Novel Powder Fuel for Firework Display Rocket Motors

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ABSTRACT

An inexpensive, readily prepared and relatively insensitive powdered fuel suitable for the filling of small firework display rocket motors using a funnel and rammer technique is discussed.

Firework display rocket motors are typically cardboard or aluminium tubes filled with a gunpowder derivative. Consolidation is achieved by incremental filling and pressing or, as at Standard Fireworks, by a mechanically operated funnel and rammer system.

The objective was to provide a simple in-house method to prepare a free-flowing powdered fuel compatible with the available filling equipment. The raw materials are inexpensive and readily available.

The paper will discuss the following aspects: choice of binding agent for the powder, choice of raw materials and relative proportions, hazard data, and performance data.

Introduction

The largest majority of firework rockets are powered by gunpowder filled motors; for example, Standard Fireworks uses 40 tonnes per annum of gunpowder simply as a fuel for rocket motors. In addition to the bulk purchase of this gunpowder, there are associated costs involved in both storage and transport.

This paper describes the work done towards providing an alternative fuel that can be readily manufactured at Standard Fireworks, when required, thus reducing the overall amount of gunpowder that needs to be held in store for the manufacture of fireworks.

The following information is the subject of a Patent Application. G.B. 2,274,480 A.

1. Rocket Motor (Description)

The motor tube is a small open-ended cardboard tube having a choked aperture (ventura) at one end, produced either by crimping the tube or by pressing into place an internal clay washer. The tube is filled with gunpowder, which is compressed around a tapered brass insert, thus providing a cone-shaped gallery in order to increase initial burn rate and produce the required thrust.

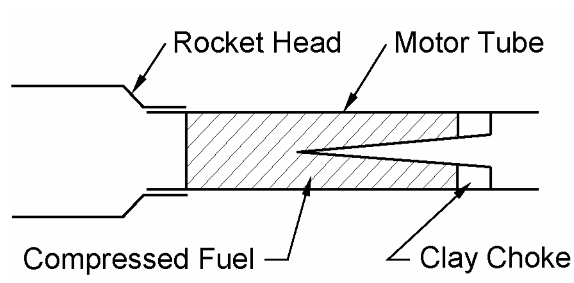

Figure 1. Schematic diagram of small rocket motor.

The tube is open-ended, allowing the final 'burn through' to ignite the effects enclosed within the attached rocket head.

2. Replacement Rocket Powder

Requirements

1) Safety considerations during manufacture, use and storage (i.e., impact and friction sensitiveness).
2) Physical Nature: free-flowing, non bridging powder/granules.
3) Quick and simple on site method of manufacture (i.e., prepared as required) and thus eliminating the problems associated with storage and transport of large mounts of explosives.
4) Readily available, multi-sourced, relatively inexpensive, non-toxic raw materials.

3. Background

From past experience, using a simple blend of the ingredients of gunpowder does not produce a rocket motor with the required burn properties. The gunpowder, currently in use at Standard Fireworks, has the chemical composition shown below:

Ingredient	%
Potassium nitrate	68±1.5
Charcoal	9±1.0
Sulphur	23±1.0

However, it is well known that simple whistle-effect pyrotechnic admixtures have properties which are suitable for use as a propellant for small rockets. A typical mixture is a blend of potassium perchlorate with a metal salt of an aromatic carboxylic acid and a liquid binder; such an example is shown below:

Ingredient	Parts
Potassium perchlorate	60
Potassium benzoate	40
Polystyrene binder soln.	2

With this background knowledge, it was decided that an attempt would be made to adapt the whistle mixture and to give it suitable flow characteristics to be used with the powder filling equipment at Standard Fireworks.

4. Development Work

It was decided initially to keep the oxidant as potassium perchlorate and the aromatic acid as potassium benzoate, as currently used at Standard Fireworks.

4.1. Binder

The desired properties of the binder are:

(i) Solid.
(ii) Relatively low melting (<100 °C).
(iii) Easily oxidised to produce mainly oxides of carbon as the major gaseous product.
(iv) Readily available and moderately priced.

With the above properties in mind the binder of choice was selected from aromatic compounds either unsubstituted or substituted with OR or NR_1R_2, where R, R_1, R_2 = hydrogen, low alkyl or an aromatic ring. Especially those having carbon to hydrogen weight ratios ≥ 13:1. Examples of such materials are given in Table 1.

The compositions used for the initial trials were based upon whistle effect signal mixtures used at Standard Fireworks (i.e., admixtures of potassium perchlorate and potassium benzoate). Such mixtures, upon ignition, proved to be too violent for use as a rocket motor composition. However substitution of part of the potassium perchlorate with potassium nitrate eventually gave satisfactory results. Examples of experimental mixtures are given in Table 2.

The tests were carried out using a small rocket with a loaded plastic head (Net Explosive Content [N.E.C.] of motor = 10 g).

The composition of choice was No. 9 (Code WPR 40). This was made after consideration of performance test results, chemical hazard data and availability of raw materials. The composition compares favourably with the currently used gunpowder in all aspects of performance, cost and ignition sensitivity.

Table 1. Examples of Chosen Binders.

Binder	Formula	C/H Weight Ratio	Melting Point °C
Naphthalene	$C_{10}H_8$	15:1	80–82
2-Methoxy-naphthalene	$C_{11}H_{10}O$	13:1	73–75
Diphenylamine	$C_{12}H_{11}N$	13:1	52–54
Diphenylether	$C_{12}H_{10}O$	16.5:1	26–30
Biphenyl	$C_{12}H_{10}$	14.5:1	69–72
2-Hydroxybiphenyl	$C_{12}H_{10}O$	14.5:1	57–59
Stearic acid *	$C_{18}H_{36}O_2$	6:1	67–69

* control

It is prepared *simply* by tumble mixing of the weighed and sieved ingredients. The motors retained their effectiveness after storage through two cold and damp English winters in an unheated magazine.

5. Performance and Sensitiveness Tests

Comparison of the performance of WPR 40 with gunpowder (R81) is shown from the trace given by measurement of the thrust output from identical size of motors. See Figure 3.

The thrust measurements were made on equipment developed in conjunction with Royal Military College of Science, Shrivenham, a diagrammatic representation of which is shown in Figure 2.

Table 2. Experimental Mixtures.

No.	Constituent Parts				Flight Results
	Potassium Perchlorate	Potassium Nitrate	Potassium Benzoate	Binder (parts)	
1	60	—	40	Naphthalene (10)	50% motors exploded upon ignition
2	60	—	40	Biphenyl (10)	50% motors exploded upon ignition
3	60	—	40	2-Methoxy Naphthalene (10)	All motors exploded upon ignition
4	45	15	40	Biphenyl (5)	Good vigorous flight
5	45	25	30	Diphenylamine (5)	Weak flight
6	50	20	30	Diphenylamine (5)	Vigorous flight
7	35	35	30	2-Hydroxy Biphenyl (5)	Weak launch
8	40	30	30	2-Hydroxy Biphenyl (5)	Improved on No. 7
9	45	25	30	2-Hydroxy Biphenyl (5)	Vigorous launch
10	45	25	30	Stearic acid (1)	No launch

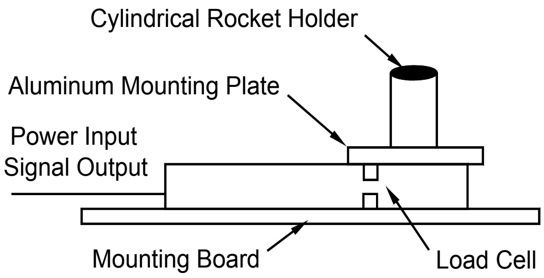

Figure 2. The thrust meter device.

The Thrust Measurement Device

The device consists of an adapted load cell. The load cell is a beam arranged so that an applied load will result in a proportional strain along that beam. The strain so produced is detected using an array of strain gauges, which convert the strain into an electrical signal, the magnitude of which is related to that of the applied strain.

The load cell is mounted on a flat metal plate, which provides extra overload protection for the device.

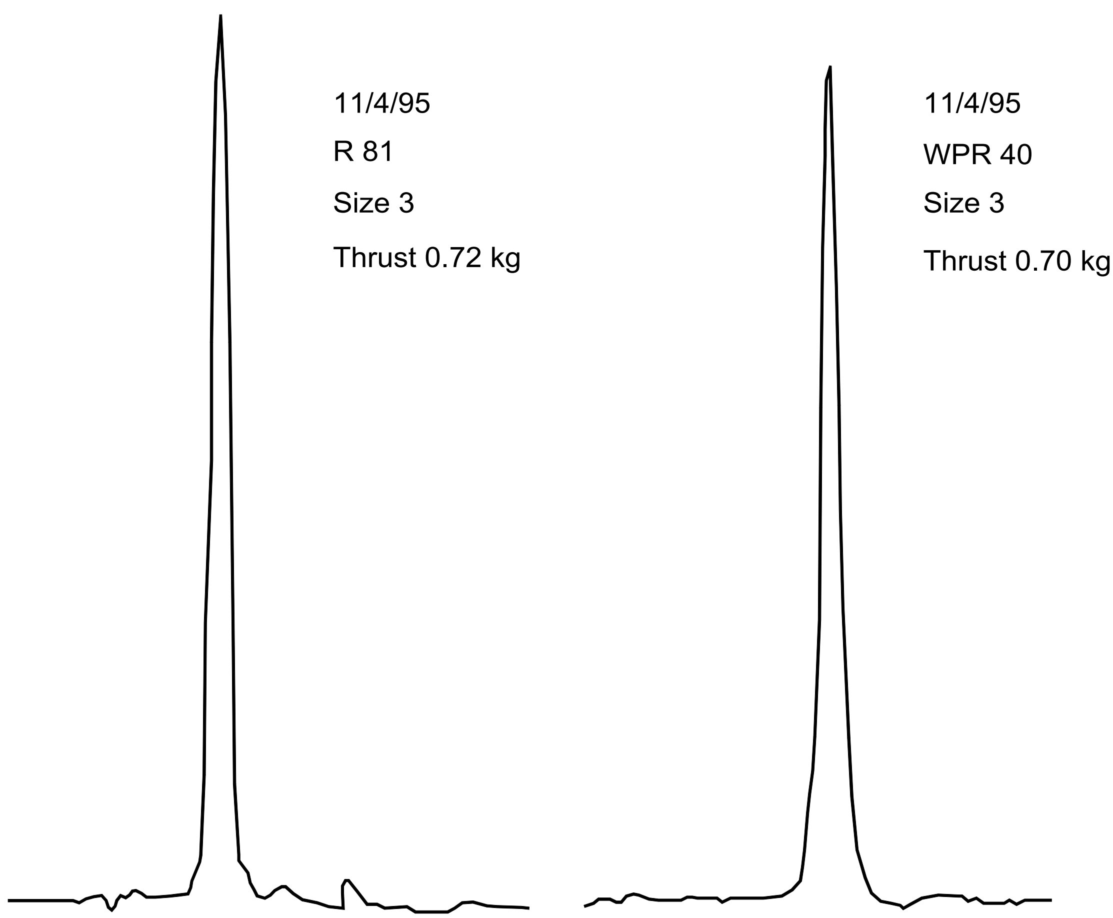

Figure 3. Comparative thrust measurements.

Table 3. Mallet Friction Test Results.

Composition: White Powder Rocket 81

Part number: WPR40

Mallet →	Rock Maple			Nylon	Steel	
Anvil →	York-stone	Hard Wood	Soft Wood	Mild Steel	Mild Steel	
1	×	×	×	×	×	E
2	×	×	×	×	×	×
3	×	×	×	×	×	×
4	×	×	×	×	×	×
5	×	×	×	×	×	×
6	×	×	×	×	×	×
7	×	×	×	×	E	×
8	×	×	×	×	×	×
9	×	×	×	×	×	×
10	×	×	×	×	×	×
Total E	0	0	0	0	2	
%E	0%	0%	0%	0%	50%	

× = non event E = event

6. Ignition Sensitiveness Testing

6.1 Mallet Friction Test

In this test a small sample of explosive is spread onto an anvil and struck a glancing blow with a standard wood or steel-tipped or nylon-tipped mallet held in the operator's hand.

The combinations used are:

Steel-tip mallet on steel anvil;
Nylon-tip mallet on steel anvil;
Wood mallet on: softwood
hardwood
and Yorkstone.

An ignition is judged to have occurred if the observer detects any of the following:

a) sparks or flame,

b) a crack as some or all of the trace reacts,

c) for the all-wooden mallet only, a smell of burning.

Results are reported as the number of ignitions occurring during ten cycles. For the steel-on-steel combination therefore, the number of ignitions from twenty cycles is divided by two and rounded up to the nearest integer and quoted as the equivalent number of ignitions from ten cycles.

For Hazard Data Sheet purposes results are rounded for each surface combination as follows:

No ignition in ten cycles	0%
Up to six ignitions in ten cycles	50%
More than six ignitions in ten cycles	100%

Comparative results are given in Tables 3 and 4.

6.2 B.A.M. Fallhammer Test

The BAM Fallhammer Test [Bundesanstalt für Materialforschung und -prüfung] involves dropping a range of standard weights from known heights onto an explosive sample and observing an "explosion" or a "no reaction". The height at which a decrease of 10 cm of drop height causes a change in sample response from "explosion" to "no reaction" for six consecutive trials is determined. This value is then converted into an energy value (in joules) and

Table 4. Mallet Friction Test Results.

Composition: Gunpowder Rocket 81

Part number: 16050

Mallet →	Rock Maple			Nylon	Steel	
Anvil →	York-stone	Hard Wood	Soft Wood	Mild Steel	Mild Steel	
1	×	×	×	×	×	×
2	×	×	×	×	×	×
3	×	×	×	×	×	×
4	×	×	×	×	×	×
5	×	×	×	×	×	×
6	×	×	×	×	×	×
7	×	×	×	×	×	×
8	×	×	×	×	×	×
9	×	×	×	×	×	×
10	×	×	×	×	×	×
Total E	0	0	0	0	0	
%E	0%	0%	0%	0%	0%	

× = non event E = event

this value is termed the Limiting Impact Energy (LIE). The detection of a positive event is by an explosion.

Results:

Limiting Impact Energy	(L.I.E.)
Rocket 81 (Gunpowder)	10.0 J
WPR 40	<30 J

6.3 Ignition Temperature

The ignition temperatures obtained from a Differential Scanning Calorimeter trace are shown below:

Material	Ignition Temperature
Rocket 81	350 °C
WPR 40	480 °C

7. Conclusions

The composition of choice (i.e., WPR 40) has proved to be a relatively safe and cost effective replacement for gunpowder in small rocket motors. It is anticipated that further work, chiefly involving modification of the granular form of this material, will make it acceptable for use in all the rocket motors currently in production.

Obvious advantages of this composition are ease of manufacture, readily available and multi-sourced raw materials and reduced problems associated with gunpowder storage.