413	0.572	0.587	Naskaupi River, Labrador	Focused sonic boom # 1;	Pointing downhill; geophone burried ~15 cm	Bottom of slope 1; west
4419	Jul 22 /04	14:01:27	Long	0.445	0.381	0.508	0.683	Naskaupi River, Labrador	Focused sonic boom # 1;	Pointing downhill; sand-bagged	Top of slope 1; east
4418	Jul 22 /04	14:01:30	Long	0.127	0.445	0.572	0.730	Naskaupi River, Labrador	Focused sonic boom # 1;	Pointing downhill; sand-bagged	Middle of slope 1; east
5037	Jul 22 /04	14:04:18	Vert	0.381	0.762	0.635	0.925	Naskaupi River, Labrador	Focused sonic boom # 2;	Pointing downhill; geophone burried ~45 cm	Bottom of slope 1; east
1796	Jul 22 /04	14:05:17	Long	0.445	0.603	0.841	0.873	Naskaupi River, Labrador	Focused sonic boom # 2;	Pointing downhill; geophone burried ~15 cm	Bottom of slope 1; west
4418	Jul 22 /04	14:06:00	Vert	0.254	0.762	0.572	0.762	Naskaupi River, Labrador	Focused sonic boom # 2;	Pointing downhill; sand-bagged	Middle of slope 1; east
5037	Jul 22 /04	14:08:56	Vert	0.381	0.508	0.635	0.813	Naskaupi River, Labrador	Focused sonic boom # 3;	Pointing downhill; geophone burried ~45 cm	Bottom of slope 1; east
1796	Jul 22 /04	14:09:55	Long	0.333	0.445	0.683	0.746	Naskaupi River, Labrador	Focused sonic boom # 3;	Pointing downhill; geophone burried ~15 cm	Bottom of slope 1; west
4419	Jul 22 /04	14:10:35	Long	0.572	0.572	0.635	0.714	Naskaupi River, Labrador	Focused sonic boom # 3;	Pointing downhill; sand-bagged	Top of slope 1; east

Notes: Sonic boom event Nos. 1, 5, 10 and 24 were not recorded as the boom path missed the seismograph target area for measurement.