# In-Flight Pressure-Time Recording for Short Burning-Time Rocket Motors

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**An in-flight recorder system has been developed to measure the pressure-time history of rocket motors designed for shoulder-launched infantry weapon systems. The forebody of the projectile contains a pressure transducer whose output is sampled 256 times during the motor firing, each reading being converted into an 8-bit word providing a theoretical resolution of 0.4%. The 256 words are stored in two CMOS 256×4 bit memories and retained for up to 500 h by dedicated batteries. On recovery the unit's memory is interrogated and the output produced on punched paper tape. The unit has been demonstrated to function both during the high acceleration at launch and is undamaged by the deceleration loads experienced in the recovery butt. Results are presented comparing the pressure-time records of an experimental rocket motor obtained under both dynamic and static firing conditions which demonstrate the absence of any significant differences in the internal ballistics due to acceleration effects. Also presented are measurements of the motor chamber pressure at the instant the projectile leaves the launch tube and its relationship with observed blast overpressures.**

## Introduction

A KNOWLEDGE of the pressure-time history of rocket motors designed for use in shoulder-launched infantry weapon systems such as the UK LAW-80 and Blowpipe is essential for the following reasons. First, a sound knowledge of the motor pressure under dynamic conditions permits the determination of the residual motor pressure when the projectile leaves the launch tube. This can then be correlated with the observed effects on a dummy firer, such as the blast overpressures recorded by transducers mounted in the dummy's ears. Thus, a firm data base for the safety criteria may be established, enabling the designer to optimize the parameters of the complete weapon system. Secondly, the projection firing pressure records can then be compared with data obtained from static firings and the influence of high accelerations on the internal ballistics, if any, can be studied. The absence of any major differences provides confidence in the structural integrity of the charge design and the validity of using data obtained under static firing conditions to establish the safety factors on the motor tube burst pressures.

Studies have previously been conducted with telemetry units in forebodies, but such techniques tend to suffer from noise problems which degrade the data. Early studies were conducted with flying leads from the pressure transducer, but this technique was found to be suitable only for projectiles with a maximum velocity of only 150 $ms^{-1}$. For velocities above this an in-flight recording system had to be developed.

The effects of high acceleration on the internal ballistics of conventional rocket motors have been studied extensively,[1] but not on short burning-time rockets where the pressure-time history consists primarily of a rise and a decay transient.

This paper describes an in-flight recording system designed for the above studies within the mass constraint of the normal payload of a light antitank weapon which is reusable for many firings. Examples of the data produced by the unit are presented to demonstrate the quality of the information and its value as a research tool for motor development studies.

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## Design

### Requirements

An in-flight recording system for a shoulder-launched weapon has many severe design constraints to overcome. The mass of the system is dictated by the normal payload of the projectile and the dimensions by the calibre of the launch tube. The system must be capable of withstanding the high accelerations during the launch phase which are typically 3000-8000$g_n$ and also survive the decelerations so that the data may be retrieved after the firing. A scanning period of approximately 30 ms is sufficient to cover the action times of most short burning-time motors.

### Data Acquisition and Storage System

These requirements have been met by the Data Acquisition and Storage System (DASS) illustrated in Fig. 1. It consists essentially of three units—a pressure sensing unit, an electronics unit to record the data, and a power unit. The three units are assembled into a forebody attached to the motor as shown.

The rocket motor is fitted with the motor head endplate (fabricated in titanium alloy TA-11) and a pressure transducer, all of which may be conditioned to any required temperature, and the remainder of the forebody is attached immediately prior to firing. Thus, a wider temperature range may be covered than would be possible if the whole system were required to be able to withstand the temperature extremes dictated by the weapon system requirements.

The projectiles are fired into a butt filled with cotton waste, providing decelerations of the order of 2000$g_n$. The aluminum outer case of the forebody is not designed to survive every projection, but the semirigid polyurethane foam around the electronics and battery packs provides sufficient protection for these units to survive many firings.

After the firing the forebody is detached from the motor and connected to a data retrieval unit which interrogates the memory store and then produces a punched paper tape record of the contents for further analysis.

### Electronics

A block schematic diagram of the microelectronics unit is shown in Fig. 2. The Wheatstone bridge of the pressure transducer is supplied with a regulated 10 V. The gain of the

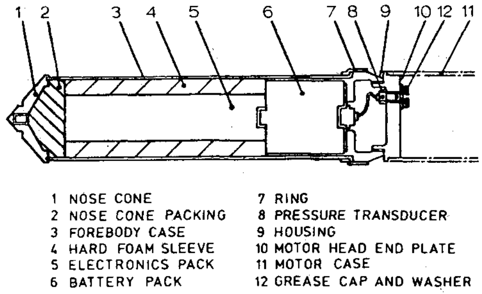


**Fig. 1 General assembly of forebody and data acquisition and storage system.**

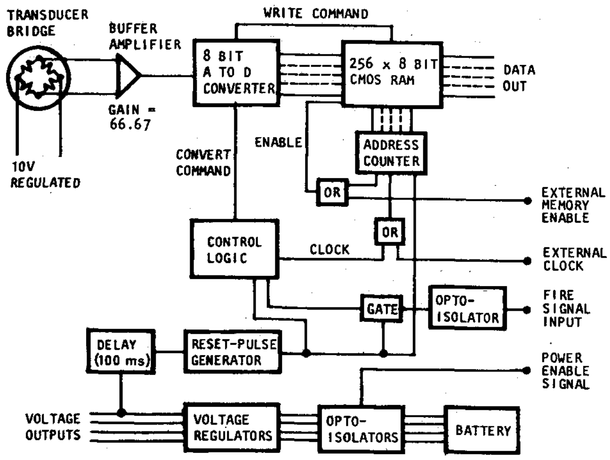


**Fig. 2 Block diagram showing main elements of the electronics peak.**

buffer amplifier is preset to give a convenient voltage output (~5 V) dependent on the sensitivity of the transducer and the expected peak pressure of the rocket motor. The 8-bit analog-to-digital converter produces a binary number between 0 and 255 for an input voltage range of 0-5 V. The binary numbers are then deposited in two 256×4 bit CMOS random access memories. The electronics unit also contains the necessary circuitry for setting up the system immediately prior to the firing, the control logic, and the system clock. The clock produces 10 μs pulses at 125 μs intervals. Analog-to-digital conversion is initiated by the leading edge of the pulse and requires 2.8 μs. On completion, the digital number is written into the memory. When the address counter is full, further writing into the memory is inhibited and the system enters a power down mode in which the memory is kept alive by a keeper power supply. Similarly, if there is a failure in the battery supply during the firing and the voltage drops below a threshold value, then the memory contents are protected, enabling all the firing data up to the instant of failure to be recorded.

In use, the system receives, via internal optoisolators, a signal to switch on the power and, after a predetermined "warm-up" interval, the pulse to trigger the scan. This latter pulse is synchronized with the firing pulse delivered to the motor igniter to establish a common time zero for all the trials' instrumentation.

The entire circuitry of the electronics unit is mounted on four printed circuit boards which are protected by encasement in semirigid polyurethane foam.

### Power Unit

The battery pack supplying 5 and ±15 V consists of stacks of cells wired to connectors and cast into polyurethane foam. Initial trials were conducted with mercury cells which had a limited life and, consequently, were discarded during development in favor of rechargeable nickel-cadmium cells.

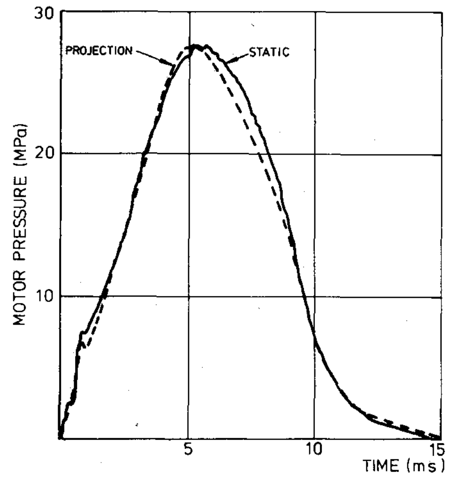


**Fig. 3 Comparison of pressure-time curves obtained from both static and projection firings.**

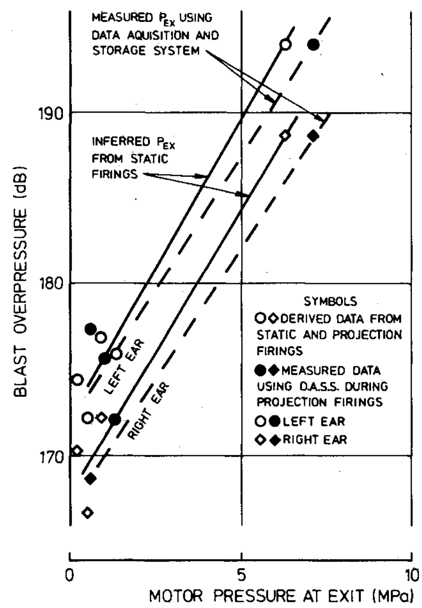


**Fig. 4 Variation of blast overpressure with motor pressure at moment of launch.**

### Forebody Design

The forebody consists of an aluminum alloy (HE30TF) 85-mm-diam tube, 2.4 mm thick and 335 mm long, with a nose cone in the same alloy bonded in with an epoxy resin. The forebody is assembled to the rocket motors with a steel clamp ring in EN-3B. The free volume of the unit is filled with a semirigid closed-cell polyurethane foam of density 200 kg $m^{-3}$ and with a compressive modulus of 90 MPa and compressive yield stress of 3 MPa. Both high strength and stiffness are necessary to prevent deflection of the cylindrical casing under the deceleration loads.

### Pressure Transducer

The pressure transducer selected for this application is a Kulite HKM-375-10000, providing at 70 MPa a maximum output of 75 mV and having a natural frequency of 385 kHz. It has been fully compensated over the temperature range to which the United Kingdom's infantry rocket systems are normally conditioned. The axial acceleration sensitivity is $60\times10^{-6}$% full scale per $g_n$, and thus, even with the very high acceleration levels experienced in these systems, the effect may be neglected.

## Results

Two typical pressure-time records from an experimental rocket motor are shown in Fig. 3, one being obtained during a static firing and the second being recorded by the DASS during a projection firing. The close similarity of the two records in this instance provides confidence in the assumption that the internal ballistics are unaffected by dynamic firing conditions.

The variation with motor chamber pressure at launch of muzzle-induced blast overpressure at the firer's ears is shown in Fig. 4. The pressure is derived from the DASS pressure-time record by determining the exit event either by a break-wire or high-speed cine record, both records being timed from the rocket motor ignition pulse.

Prior to the use of the DASS, the only method for deducing the motor chamber pressure at exit was to calculate the distance the motor would have traveled by double integration of the thrust-time records of similar motor firings conducted under static conditions. This method relies heavily on the assumption of a low round-to-round variation in the form of the thrust-time curves and also the absence of any acceleration-induced effects on the internal ballistics of the motor. Consequently, the scatter in the data thus derived was considerable and the uncertainty in the data presented grave difficulties for the weapon system designer.

## Conclusions

The in-flight recording system described here has provided the weapon system designer with a powerful tool for validating design studies and establishing safety criteria.

## Acknowledgment

The electronics and battery packs used in this system were developed by Graseby Dynamics Ltd.

## Reference

[1]Mitani, T. and Niioka, T., "An Analytical Model of Solid Propellant Combustion in an Acceleration Field," *Combustion Science and Technology,* Vol. 15, 1977, pp. 107-114.