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History of the
Early Solid Propellant
Motors of RO plc
Rocket Motors Division

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A HISTORY OF THE EARLY SOLID PROPELLANT ROCKET MOTORS OF ROYAL ORDNANCE plc
ROCKET MOTORS DIVISION

J Harlow *

1. SYNOPSIS

The separate origins and histories of the two sites of Rocket Motors Division, Summerfield and Westcott, are discussed along with many of the development projects and technologies.

From the early 1950s Summerfield, a wartime small arms factory, began working under Imperial Chemical Industries Ltd (ICI) Metals Division on cast double base (CDB) technology derived from United States Navy (USN) financed programmes. This technology evolved and enabled a whole range of modified CDB propellants to be successfully employed in a wide variety of military propulsion systems.

By the time Summerfield began working on CDB, Westcott (a United Kingdom (UK) Government establishment) had completed work on a large facility for producing plastic (uncured polymeric binder) composite solid propellants for boost and sustainer systems. Plastic propellant technology was based on work commencing in 1938 and continuing during the Second World War employing non-stratgegic materials. The evolution of some early military propulsion units into sounding rockets is also described.

With the incorporation of both Westcott and Summerfield into Royal Ordnance plc the current organisation structures were formed. Royal Ordnance plc was subsequently sold to British Aerospace in 1987.

2. INTRODUCTION

Although it might be said that efforts in the UK and its allies were not strongly focussed into the development of solid (or liquid) propellant rocketry during World War Two all the key elements for success were clearly available. It could be argued that little new in the conventional armaments field was developed during those years that was not already in development at the outbreak of war.

Of the two sites of Royal Ordnance Rocket Motors Division (RMD) Westcott began life in 1943 as a wartime RAF airfield, and Summerfield's roots were in the support of the small arms industry. Both sites suffered some run-down immediately after the war with Westcott being used as a prisoner-of-war repatriation centre in 1945 before becoming a UK Government Establishment, the Guided Projectile Establishment (GPE). the first of many titles, on 1st April 1946. Initially Westcott concentrated on the technology involved with liquid propulsion, both in developing UK projects and exploiting that from German sources. No solid propellant work was carried out at Westcott until 1948. Summerfield site was very run down and used as a Government storage and distribution centre before being reactivated in September 1951. ICI Metals Division, under contract to the UK Government, undertook to restructure Summerfield to support the production of CDB propellant and associated rocket motors.

The technology associated with CDB had been researched both in the UK, at the Royal Arsenal at Woolwich, and by the USN during the war years. An Anglo/US information exchange agreement was signed enabling the USN information to be made available to support Summerfield.

3. EARLY DAYS

Table 1 shows that those elements necessary for the production of Extruded Double Base (EDB) (basically a cordite extrusion), plastic propellant (a composition of inorganic oxidisers and an uncured polymeric binder) and early production of ammonium nitrate composites (cast charges only at this time) were available prior to the opening of hostilities in 1939. The war years saw the development of pressed charges of ammonium nitrate and larger diameter EDB capability along with the exploitation of the 2 inch and 3 inch diameter motor for a range of uses. A 5 inch diameter EDB steel cased motor was developed as well as the first of the plastic propellant 5 inch Light Alloy Plastic (LAP).

TABLE 1 - KEY ELEMENT MILESTONES IN PRE-WAR UK ROCKETRY

YEAR	EVENT
1934	Cordite-propelled rocket research begun
1935	Research initiated in plastic propellant
	Catalysis of ammonium nitrate burning
1936	1st launch of 2 inch extruded cordite motor
1937	1st launch of 3 inch extruded cordite motor
1938	Production of plastic propellant begun

Thus, the technology available at the end of World War II was in place to support EDB production of up to 7 1/2 inch diameter charges. Even this size needed 15 inch diameter presses at this time and was dwarfed by a German press used for the same purpose that was 22 1/2 inch diameter. Motor diameters using EDB were not, however, restricted to 7 1/2 inches, because charges could be built up from individual extrusions. In fact, motors of 10 inch diameter were in use in the last year of conflict in a weapon called "Uncle Tom". Typically then, the EDB motors were 2 and 3 inch used in either ground-to-air, ground-to-ground or air-to-ground role, 5 inch used for ground-to-ground and Assisted Take Off (ATO) and 10 inch in an air-to-ground mode. There needed to be a focus to bring all these elements together, and during the late 1940s the priority of air defence was to provide it.

Prior to the first firing, in 1948, of solid motors at Westcott and Summerfield, two more interesting events occurred.

1. The first Case Double Base (CDB) charges were produced at the Royal Arsenal, Woolwich
2. Guanadine nitrate had been developed as a propellant for use in pressed charges by ICI.

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Figure 1 depicts the family tree of the UK surface-to-air missile armoury.

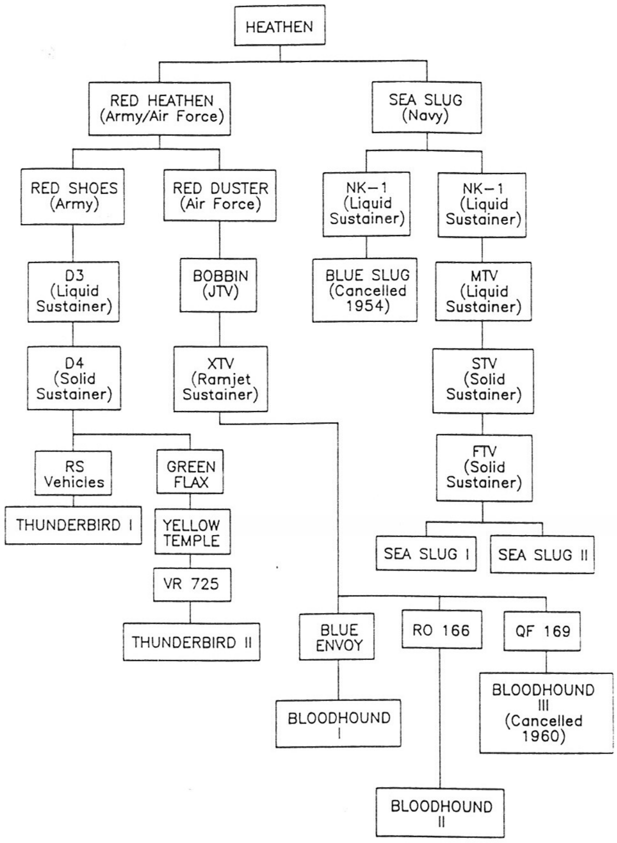

FIGURE 1 - MISSILE FAMILY TREE

The original name "Heathen" was one of four omnibus programme names of the early post-war weapon concepts.

HOWLER	Long range GAP
HEATHEN	Medium range GAP
MENACE	Long range strategic missile
HAMMER	Long range tactical rocket

Howler was not considered worth pursuing as the technology needed was that which had to be ready for the medium range Guided Aerial Projectile (GAP). Menace evolved eventually into Blue Streak, a role which is currently being fulfilled by the UK Polaris. Hammer was a requirement which was satisfied initially by the US Corporal missile, to be followed by two cancelled UK programmes - Black Rock and Blue Water. The current requirement is satisfied by the US Lance missile systems.

Heathen was the focus of early work to produce both booster and sustainer systems to support an effective surface-to-air missile system. Fairly quickly the Royal Navy's requirement evolved so that it became a separate missile system and proceeded under the name Seaslug. This system and its sister Blue Slug (later cancelled), a ship-to-ship system, had a liquid bi-propellant sustainer system NK-1, because of the low energy available from the then available solid propellants. Later Seaslug test vehicles incorporated Summerfield-designed solid propulsion for both the boosters and sustainer.

In 1947, the Projectile Development Establishment, Aberporth (PDE) designed, produced and test fired a case bonded plastic propellant ATO rocket motor. This steel cased motor was 8 inches in diameter, the largest of its type until then.

The joint Army/Air Force requirement under the same Red Heathen was increasingly considered to be of inadequate range by the Air Force. Thus, the programmes again split with the Royal Air Force (RAF) opting for a fixed emplacement ramjet sustain system, Red Duster, which eventually evolved into Bloodhound. Initially, the Westcott Mayfly, and, subsequently, Gosling motors were used as boosters.

For a more mobile system, the Army programme, now named Red Shoes, was following a similar path to that of the Navy in initially using liquid propellant sustainers. The ICI pressed charge solid sustainers took over from these but even they did not have the performance or density impulse required. Red Shoes, through a long series of test vehicles, eventually became Thunderbird and employed Westcott plastic propellant sustainer and booster motors.

The question concerning the derivation of names is of interest. ICI Ardeer began the habit of calling its motors after breeds of dogs very early on and when Summerfield began producing motors, this practise was continued. Only very recently has this practise ceased with other names of various origins, ie, famous battles, etc, now in vogue. Westcott's motors, the story goes, were not initially allowed to continue the Armaments Research and Development Establishment's (ARDE) (now RARDE) practise of naming motors after birds (an early cordite 5 inch motor, for example, being called Stork). But owing to the quiet persistence of an amateur ornithologist, later to become Superintendent of the Solid Propellant Laboratory at Westcott, the practise of using birds' names was accepted. RARDE had, after all, stopped all production of rocket motors by then.

4. MISSILE BOOSTERS

It was in May 1948 that the Guided Weapon (GW) Department of the Royal Aircraft Establishment (RAE) Farnborough issued a firm requirement for the boost rocket motor for Seaslug. This requirement for a total impulse of approximately 20 000 lbfs was influenced, in part, by similar requirements for systems in the USA, particularly as information had reached the UK on "Deacon". This 6.8 inch diameter motor contained a single star centred but externally inhibited cordite propellant charge in a light alloy tube. The UK at that time had not externally inhibited any cordite charges larger than those used in experimental 5 inch steel motor cases.

The effects of hot gases impinging on light alloy cases was well known and the attempt to obtain the required performance ruled out the possibility of using existing case bonded plastic propellant. Thus, a steel case (Figure 2) with an obturated EDB charge of diameter 6.05 inches was produced from the only readily available cordite, SU/K.

This charge diameter was chosen because the overall length of Deacon was excessive for the given requirements, thus forcing the increase in diameter. The EDB was extruded from a 15 inch press which could produce charges up to 70 lbm. In order to produce the required charge mass (100 lb) two 50 lbm charges were "composited", and often an even larger number of smaller charges were used.

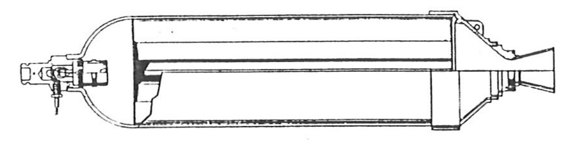

FIGURE 2 - OBTURATED STEEL CASE MOTOR

Ignition on the trials motors was initially achieved by using two standard cartons of a magnesium/potassium nitrate composition. This number was later increased to three in order to reduce ignition delay at low temperatures.

Thirty three firings of this booster were carried out from 1 December 1948 to 1 November 1949, during which time much information was gleaned on inhibition, charge set back on ignition and, later, launch. Experiments on liquid filling of the obturated amulus between the charge and motor case were also carried out.

Approximately six hundred of these boosters had been used in flight trials up to mid 1952 with a reported failure rate from all causes of 2%.

5. MISSILE SUSTAINERS

Prior to the commencement of solid propellant activities at Westcott and Summerfield, the indications from flight trials of the ground-to-air weapon system test vehicle was that solid propellant motors would be preferable to the liquid systems then planned, for safety and logistic reasons, and promised density impulse. The only solid propellant sustainer that promised anywhere near the performance required was Ratcatcher, which first flew in January 1953 in an English Electric D4 (Red Shoes) airframe.

Coincidentally, this shows why the diameter of 17 inches assumed such apparent importance over the years. The D3/D4 airframe was 18 inches in diameter and a motor (solid or liquid) needed to fit inside this diameter. The problems discussed in Section 6, concerning the inability of pressed charges to adequately survive temperature extremes, led eventually to the replacement of Ratcatcher and Elkhound by the Westcott Smoky Joe motor. Increasingly, as with the booster system, greater performance was demanded, generally within the same envelope, from both booster and sustainer systems.

6. PROPELLANT STATUS

Tables 2, 3 and 4 show the then current compositions of the early propellants used by ICI, Summerfield and Westcott. They represented the "state of the art" in the UK in pressed, cast and plastic propellants respectively.

Problems with both the lack of energy content and charge cracking were experienced with the pressed charges of ammonium nitrate/guanodine nitrate. These charges, known as "cheeses" because of their colour and shape, were loose-loaded into motors, as in the sustainer systems Mousetrap and Ratcatcher, and held in place under spring loading. An attempt to modify the charge capability of withstanding wider temperature variations was made using an elastomeric compound (Hycar) incorporated into the propellant. However, even this composition was still low on performance and the Ratcatcher motor was not proceeded with after the D4 programme for Red Shoes.

TABLE 2 - PRESSED CHARGE PROPELLANT COMPOSITIONS

CONSTITUENT	COMPOSITION			
	GD 10	MRC 12	AFW 1	N_4O_3/ N_4O_4
Guanodine Nitrate	86.8 -X	83.8 -Y	-	-
Ammonium Nitrate	12.0	12.0	80.55	76.86
Potassium Nitrate	1.2	1.2	8.95	8.54
2,4:Dinitroresorcinol	X	-	-	-
Ammonium Dichromate	-	3.0	2.0	2.3
Copper Oxide	-	Y	-	–
Superhard Wax		-	8.5	-
Sulphur	-	-	-	0.5
Magnesium Oxide	-	-	-	0.7
Hycar 1411 Solid Rubber	-	-	-	8.6
Hycar 1313 Liquid Rubber	-	-	-	2.5

TABLE 3 - CAST DOUBLE BASE PROPELLANT COMPOSITIONS

CONSTITUENT	COMPOSITION	
	010	AID
Nitrocellulose (cotton 12.6%)	58.3	51.1
Nitroglycerine	23.8	25.4
Triacetin	7.3	7.3
2-Nitro-Diphenylamine	1.7	0.3
Lead Stearate	1.7	2.9
Di Methyl Phthalate	2.3	-
Sucrose Octa-Acetate	0.8	7.9
Potassium Sulphate	2.0	2.0
Polymethyl Methacrylate	2.0	2.0
Carbamite	0.1	1.1
Graphite	0.03	0.03

TABLE 4 - PLASTIC PROPELLANT COMPOSITIONS

CONSTITUENT	COMPOSITION RD XXXX					
	2311	2313	2332	2402	2408	2409
Ammonium Perchlorate	85.5	25.5	26.5	39.0	26.0	66.0
ammonium Picrate	-	60.0	60.0	45.0	60.0	20.0
Lecithin	1.0	1.0	1.0	-	-	-
Oxamide	-	-	-	5.0	-	-
S 101	-	-	-	1.0	1.0	1.0
Polyisobutylene	12.5	12.5	12.5	10.0	12.0	11.0
Titanium Dioxide	1.0	1.0	-	-	1.0	1.0
Copper Chromate	-	-	-	-	-	1.0
Use	[illegible]	[illegible]	Smoky Joe	Smoky Joe	Smoky Joe	[illegible]
With Charge Design	6	94b	6	6	6	6

Initially, the CDB propellants such as OIO used by Summerfield were produced using a stabilised single-base casting powder of 12.6% nitrogen content nitrocellulose. This powder was cast into a cellulose acetate inhibitor of cylindrical shape and 72% nitroglycerine containing both desensitiser and chemical stabiliser was added. This propellant gave a burning rate, at plateau, of 0.3 in/s at 21°C giving a specific impulse of 210 lbfs/lbm at 1 000 psig. This propellant was typical of the restricted range of compositions

available at that time, and was used for the first 16 inch diameter multiconcentric charge weighing some 750 lbm.
As with the pressed charge compositions, the plastic propellants had been relatively well researched by the time Westcott began filling motors with this propellant in 1952. With Crook and Errington joining the work force at Westcott, all plastic propellant motor research and development was concentrated there.
The major innovative factor influencing the performance of the plastic propellants was the widespread use of ammonium perchlorate instead of metallic salts as the oxidiser. Polyisobutylene was and still is the preferred binder and it is this material, an uncured polymer, that gives the plastic propellants a great advantage. If for any reason a charge defect is detected during non-destructive testing, then the charge may be repressed. This is achieved by evacuating the motor which has been warmed to allow the propellant to "flow" on the application of a pressing tool or former giving the required charge geometry. Because of this there is no production loss on motor filling.

7. WESTCOTT - THE BEGINNINGS

Whilst there were many firing sites already available at Westcott for the use of liquid propellant rocket engine testing, by the time the first solid motors were on site and ready for firing no sites were specifically available for them. Thus, 1948 saw the firings of 2 inch EDB and 5 inch LAP motors on a flat bed of concrete with little or no instrumentation. Figure 3 shows the construction of a 5 inch LAP motor.

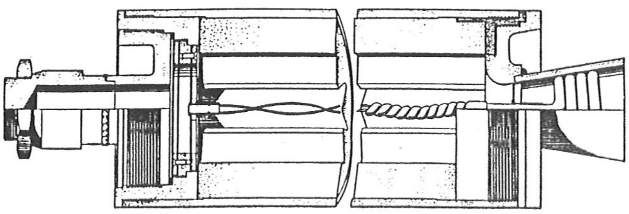

FIGURE 3 - 5inch LAP MOTOR

The successful exploitation of the clear advantage of bonding charges to the motor case, thus eliminating wasted volume within the motor, was uppermost in the minds of the development engineers at this time. EDB suffered from the fact that the difference between the coefficients of expansion of the steel case and the cordite was so high as to quickly create excessive stress in the bond causing cracking. EDB was therefore limited to being used as a loose charge and, as such, was wasteful of the internal volume of the motor.
Depending on the required charge design and thus burning surface area, it sometimes needed an obturator to prevent the flow of gases between the outside of the charge and motor case. The 5 inch LAP promised a high volumetric efficiency and has been in development over many years. It is still used today as boost units as sled track work. Table 5 lists some of the many projects that employed 5 inch LAP for flight propulsion

TABLE 5 - FLIGHT VEHICLE USE OF 5 inch LAP MOTORS

FLIGHT VEHICLE	NATIONALITY	PURPOSE	PURPOSE	MOTOR UNITS No OFF	NOTES
Aeolus	Aust	S	B	7	7 fired, Mayfly U/Stage
BTV	UK	T	B	2 or 3	Bomb Test Vehicle (Blue Boar)
Bronco Bill	UK	T	B	1	Delta Wing Dynamic Stability Trials
Blue Sky	UK	D	B	2	Became Fireflash
CTV 1	UK	T	B	1 or 3	Trials Vehicle for Red
CTV 2a	UK	T	B	1	Hawk dart
DTV	UK	T	B	7	Doppler Test Vehicle (RTV 1 Programme)
Fairey VTO	UK	T	B	2	HALA Programme
Fireflash	UK	W	B	2	Cancelled in favour of Firestreak
RTV 1	UK	T	B	7	Stop-gap Booster
Spinning Jenny	UK	T	B		Roll-damping Trials
STV 1	UK	T	B	4	Separation Test Vehicle (Fairey)
Squid	UK	T	B	2	
TVT	UK	T	B		Thrush Test Vehicle
HAD	Aust	S	2nd	1	High Altitude Density (119 fired)
HAT	Aust	S	2nd	1	High Altitude Temperature (54 fired)
Petrel/Thrush	UK	S	3nd	1	Bristol Aerojet Vehicle

KEY

Aust	Australia
S	Sounder
T	Test Vehicle
D	Development
W	Weapon
B	Booster
2nd, 3rd	Stage

With the increasing demands of higher speeds for separation and take-over of the sustainer system the current 5 inch LAP boosters were inadequate in performance terms: at this time each motor had a total impulse of 8 350 lbfs. Even duplex (twin) sets of four wrapped round the sustainer proved to be inadequate, and, for trials purposes only, the expedient of triplex (three) sets were used. Thus, at launch up to twelve 5 inch motors were often ignited together with the sustainer system on the launching pad. These systems became standard on both the D3/D4 (Red Shoes) and early liduid Seaslug trials vehicles before the advent of larger diameter and higher performance booster motors.
The first guided weapon boost motor to be designed and developed at Westcott was the Mayfly 1, and it was intended for use with the seaslug missile. During the development of this missile it became obvious that a boost motor of far higher performance than the initial 40 000 lbfs impulse would be required. Thus, almost immediately a demand for more impulse along with a shorter burning time was stated. This increase in motor performance necessitated a complementary increase in propellant performance;

specifically a higher burning rate. Many problems were encountered in attempting to satisfy this new requirement from the EDB propellant, specifically concerning attempts to use precise pressure/burning rate characteristics in unplatonised cordite. Figure 4 illustrates the steel-tubed Mayfly motor which contained 121 kg of DU cordite in an obdurated star-centred charge design (CD 15). Mayfly 1 was, when fully developed by 1956, able to provide a total impulse of 55 000 lbfs, some 37% above the original requirement.

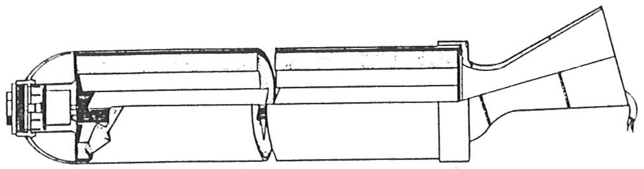

FIGURE 4 - MAYFLY 1 MOTOR

Table 6 gives typical data for the range of early Westcott motors used in projecting ground-to-ait weapon test vehicles. As can be seen they display a considerable increase over the original performance requirements.

TABLE 6 - EARLY WESTCOTT BOOSTER MOTOR PERFORMANCE

MOTOR	MOTOR DIA (in)	No OF BOOSTERS PER MISSILE SET	TOTAL IMPULSE PER SEC (lbfs)
Stork	5	4	24 800
		8	49 600
		12	74 400
Mayfly i	7.5	4	160 000
Demon	7.5	8	180 000
Mayfly III	7.5	4	208 000
Mayfly IV	7.5	4	236 000
Gosling I	10	4	250 000
Gosling II	10	4	348 000

Westcott continued developing boosters for Thunderbird and Bloodhound systems through the development of a number of Gosling types. This motor also provided propulsion for an enormous variety of test vehicles (Table 7).

Of the sustainer systems Smoky Joe, so-called because of its sooty exhaust, took over from the ICI Ardeer's motors Ratcatcher and Elkhound to provide propulsion for Thunderbird. Albatross, an upgraded Smoky Joe design, was used along with Summerfield's Wolfhound to provide sustainer propulsion on programmes leading to VR 725. The capability of producing and testing large high performance motors naturally allowed Westcott to offer propulsion for supersonic and hypersonic test vehicles proposed at that time by RAE Supersonics Department.

TABLE 7 - GOSLING-POWERED VEHICLES

VEHICLE NAME	PURPOSE	HISTORY/DETAILS
Aoleus	S	7 fired
Aero High	S	
Badger	T	Heat transfer on caret wing
Bloodhound 1	W	Saw RAF service
Bloodhound 2	W	Saw RAF service (also S'pore & Sw'land)
Bloodhound 3	T	Cancelled
Bobbin	T	Recovering ramjet vehicle
Cuckatoo	S	Falling sphere tests
CQ 941	T	Subsonic stability
FTV 941	T	Flight (Foxhound) test vehicle
Green Flax	T	Red Shoes development
GTV	T	Gosling test vehicle
HAD	S	High altitude density
Jabiru I	T	Heat transfer & mat'ls survivability and
Jabiru II	T	supersonic stability
Leo	T	Drag & stability of slender wing/body
Leopard	T	
Long Tom	S	1 off
Lynx I	T	
Meadowlark	S	
NK 1	T	Nitric/Kerosene sustainer
Orion	T	Dynamic stability on highly swept wings
Panther	T	Heat transfer & flow tests
Perseus	T	
Ranger	T	Various uses
RS	T	Many 17in S/P sustainers employed
Sea Slug I	W	Saw RN service
Sea Slug II	W	Saw RN service (still with Chilean Navy)
Shark	T	Base pressure measurements
Skylark 10	S	Not flown
STV 1	T	
Thunderbird 1	W	Saw BAOR service
Thunderbird 2	W	Saw BAOR service
Tiger III	T	Heat transfer on a conical body
Titania	T	Dynamic stability on model of BAC 221
Viking	T	Dynamic stability ob delta wing
VR 725	T	Wolfhound also used as a sustainer
XTV	T	Red Duster sub & full scale trials

8. SUMMERFIELD - THE BEGINNINGS

Although small experimental motors, 5 inch diameter ATO rockets, were fired at Summerfield in early July 1952, the firing sites available at that time were unable to cope with the larger motors. Thus, the first 16 inch diameter booster, Bullpup (Figure 5) and 15 inch diameter sustainer, Foxhound (Figure 6) were taken to Westcott for firing. Foxhound was the first of these motors to be designed and developed at Summerfield, in response to the requirement for a solid propellant version of the Seaslug missile system. Table 8 lists the various sustainer motors identifying the motor design authority and the dates of their first firing and use.

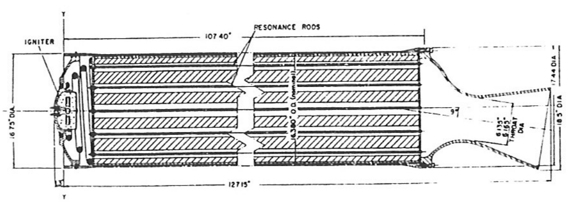

FIGURE 5 - BULLDOG 16 inch BOOST MOTOR

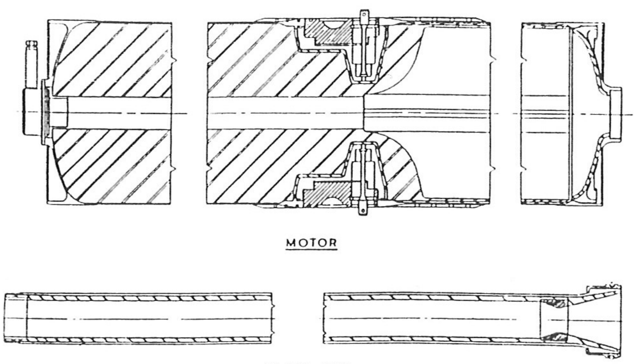

FIGURE 6 - FOXHOUND 15 inch SUSTAIN MOTOR

TABLE 8 - 17 inch SUSTAINER MOTORS

MOTOR	SITE	1st STATIC FIRING	USES
Ratcatcher	Ardeer	July 1952	Red Shoes
Smoky Joe	Westcott	Mar 1953	Red Shoes, Thunderbird
Foxhound	Summ'd	June 1953	Seaslug
Elkhound	Ardeer	Sept 1953	D4
Wolfhound	Summ'd	Feb 1957	Yellow Temple, Green Flax, VR 725
Greyhound	Summ'd	Dec 1959	
Deerhound	Summ'd	Jan 1961	Seaslug
Albatross	Westcott	Mah 1961	Yellow Temple, Green Flax, VR 725

As stated above the first booster produced at Summerfield was a 16 inch diameter motor called Bulldog. Based on the design of the Terrier motor, it was so powerful that it could not be tested at Summerfield as the ranges were not yet ready. Tests at Westcott confirmed a total impulse of 140 300 lbfs from a 750 lbm charge. This booster was flown successfully many times in the Red Shoes D6 missile, although it was originally intended to boost the Red Duster (ramjet sustain) missile in tandem fashion. All the programmes originating from Heathen employed wrap-around boosters in order to reduce overall length. Booster development continued and the final motgor design incorporated in Seaslug II was Summerfield's Retriever.

Foxhound was the first Summerfield sustainer motor which was statically fired on 10th June 1953, giving a total impulse of some 142 500 lbfs. This motor was the first of a series of designs which went on to power Seaslug in the sustainer mode. Summerfield's research and development activities produced many motor designs, but like Westcott, looking back they appeared to have most successful in particular areas. Seaslug was an obvious example, and this success continued into the provision of anti-tank weapon propulsion, where expertise in thrust vector control was essential.

The evolution of propellant technology into low smoke emission has allowed good penetration of markets where optical sighting is essential, such as Rapier, Blowpipe and other portable ground-to-air systems.

9. SOUNDING ROCKET & TEST VEHICLE PROPULSION

In August 1953, an Anglo-American conference was held at Oxford, under the auspices of the Gassiot Committee of the Royal Society, on the topic of the use of rockets for upper atmosphere research. The altitude of particular interest was given as between 100 000 and 200 000 ft and questions were asked by the committee if any rocket motors now in production for guided weapons use could fulfil the requirement. A study at RAE suggested the use of a Mayfly boost motor on a Smoky Joe sustainer to project payloads of around 50 lb close to the altitudes required. Calculations showed that both systems although non-optional for this use achieved altitudes between 90 000 and 100 000 ft for this mission. The study report (Ref 1) suggested that achieving low apogee was directly a consequence of the different design aims for the motors concerned and that a suitably designed motor would probably achieve much greater performance. Thus began Raven, the largest of the 17 inch motor designs.

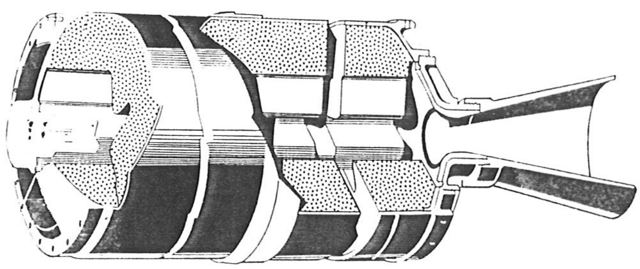

FIGURE 7 - RAVEN MOTOR

The Raven motor (Figure 7) was essentially three Smoky Joe tubes welded together, and contained 1 tonne of plastic propellant. This motor could power a vehicle which would send 100-150 lbm to an apogee of 100 miles. First static firings of Raven occurred in August 1956 followed in February 1957 by a successful first flight from Woomera, Australia. To date, 418 Ravens, of various types (see Table 9), have been launched, all but one being used as the main propulsion unit of the BAe Skylark sounding rocket. Motor flight reliability is 96% from all causes.

TABLE 9 - RAVEN PERFORMANCE DATA

MARK	MOTOR MASS (kg)	PROP. MASS (kg)	BURNING TIME (s)	TOTAL IMPULSE (kNs/kg)
I	1120	900	30	1601
II	1010	840	30	1535
V	1125	950	42	1748
VA	1175	980	27.5	1877
VI	1150	975	30	1820
VIIA	1010	840	30	1535
VIIIA	1010	840	30	1510
X	1200	1020	16.8	2190
XI	1200	1020	30	2220

Following on from the initial flight trials of the Raven in the Configuration Test Vehicle (CTV), later to become "Skylark", a requirement was for a booster to enable higher performance in terms of payload to altitude. A critical parameter in determining the length of booster motor was the overall length of Skylark vehicle, which could fit reasonably in the launcher at Woomera. This gave a parallel length of motor tube of 29 inches and the motor known as Cuckoo was born. Basically, Cuckoo was a half length Smoky Joe tube, the blast pipe replaced by a simple convergent/divergent nozzle containing 180 kg of plastic propellant. Cuckoo was further developed for use, as Marks IB and II, atop the liquid Black Knight booster, in a re-entry physics programme called Dazzle. In this programme, Cuckoo was lofted many hundreds of miles into space to ignite just before re-entry to boost the re-entry speed of the test article. Cuckoo III and IV were continued developments for use as the third stage of the Skylark sounding rocket, which by now was being produced under the auspices of British Aerospace. To date, a total of 259 Cuckoo motors have been used in flight vehicles with a 100% success record. An even later version of Cuckoo was used as primary propulsion for an underwater test vehicle - a truly remarkable motor.

The next motor to be incorporated into the Sounding Rocket programme was Goldfinch. The Mark I version began life as a booster for a UK Anti-Ballistic Missile programme called Sprint. Sprint was cancelled long before the US system of the same name appeared. This motor contains 330 kg of plastic propellant in a similar motor tube to Smoky Joe. Goldfinch II was a derivative of the Mark I, and fitted beneath a Raven comprised the Skylark 7 sounding rocket system. The addition of Cuckoo IV to the top of the Skylark 7 is called Skylark 12. Currently, 133 Goldfinches have flown in many programmes with a 100% success record.

The last member of the 17 inch Test Vehicle/Sounding Rocket family is called Rook. This motor has the same case as Raven but the propellant mass is reduced to 880 kg and burning time is between 4-5 seconds. Obviously, the nozzle associated with such a performance is larger than that for the Raven motor. Rook has served the RAE Supersonics Department extremely well in providing booster systems either alone or in conjunction with upper stages in Hypersonic Test Vehicles. 75 Rook motors of all marks have flown with a 100% success record.

10. OTHER FIRSTS

In terms of propellants, the CDB variety has come an enormous distance from the original OIO, which used a single base casting powder. This propellant gave a standard specific impulse of 190-210 lbfs/lbm and was developed over the years to give 245-260 lbfs/lbm. Using a double base NG/NC casting powder, following traditional UK small arms and ordnance practise, a standard specific impulse of 225-235 lbfs/lbm was obtained. The addition of fine aluminium powder with a suitable oxidiser, ammonium perchlorate, to give a Composite Modified Cast Double Base (CM CDB) increased the equivalent performance level to 240-245 lbfs/lbm. To increase the performance still further, the addition of energetic compounds such as nitramines (RDX and HMX) into the double base casting powder matrix was undertaken. This increased the performance to 245-255 lbfs/lbm under standard conditions. In addition, an enormous amount of work was also carried out in the areas of flash and afterburning suppression along with formulations yielding low smoke in the exhaust.

When a requirement was set for the design and development of a solid propellant third stage for the small orbiter Black Arrow, both Westcott and Summerfield produced designs based on thair respective technologies. In the event, the Westcott motor, Waxwing, was selected and an extensive programme of clearance bagun. This programme involved the first use of a jet pump system, in a test cell at RAE Pyestock, to allow firing of the motor under low pressure conditions, and also while spinning. Waxwing (Figure 7) was a spherical motor, 28 inches in diameter, containing 318 kg of propellant which burnt for 55 s. On both flights of Black Arrow the Waxwing performed perfectly, although on flight R2 the second stage (Liquid) underperformance did not allow orbit to be achieved. Flight R3, in October 1971, was successful in placing the UK satellite Prospero into orbit. Both satellite and Waxwing are still there.

In a programme called Dazzle (referred to in Section 9) Cuckoo IB, and later CuckooII motors were lofted to miles above the earth and ignited on re-entry. This was the first time the UK required ignition in space, and the motors were cleared for ignition under evacuated conduit conditions, allowing ignition even when the motor seals had broken.

The largest solid propellant motor produced in the UK in terms of propellant mass was Westcott's Plastic propellant Stonechat, a 36 inch diameter motor. This motor first fired statically at Westcott on 5th May 1961, and first flew From Woomera as the Mark I on 1st October 1969. Later the Mark II, with 4 350 kg of propellant, flew seven times between 9th May 1975 and 4th April 1979 in support of the Falstaff programme (Figure 10). In terms of diameter, an experimental plastic propellant motor of 54 inhch diameter was test fired at Westcott on 11th June 1965. The design was not proceeded with.

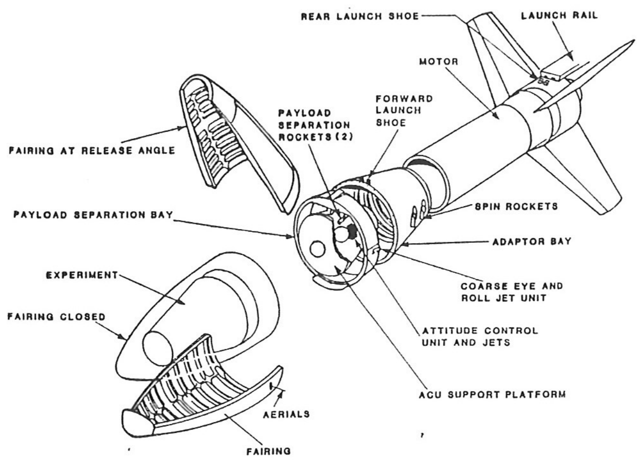

FIGURE 10 - STONECHAT MOTOR

CONCLUSIONS

Whilst the foundations of adequate propellant performances were available prior to the formation of the Solid Propellant Facilities at Summerfield and Westcott, there is no doubt that within their own remits, the two Sites of Rocket Motors Division have carried out an anormous amount of work in exploiting to the full that nascent potential. The major focus for the research and development programmes was to satisfy the requirements for weapons of air defence in the ground to air mode.

Development of these motors enabled either directly or indirectly, the ability of Rocket Motors Division to satisfy a far broader spectrum of requirements ranging from outer space to under water.

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