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EVALUATION OF HAZARDS TO OCCUPANT OF THE "COMPACT 230 MINECAT" EXPOSED TO BLAST FROM 10 KG TNT

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8) ABSTRACT

A mineclearing vehicle, Compact 230 MINCAT, of the rotating flail type has been developed by Norwegian Demining Consortium (NoDeCo). The machine is of the rotating flail type, and is based on the Bobcat 863 compact loader chassis.

This report evaluates the hazards to an operator seated in the vehicle when a blast mine detonates during normal clearing operations. A simplified dummy equipped with accelerometers and a spine force load cell was employed during detonation of 10 kg TNT under the flail. Internal cabin pressure and cabin floor acceleration was also recorded.

By use of established damage criteria from the literature, it can be concluded that the operator will not be injured, provided that the cabin is undamaged, the doors remain properly shut, and the operator wears head and ear protection.

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EVALUATION OF HAZARDS TO OCCUPANT OF THE "COMPACT 230 MINECAT" EXPOSED TO BLAST FROM 10 KG TNT

1 INTRODUCTION

A mine clearing vehicle named Compact 230 MINECAT is brought forward by the company Norwegian Demining Consortium (NoDeCo). It is based on a Bobcat 863 compact loader chassis, and is a rotating flail type machine intended for clearing anti personnel mines (AP mines) and anti tank mines (AT mines).

The MINECAT prototype has undergone a series of trials in order to evaluate its ability to withstand blast load from detonating mines. A vital issue is the potential of injury to an operator sitting in the cabin, which is mounted at the rear of the vehicle (Figure 1.1).

Forsvarets forskningsinstitutt (FFI, Norwegian Defence Research Establishment) was requested by NoDeCo to participate in some of the trials, with focus on assessing what kind of forces the operator will be exposed to during mine blast. These tests were carried out at Aklangen Firing Range at Hønefoss, Norway, on June 3rd 1999.

Different charge weights and configurations were used. This will be described in a report released by the Norwegian Army Engineer Corps, who were responsible for the explosives work. FFI has performed measurements of acceleration, forces and pressure in the cabin.

Some of the smaller charges of up to 5 kg TNT were detonated under the flail with an operator seated in the cabin. No particular discomfort was reported. Two tests were performed with sensors installed in the empty cabin and with no operator present:

- 10 kg TNT detonated under the flail
- 7,5 kg TNT detonated under the cabin

In the case of detonation of 7,5 kg under the cabin, the signal cables were damaged by the blast, and no data was obtained.

This document reports the measured values and gives a hazard evaluation of the operator's environment in the case of 10 kg TNT being detonated under the flail, which may be considered a worst case scenario under most normal conditions. Dangers related to shaped charges and accidental detonations in other locations relative to the vehicle are not treated.

2 INSTRUMENTATION

The cabin was equipped with the following sensors:

- Simplified "back-pelvis-thigh" dummy with a force tranducer F1 detecting lumbar spine load

- 5 accelerometers, referred to as A1-A5 (A1-A4 mounted on the dummy, AS on the floor)
- Pressure transducer P1

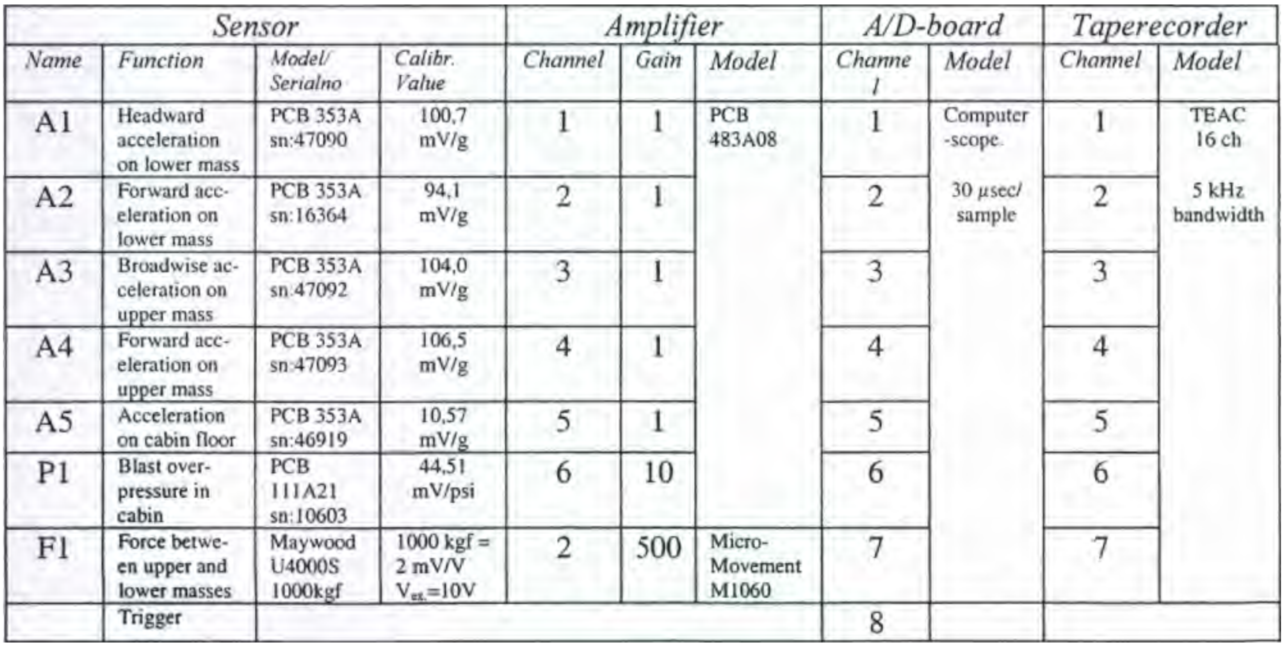
The employed equipment is listed in Table 1, and the dummy is shown in Figure 2.1.

Accelerometer AS was mounted to the cabin floor to measure anticipated headward loading to the feet. The others (A1-A4) were mounted on the simplified "back-pelvis-thigh" dummy strapped in the driver's seat. As illustrated in Figure 2.1, A1 measured headward acceleration on the lower body part, while A2 measured forward acceleration at the same location. A3 and A4 measured broadwise and forward acceleration respectively on the upper body part. A1-A4 were fitted on pieces of plywood whose purpose was to reduce noisy ringing from the steel. Due to some difficulties with bolting plywood to the floor, AS was mounted directly onto the steel plate. The noise was still at an acceptable level.

The dummy (Figure 2.1) has a weight distribution similar to a human body. The anticipated lumbar spine load was measured with a force transducer, Fl, coupled between the upper and lower masses. The two pillars on the sides are guides for preventing bending and rotation, and transmit no vertical force. The upper part weights 36 kg, while the lower part weights 26 kg.

A pressure transducer (P1) was fitted in a box placed on the dummy's lap. P1 was mounted in the box wall with its sensing element outward, so that it measures the anticipated reflected pressure in the cabin.

Table 2.1 Employed instruments



Sensor				*Amplifier*			*A/D-board*		*Taperecorder*	
Name	*Function*	*Model/ Serialno*	*Calibr. Value*	*Channel*	*Gain*	*Model*	*Channel*	*Model*	*Channel*	*Model*
A1	Headward acceleration on lower mass	PCB 353A sn:47090	100,7 mV/g	1	1	PCB 483A08	1	Computer -scope. 30 µsec/ sample	1	TEAC 16 ch 5 kHz bandwidth
A2	Forward acceleration on lower mass	PCB 353A sn:16364	94,1 mV/g	2	1		2		2	
A3	Broadwise acceleration on upper mass	PCB 353A sn:47092	104,0 mV/g	3	1		3		3	
A4	Forward acceleration on upper mass	PCB 353A sn:47093	106,5 mV/g	4	1		4		4	
A5	Acceleration on cabin floor	PCB 353A sn:46919	10,57 mV/g	5	1		5		5	
P1	Blast overpressure in cabin	PCB 111A21 sn:10603	44,51 mV/psi	6	10		6		6	
F1	Force between upper and lower masses	Maywood U4000S 1000kgf	1000 kgf = 2 mV/V $V_{ext.}$=10V	2	500	Micro-Movement M1060	7		7	
	Trigger						8			

The signals were recorded with a PC equipped with AID-board and a tape recorder in parallel as backup. Due to limited memory on the A/D-board, the PC captured signals for 163 msec only. This turned out to be insufficient, so the published signals had to be replayed from the tape.

In order to remove unwanted frequency components, all signals except pressure were digitally filtered to comply with frequency class CFC1000 specified by Society of Automotive Engineers (SAE) [1] for the body parts in question here. The CFC number corresponds to the frequency (Hz) at which the frequency response curve is between +0.5 dB and -1,0 dB, and the attenuation is further specified by corridors into which the frequency response curve must fall.

3 MEASURED VALUES AND HAZARDS EVALUATION

3.1 Introduction

The simplified dummy used in these tests will of course provide less detailed information than a professional dummy, such as e g the General Motors Hybrid III [2], which is a biofidelic copy of the human body, fitted with an extensive number of sensors. Biofidelic means that the dummy duplicates the biomechanical response behaviour of a living human exposed to the same impact conditions. However, our simplified dummy should provide information on the most important loads that may cause injury to the operator.

The measured values will he held up against injury thresholds found in various sources. In general these values turn out to he well below the actual tolerance criteria, and for the sake of simplicity, this allows us to take a conservative approach to the matter.

In our case, the operator is less affected by the initial blast but rather by the subsequent movement of the vehicle, because the detonation is at some distance from the subject. The shock wave reaches the cabin after approximately 5-10 milliseconds, and it can be seen from Figures 3.1 and 3.3 – 3.8, that the dominant acceleration and force is after that.

3.2 Floor acceleration

The accelerations measured at the cabin floor are integrated to give velocity versus time, see Figure 3.1. This is a feasible way to account for the duration of the acceleration.

The maximum acceleration and velocity associated with each pulse are plotted into the shock spectrum of Figure 3.2 given by [3]. It is apparent that our values are well below the injury level, even for standing men, with respect to the legs.

3.3 Spinal forces

The perhaps most important question is whether there is risk of spinal injury. High acceleration parallel to the vertebral column is likely to injure a lumbar vertebra.

The signal from the force transducer F1 is presented in Figure 3.3. Compression is negative. A maximum force of 1800 N is present. Forces less than 5000 N is regarded as safe according to [4].

Spinal injury potential may also be evaluated from acceleration by applying the Damage Response Index (DRI) model described in [2]. The DRI model, which was developed for use with ejection seats, treats the body as a damped spring-mass system. Applying it on the A1 signal gives DRI=5,7. According to operational experience from military aviation, 1 % of the pilots will be injured when subjected to DRI =16.

The vertical accelerations (Al) on lower dummy part in Figure 3.4 show reasonable correspondence with the force signal, keeping in mind that the upper part is 34 kg and lower part is 26 kg and that force distribution between shoulder and lap webbing may alter.

3.4 Neck loading

The horizontal shear forces on the neck are estimated from accelerations on the upper body part. The recorded signals from A3 and A4 are presented in Figure 3.6 and 3.7, respectively. Using a head mass of 4,50 kg and the maximum acceleration value of A4, the force is calculated by Newton's second law:

$$F = ma_{A4max} = 4{,}50 \cdot (kg) \cdot 170 \cdot (m/s^2) = 765 \cdot N \qquad (3.1)$$

The maximum horizontal shear force is estimated to be 765 N. This value may be compared to the tolerance level of 1100 N given by [2] for a mid-sized male. The forces are probably overestimated due to the unnaturally rigid dummy, but again, we can afford a conservative approach.

3.5 Head injury

Our dummy did not have any head. The accelerometers A3 and A4 are in the same position as the head would have been, but rigidly connected to the body. As illustrated by the integrated A4 signal in Figure 3.7, the top of the dummy gains a velocity of 3 m/s. Decelerating from 3 m/s onto a hard surface is regarded to be mostly safe for both head and body [5]. However, in our case a naturally hinged head might obtain velocities even beyond that due a "sling-effect ", so the possibility of head injury can not be excluded completely. If the driver wears a helmet, it is not reasonable to expect head injury.

3.6 Blast pressure in the cabin

The pressure recording is presented in Figure 3.8 along with the impulse. In Figure 3.9 peak pressure and impulse from Figure 3.8 is plotted together with the relevant damage curve given by R Ross in [5]. This represents the case where 90 % of those exposed are not likely to suffer an excessive degree of hearing loss.

The operator will in our case be exposed to a blast loading just above this curve. This means that, more than 10 % of the potential drivers are not safe. Ear protection is therefore recommended.

4 SUMMARY

A simplified dummy equipped with accelerometers and a spine force load cell has been employed during detonation of 10 kg TNT under the flail of the Compact 230 MINECAT. In addition, internal pressure and cabin floor acceleration has been recorded.

Use of a more advanced dummy would have provided more detailed information, but our simplified type should give reliable data on the most important loads that may cause injury to the operator.

By use of established damage criteria from the literature, it can safely be concluded that detonation of 10 kg TNT under the flail will not injure the operator, provided that the cabin is undamaged, the doors remain properly shut, and the operator wears head and ear protection.

The consequences of charges detonating in other locations with respect to the vehicle, and the dangers associated with shaped charges of any kind, have not been investigated in this report.

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SAE J211b Instrumentation for Impact Tests, 1974

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AGARD AR 330, 1996

3 Hirsch, Arthur E. - Man's Response to Shock Motions
Department of the Navy , Washington 1964

4 Paulsen, T. Rest, J — Report on Blast Trials on a Modified Leopard 1 Tank,
Norwegian Army Material Command, Hønefoss 1999

5 Compendium from A Short Course on Explosion Hazards Evaluation,
Southwest Research Institute,

Figure 1.1 *The Compact 230 MINECAT mineclearing vehicle, with hood open (Photo: NoDeCo)*

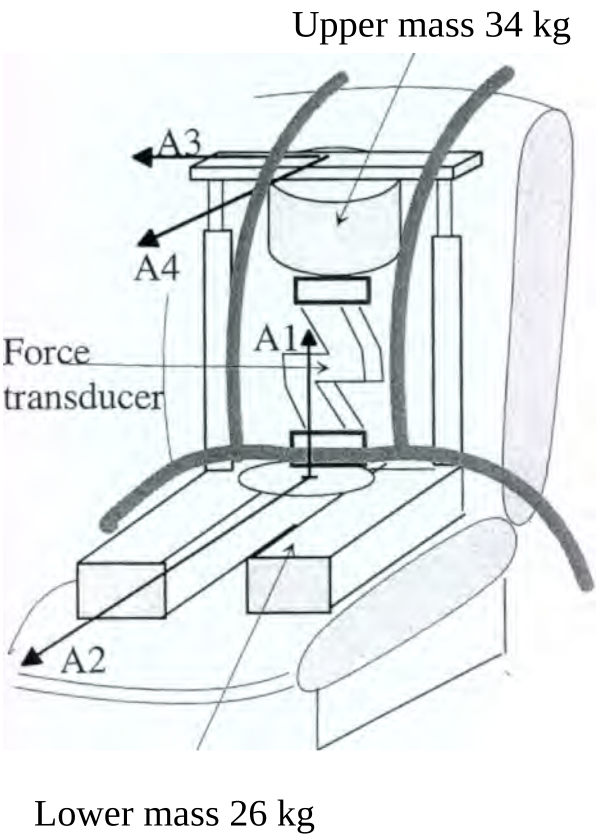

Figure 2.1 *The simplified dummy strapped to the seat*

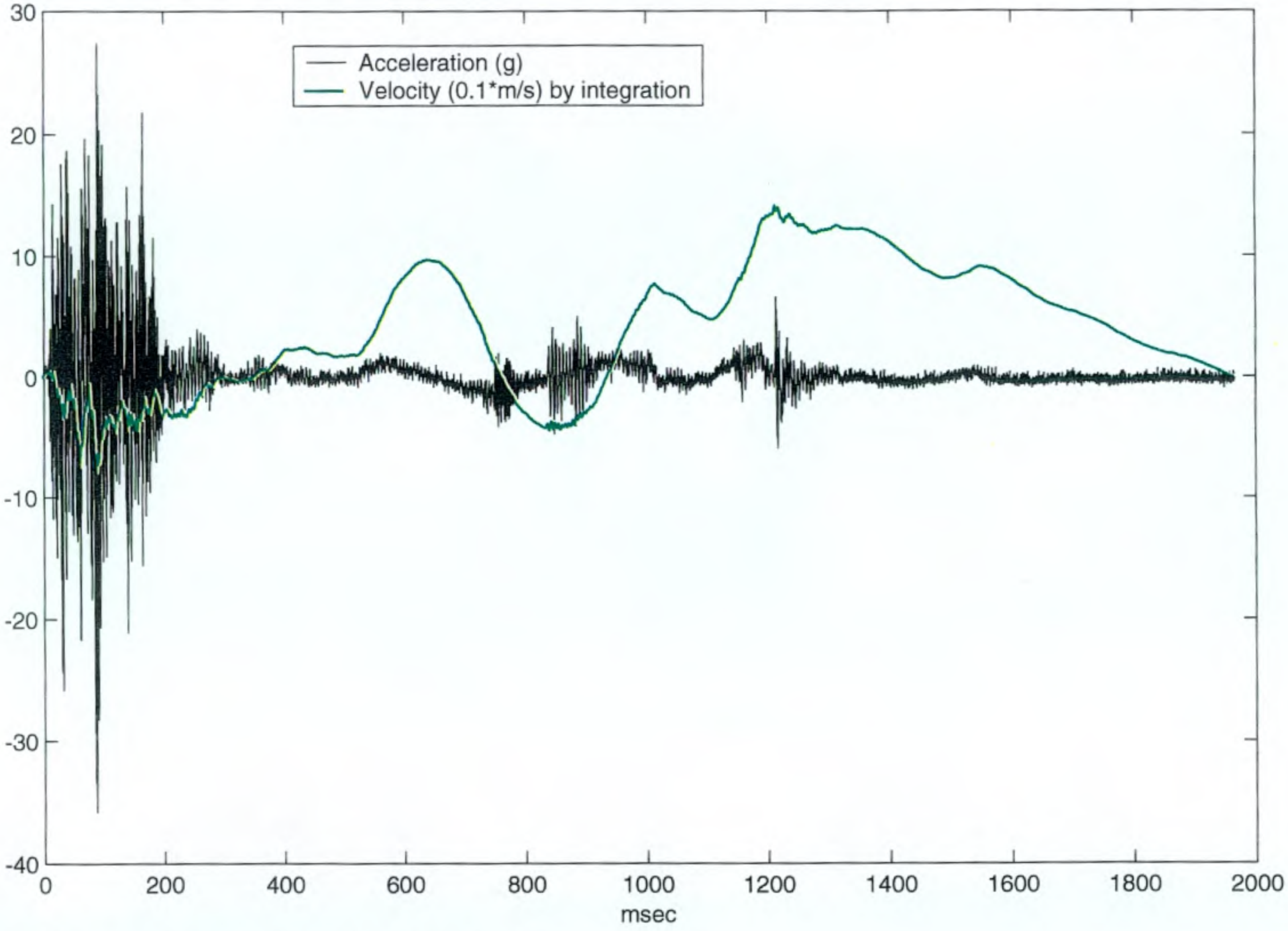

Figure 3.1 *Acceleration measured at the cabin floor, sensor A5.*

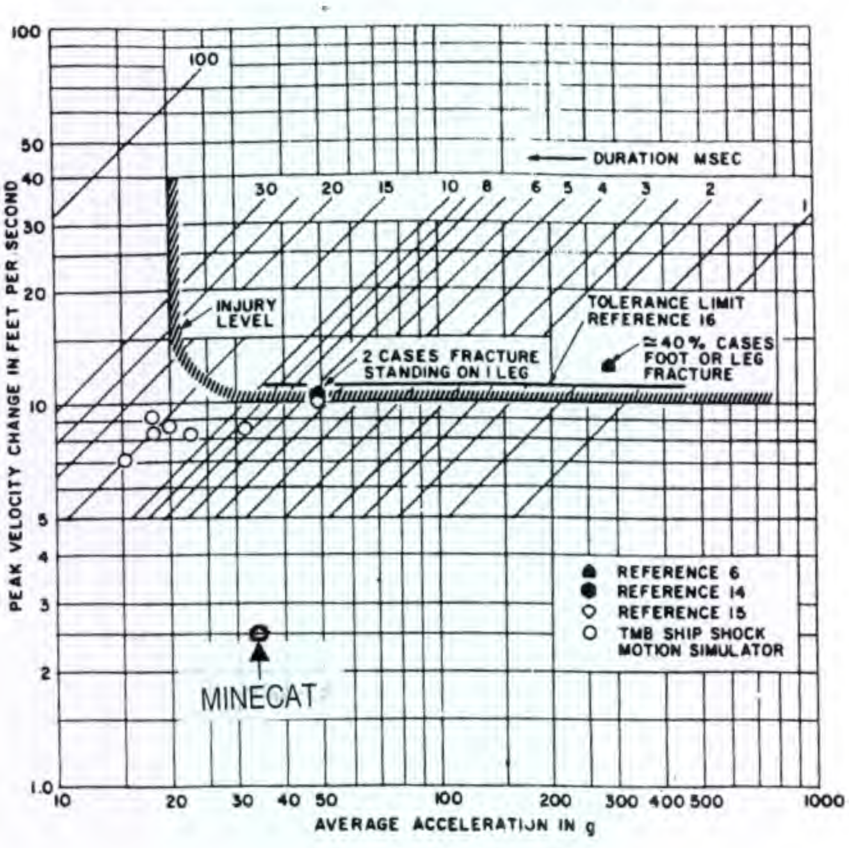

Figure 3.2 Tolerance of stiff-legged standing men to shock motion of short duration [3].

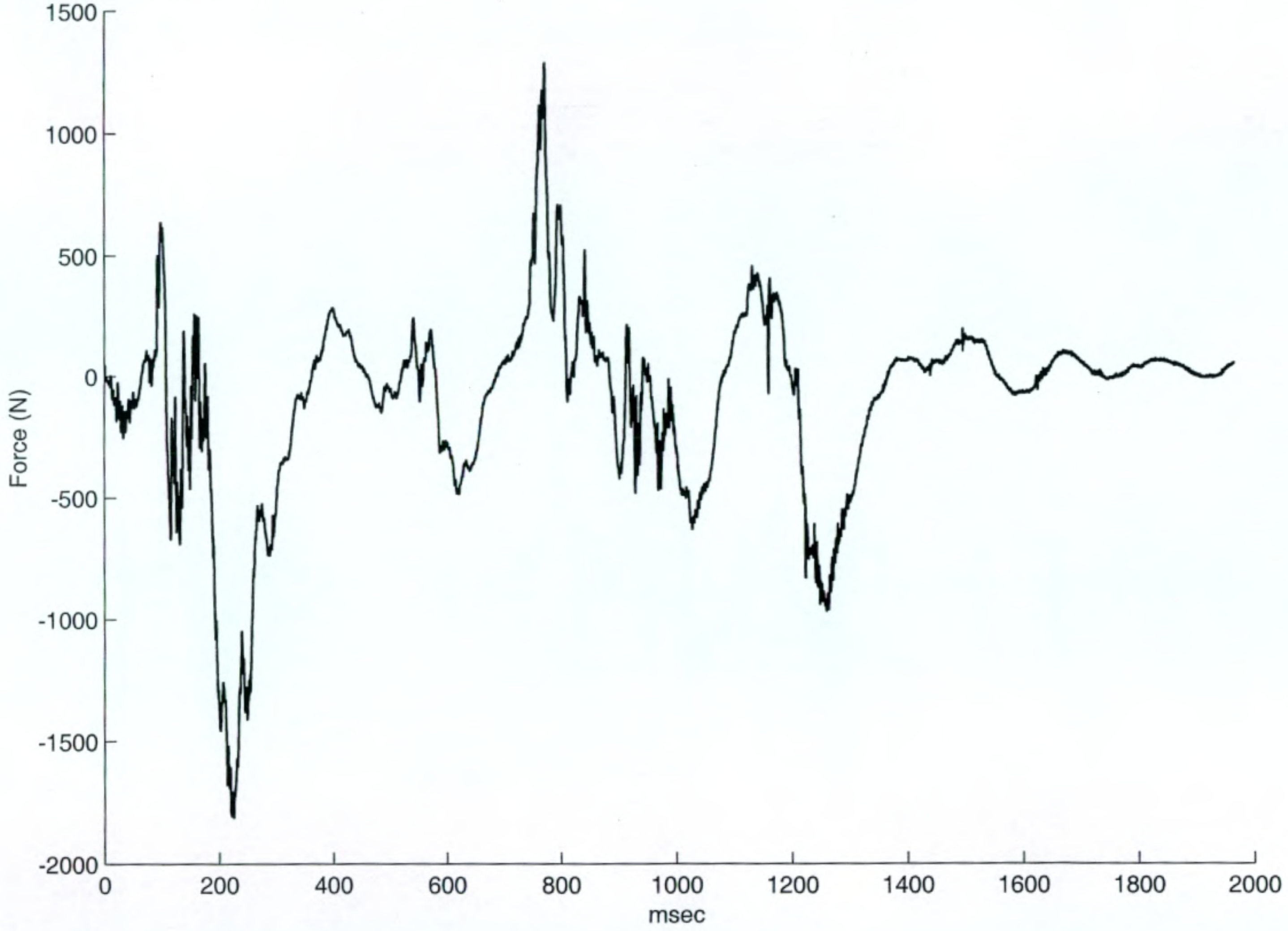

Figure 3.3 *Force between upper and lower mass, sensor F1.*

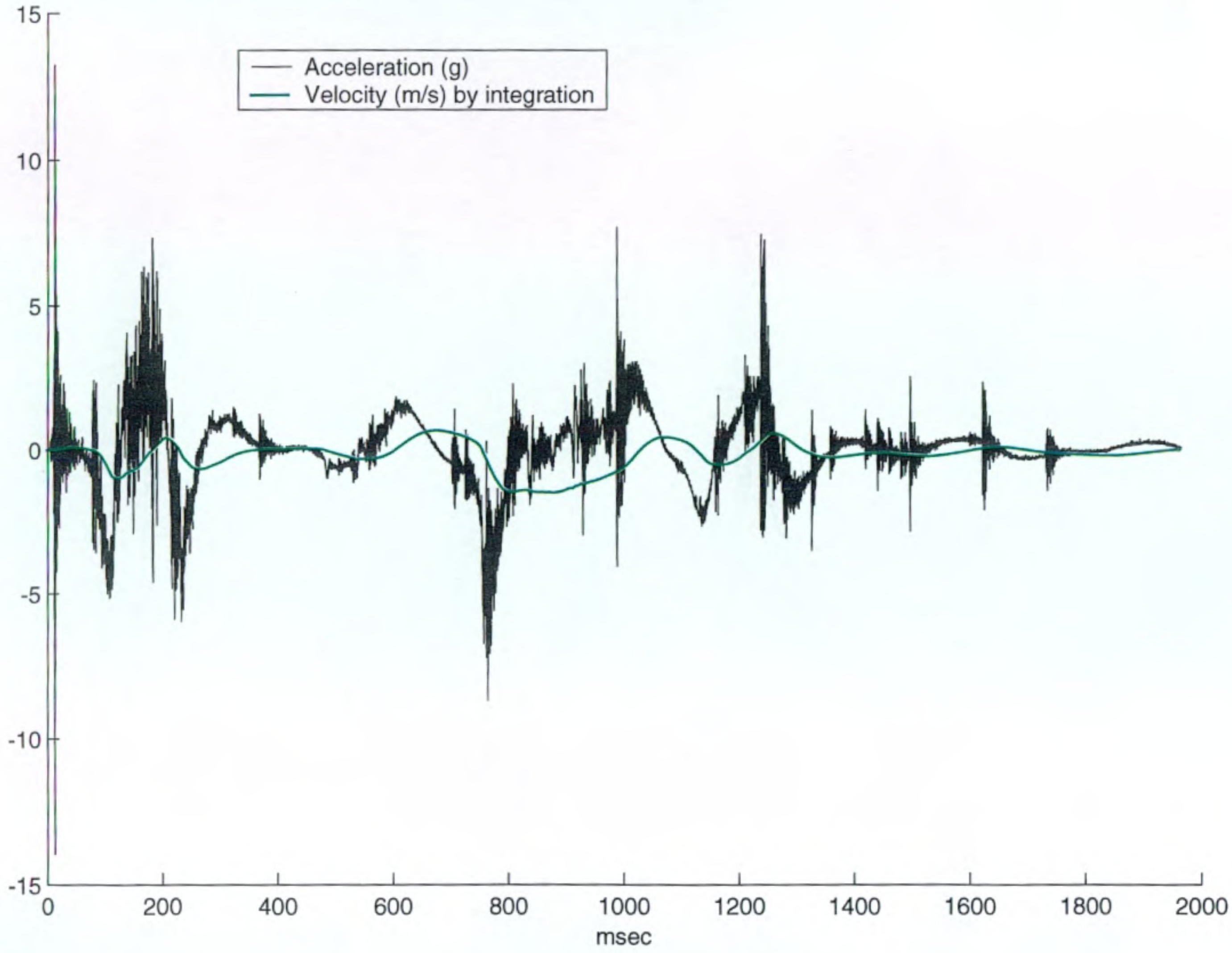

Figure 3.4 Headward acceleration on the lower mass of dummy, sensor A1.

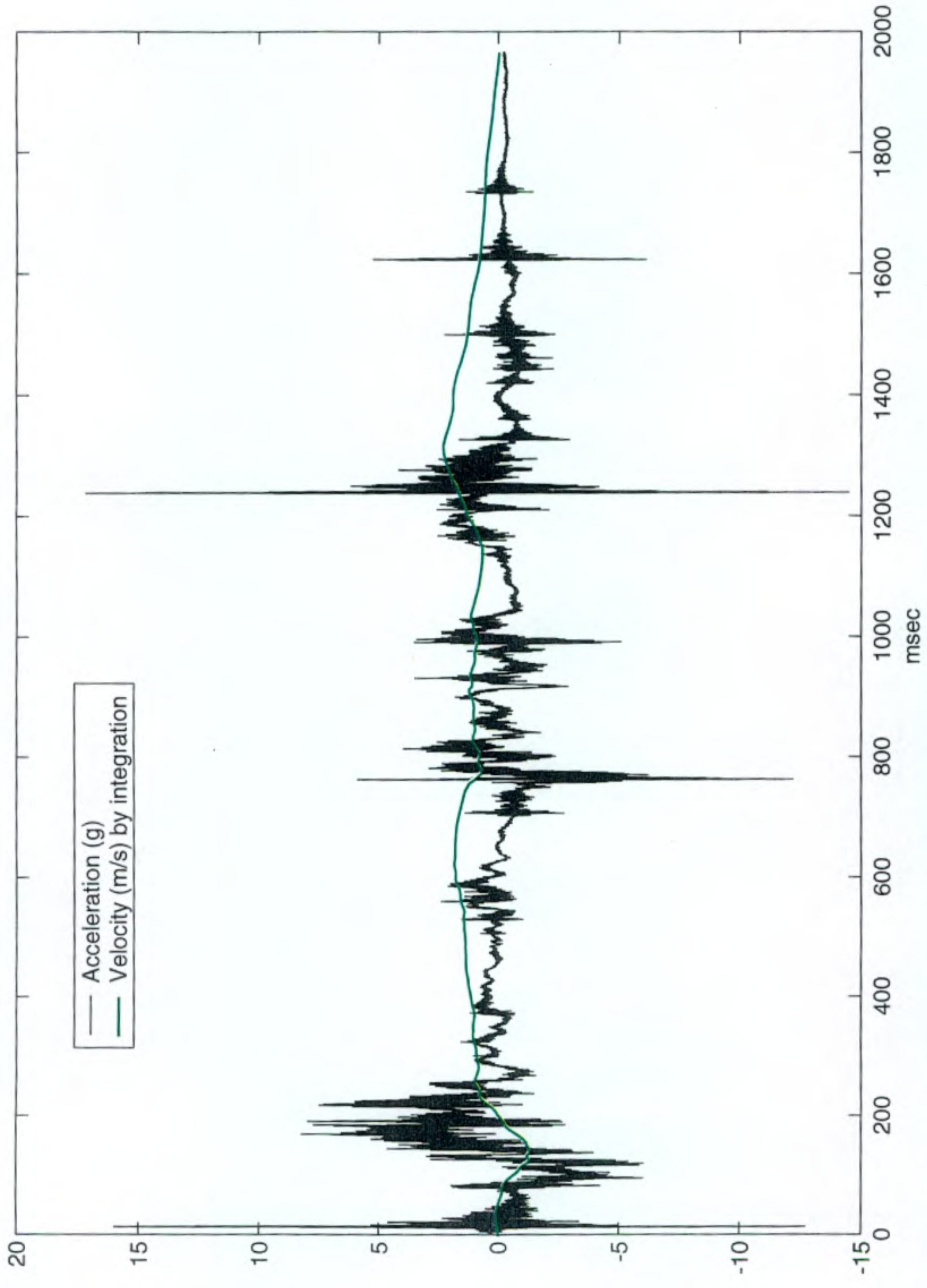

Figure 3.5 Forward acceleration on lower mass of dummy, sensor A2.

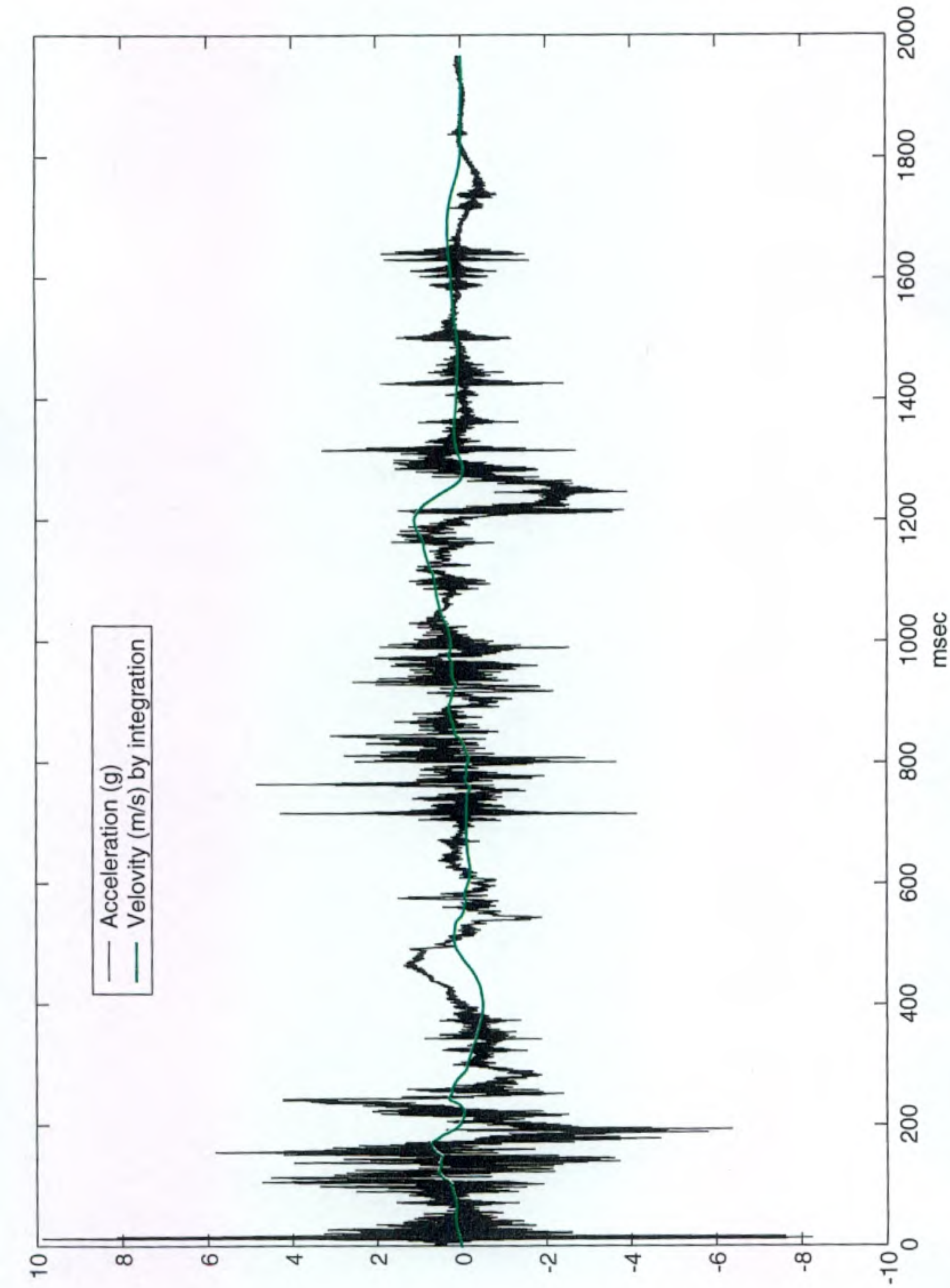

Figure 3.6 Broadwise acceleration on the upper mass of dummy, sensor A3.

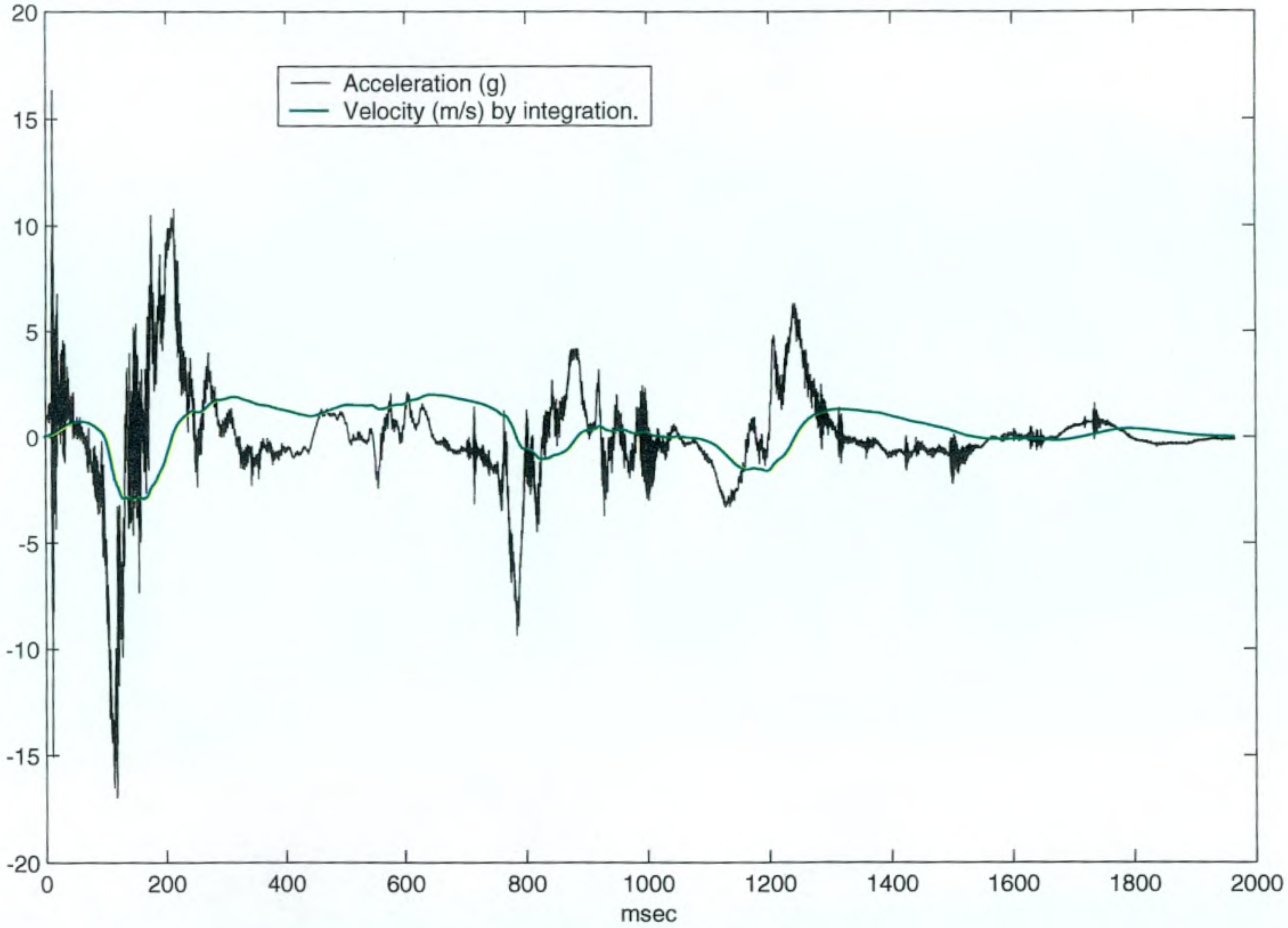

Figure 3.7 Forward acceleration on the upper mass of dummy, sensor A4.

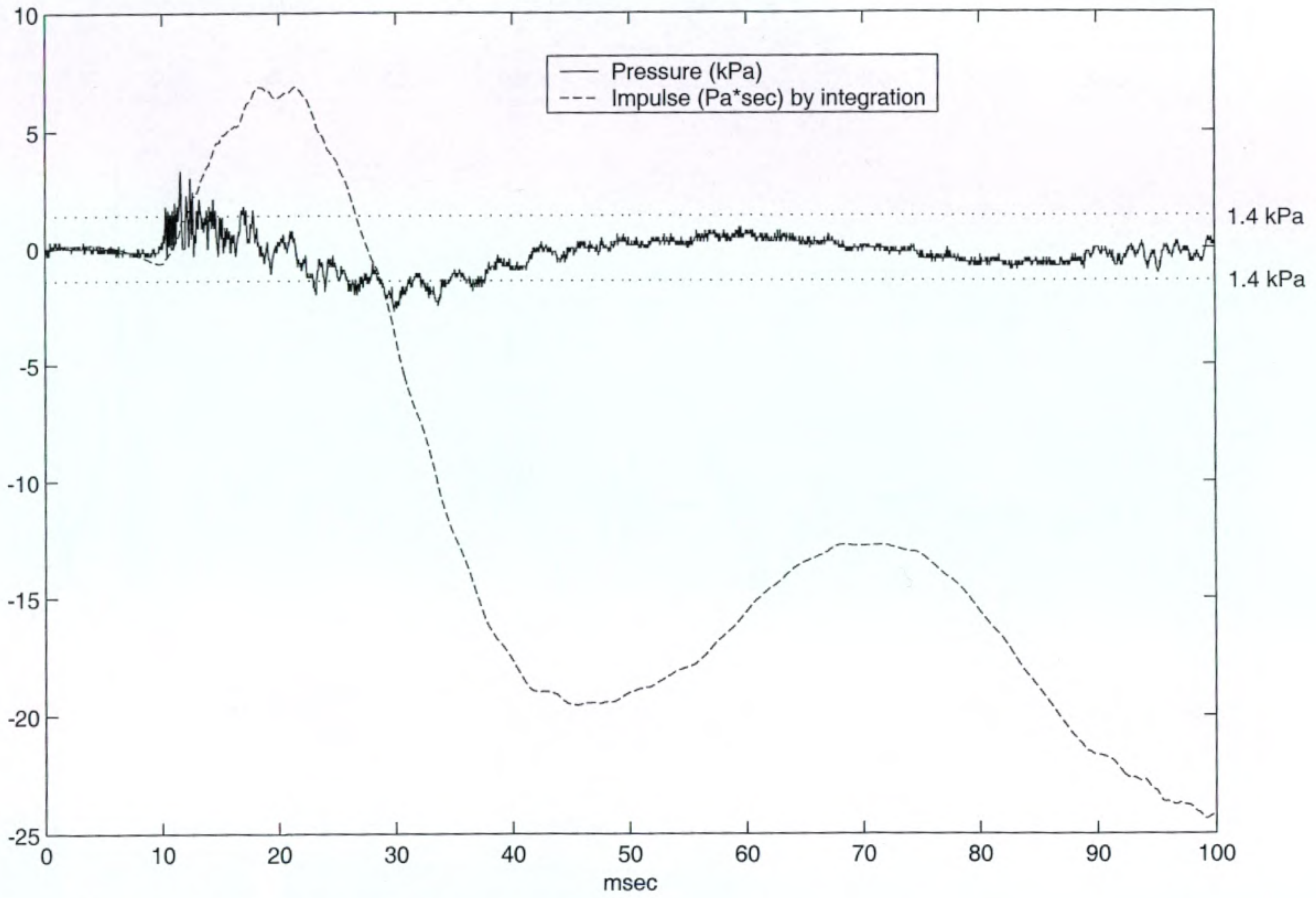

Figure 3.8 *Blast overpressure inside cabin, sensor P1.*

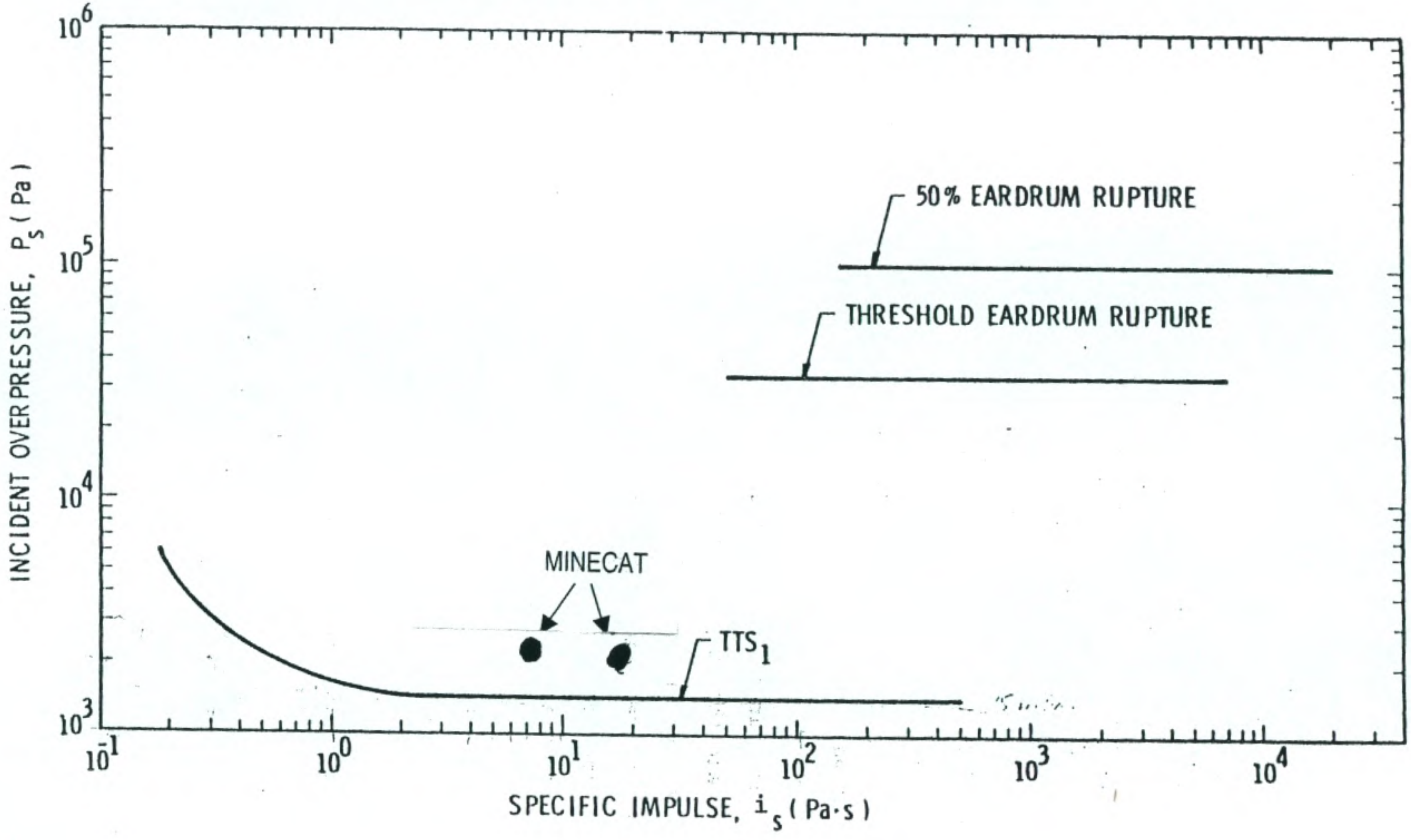

Figure 3.9 Human ear damage curves for blast waves [5].