WASC 2273
WA1 621

Gunpowder and early Propellants

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By

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Presented at

RAF Cosford

5 November 2011

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I will talk at first about gunpowder manufacture and in particular to that at the Royal Gunpowder Mills at Waltham Abbey.

Recipes for gunpowder were discovered in China during the 9th century possibly in the quest to turn base metal into gold. The original use was in fireworks to ward off evil spirits in religious ceremonies.

The discovery of its explosive properties led to the development of gunpowder for simple bombs and grenades thrown by large catapults. About 1230 its propellant properties were utilised in large diameter bamboo tubes packed with gunpowder. By 1290 a metal barrelled cannon had been developed.

The use of gunpowder spread through the Arab lands probably along the spice route to Europe and finally England where the name of Roger Bacon a 13th century Franciscan monk is linked to the discovery of gunpowder in this country. (Fig 0)

He probably learnt of its existence from an Arab trader but he experimented by varying the proportions of its ingredients and noting the effects on its explosive properties.

He was the first to make reference to the type of charcoal required and recommended the use of young hazel twigs for the charcoal. Although fascinated by gunpowder Bacon realised the deadly implications of the material and wrote down the formulation in a cipher in 1267. This was not published because of objections from his abbot and was not finally decoded until 1904. You will note a connection with monks and Waltham

By 1326 the discovery of the cannon had spread to Europe and a manuscript of that date shows an illustration of a vase shaped cannon with an arrow shaped projectile. (Fig 1)

The first record of gunpowder being used by English troops was in 1346 at the battle of Crecy. (Fig 2)

Legend has it that the gunpowder came from Waltham Abbey where it was made by monks. You have to remember at this time Waltham Abbey was one of the biggest monasteries in England and the burial place of King Harold.

Legend also has it that Guy Fawkes and his conspirators purchased their gunpowder from WA and they were certainly in the area a few days before but there is no documentary evidence to support this. As I understand it his gunpowder was damp so that suggests it may have come from over the channel.

What does exist is a receipt for the gunpowder by the keeper of the Tower of London for the unused gunpowder. The civil service always keeps records of everything.

Having said that about the source of Guy Fawkes powder, there is a letter in the State Papers on behalf of Queen Elizabeth 1st to a John Thomsworth of Waltham for the purchase of saltpetre, sulphur and bowstaves for barrels dated 1561 so someone was making it near Waltham well before Guy Fawkes time.

The first definitive reference to the milling of gunpowder at Waltham is contained in Dr Thomas Fullers " History of the Worthies of England" published in 1662.

He was curate at Waltham Abbey Church and wrote that "there is more gunpowder made by mills of late erected on the river Ley betwixt Waltham and London than in all England besides".

He went on to write " it is questionable whether the making of gunpowder be more profitable or more dangerous, the mills in my parish have been 5 times blown up within 7 years but blessed be to God without loss of life".

Unfortunately it was not long after this that the first deaths were recorded in the parish register of burials for October 1665. (Fig 3)

The first title deed to the site at Waltham we have on record is dated 1669 to one Samuel Hudson. Apparently the mills were a bit of a nuisance and Hudson was fined £10 for interfering with the local water supplies.

The mills then passed into the hands of the Walton family and were described as the largest and most completest works in England. An illustration of the site survives and several buildings and features can be identified today.

At this time Stamp Mills were used to grind the powders using cam operated hammers. This was dangerous and noisy so the Waltons engaged the engineer John Smeaton to redesign the mills. He introduced Edge Runner mills as shown in the drawing of 1771. These were originally water powered and mills of almost identical design remained in service until 1940. (Fig 4)

At a time of deteriorating international relations (French again) in the second half of the 18th century the government wanted to control the supply of gunpowder and purchased the Faversham mills in Kent in 1759. In 1783 private industry leaned on the Prime Minister Sir William Pitt to sell the mills at Faversham but Sir William Congreve 1st who was deputy Controller of the Royal Laboratories at Woolwich stated that the mills now under his control made better powder more cheaply. As a result Faversham was kept in Government hands and Waltham Abbey mills were purchased in 1787.

Congreve concentrated on understanding the processes and making sure that the ingredients were pure and consistent. This was particularly so for the charcoal which up to this time had been made in open pits. Congreve introduced iron retorts for making the charcoal.

Congreve demonstrated the superiority of his powders with a shoot off in 1810. (Fig 5)

The formulation of gunpowder is given in the next slide. (Fig 6)

Congreve and Smeaton together were undoubtedly the most important figures in making British gunpowder of the highest quality.

Congreve was followed by his son , also called William who was not only deputy Controller but also an entrepreneur perhaps even a bit of a sharp operator He is credited with inventing the Congreve rocket (Fig 7) which I believe you will hear more of this afternoon.

Congreve probably got the design from Indian war rockets and developed these into an iron tube filled with a pressed gunpowder charge of low sulphur content. The original rocket had an offset wooden rod for stability. He proceeded to set up his own factory to make these rockets and may not even have got his gunpowder from government sources.

They were not particularly effective at first but although they may not have killed many of the enemy they certainly frightened the horses.

Congreves rockets were followed by a design by William Hale. These were much more like modern rockets in that the wooden rod had been disposed of and replaced with a tail containing 3 vents which caused the rocket to spin.

After the withdrawal of the Congreve and Hale rockets at the end of the 19th century little interest was shown in rocketry. The Army and Navy had their big guns and the Air Force was in its infancy.

However in 1935 rockets were again perceived as a possible weapon and a requirement was drawn up based on the performance of a 2" anti aircraft shell –i.e. to reach 10,000 feet, later the height required was increased to 15,000 feet.

No experience was available but from ballistic calculations it was believed this could be achieved with a simple tubular cordite charge with a burn time of 1-2 seconds thus avoiding the need for inhibition although work was put in hand to develop inhibitors. Cordite was readily available having been developed by 1890 replacing gunpowder as a propellant in guns.

Problems were found with thin steel tubing not being sufficiently straight so in 1937 a carbon steel tube was adopted. Work concentrated on 3" anti aircraft rockets but was cancelled by the general Staff in 1939 due to dispersion problems and not being seen as a priority.

After September 1939, the Admiralty wanted an aerial parachute mine system and shortened 3" rockets were used to send these up. During 1940/1941 2" and 3" anti aircraft rockets were rapidly developed and launched from a simple tube to provide an aerial barrage and these were moderately successful. 5" rockets were also produced using an 11 stick design.

The 2"cordite charges were extruded with a star shaped conduit and used uncoated . The charges were supported by an iron grid at the nozzle end and held off the tube with stuck on pads. The tube itself was insulated with a slurry of alumina in sodium silicate solution. The general arrangement of the 2" rocket is shown on the next slide. (Fig 8)

You will note that it is not very different to 2" rockets produced years later other than by now the cordite was inhibited with Ethyl cellulose. (Fig 9)

The pressure –time curves for the different conduit shapes had been established in the mid 30s by Dr H J Poole. However, you will note that most cordite charges produced at this time were not for rockets. (Fig 10)

Development work continued at Aberporth on dispersion problems and the designs of tails. Work on alternative propellants continued at RARDE and Runnicles published some work where he tried NC/triacetin, blown caster oil and Rapeseed oil as binders. (Plastic Props Interim report Dec 1942)

In August 1944 a report by Runnicles (RARDE 627/44A) published compositions of two types of plastic propellant. (Fig 11)

In 1945 there was a note in the Ministry of Supply files concerning the supply of DEGN (diethyleneglycol dinitrate) Apparently we had only small amounts in this country but there was plenty in Germany. It was noted that the Waltham Abbey plant would be on stream by September.

The first reference I can find to the use of these newer propellants is in a PDE Aberforth report in 1946 to a 5" light alloy plastic rocket (LAP) with two types of propellant, a high energy propellant RD2633 and a lower energy propellant RD2049 The anodised aluminium tube was coated with Alvar laqueur before filling. Filling itself was by displacement casting using a shaped former.

This report notes two types of failure:

1 Loss of adhesion of the propellant to the wall resulting in a pressure burst.
2 failure late in burning due to the aluminium losing strength.

In 1947 the OB requirement for the development of light alloy RP motor was cancelled noting that the problems of high-energy propellant on storage were formidable and low energy only would be allowed. It noted that if the 5" motor was urgently required a wrapped cordite charge should be used.

However Runnicles further developed the lower energy propellants and these were known as Dispolene propellants. Typical formulations are shown in Table 2. (Fig 12)

Some 200 light alloy motors were filled between 1947 and 1949 using 2043 or 2049 but there were failures particularly below -5°C.

Cordite was available during this period but on one file I noted that there were no large presses as yet installed to make large charges except for the Navy Formulations such as SU and SUK had already been developed (Table 3). (Fig 13)

Work on rocket motors up to this stage was pretty fragmented and most effort was on liquid motors following the end of the war and the German expertise in the V2.

Solid motor work was split between RARDE, RAE, Aberforth and Woolwich. However this was to change with the setting up of CRDE later ERDE in 1945 and Westcott under the Ministry of Supply in 1946. Just to show you how primitive the UK rocket work was I have an illustration of the first proof stand moved from Aberporth to Westcott in 1947. (Fig 14) The first proof stand at WA was built in 1947/48.

In 1949 there was still problems with RD2049 and they were using recovered picrite. By 1950 however both RD 2043 and 2049 had been reformulated for the LAP motor with ammonium perchlorate instead of sodium nitrate.

In 1951 a specification was issued RD 2122 showing these type of propellants were still in use and an RAE report RPD 38 showed again that a LAP motor failed at –5ºC.

((poly meth+ polystyrene 11, Lecithin + TiO2 1, Ammonium picrate 52.9, Ammonium perchlorate 34.9))

This range was given up in 1952

Work must have been started at ERDE at about this time on using poly isobutene as a binder because in 1955 the first specifications for a range of plastic propellants based on PiB was issued (ERDE XR/450/69 1955) See also ERDE 22/R/54.

In the next slide I have just shown a few of the compositions listed Table 4. (Fig 15)

It was noted that the supply of PiB (Oppanol) was limited but it was becoming more readily available from both the USA and Germany and that the existing machinery for grinding ammonium perchlorate was unsatisfactory.

It was noted that 200 2″ motors presumably k-rounds had been fired and a few 5″ fired at RPD Westcott with burning rates form 0.3 to 0.8 inches/sec but the compositions were not fully tested.

At the same time as this was going on ICI were developing a range of pressed charged for Ratcatcher and Red Shoes. Table 5 (Fig 16)

Several 17 inch motors were filled and fired but the storage characteristics of the propellant at high temperatures was not good.

After 1955 things moved on quickly and as you know PiB based plastic propellant proved very successful in a range of motors particularly the **Raven/Skylark** project of which over 400 were made.

Did you know that the cost of a Raven/Skylark complete but without instrumentation was £4600 in 1958?

Unfortunately development and production of solid rocket motors was not as centralised as it should have been and it remained a dogs dinner with many organisations involved (Fig 17). Without strong leadership and political backing this has ultimately led to the virtual disappearance of the rocket motor industry in the UK.

Table 1

High energy plastic

NC	2.6	1.7	1.6
DEGN	12.4		
NG		11.6	10.9
Dbphthalate		1.9	
Dinitrotoluene			2.7
Carbamite	1.0	0.8	0.8

Ammonium Picrate 42-70
Sodium Nitrate 42-14
Rate of burning 0.4-0.8 inch/sec @1000 psi

Low energy plastic

Polystyrene	3	3
polymeths	7	
Dbphthalate	-	7

Polymeths is a solution of polystyrene in poly-α methyl styrene 30/70

Ammonium Picrate 42-70
Sodium Nitrate 45-70
Rate of burning 0.2-0.45 inch/sec@ 1000 psi

Table 2 Dispolene propellants

Type	Sod Nitrate	Amm Picrate	Binder	Lecithin	Burn rate″/s@1000psi
RD2030	44.5	44.5	10	1	0.41
RD2043	34	55	10	1	0.27
RD2049	54	35	10	1	0.38

The binder was polymeths a solution of polystyrene in poly-α methyl styrene in the ratio 30:70

Table 3 Typical cordite compositions

Type	NC12.2%	GN	NG	DNT	Carb	Kcry	Wax
SU	49.5	-	41.5	-	9	-	0.075
SUK	49.5	-	41.5	-	9	2,25	0.075
RS	56.5	-	28	11	4.5	-	0.075
F478/131	15	40	43	**	2	-	0.075

** contains graphite 2 parts

Table 4 Provisional Specification for Plastic Propellant based on PiB

Spec	Amm Perchlorate	Amm Picrate	TiO2	Lecithin	Burn "/sec@1000psi
RD2301	47.5	38	1	1	0.28
RD2304	70.5	15	1	1	0.65
RD2307	65.5	20	1	1	0.55
RD 2311	85.5	-	1 Cr2O3	1	0.98
RD2332	26.5	60	-	1	0.09

Table 5 Pressable compositions developed by ICI

	Ratcatcher	Red Shoes
Guanidine nitrate	83.8	62
Ammonium Nitrate	12	32.5
Potassium Nitrate	1.2	3.5
Ammonium Dichromate	3	2
Cupric Oxide	1	Clay 1

List of figures

References form National Archives

AVIA 41 TRs issued by PDE Aberforth
1925-1949   401 issued

AVIA 68 RPE reports
1958-1976   126 issued

AVIA48 Ministry of supply and Min of aviation
1925-1950+ 138 issued

AVIA 37 CRDD and ERDE reports
1925-1949   147 issued
1959--   1293 issued

Worth looking at
41 series
41/24 charge shapes for plastic propellant
41/324 plastic propellant with light alloy motor
41/307 history of the development of british rockets
41/315 german rocket props and SU composition
41/398 Charge storage of SU and SUK propellant
41/111 alternative propellants monthly report 1942

22series
22/1857   propellants for rockets 1943-48

48 series
48/78 5" boost motors 1949-58
48/79 plasic propellant development 1950-1958

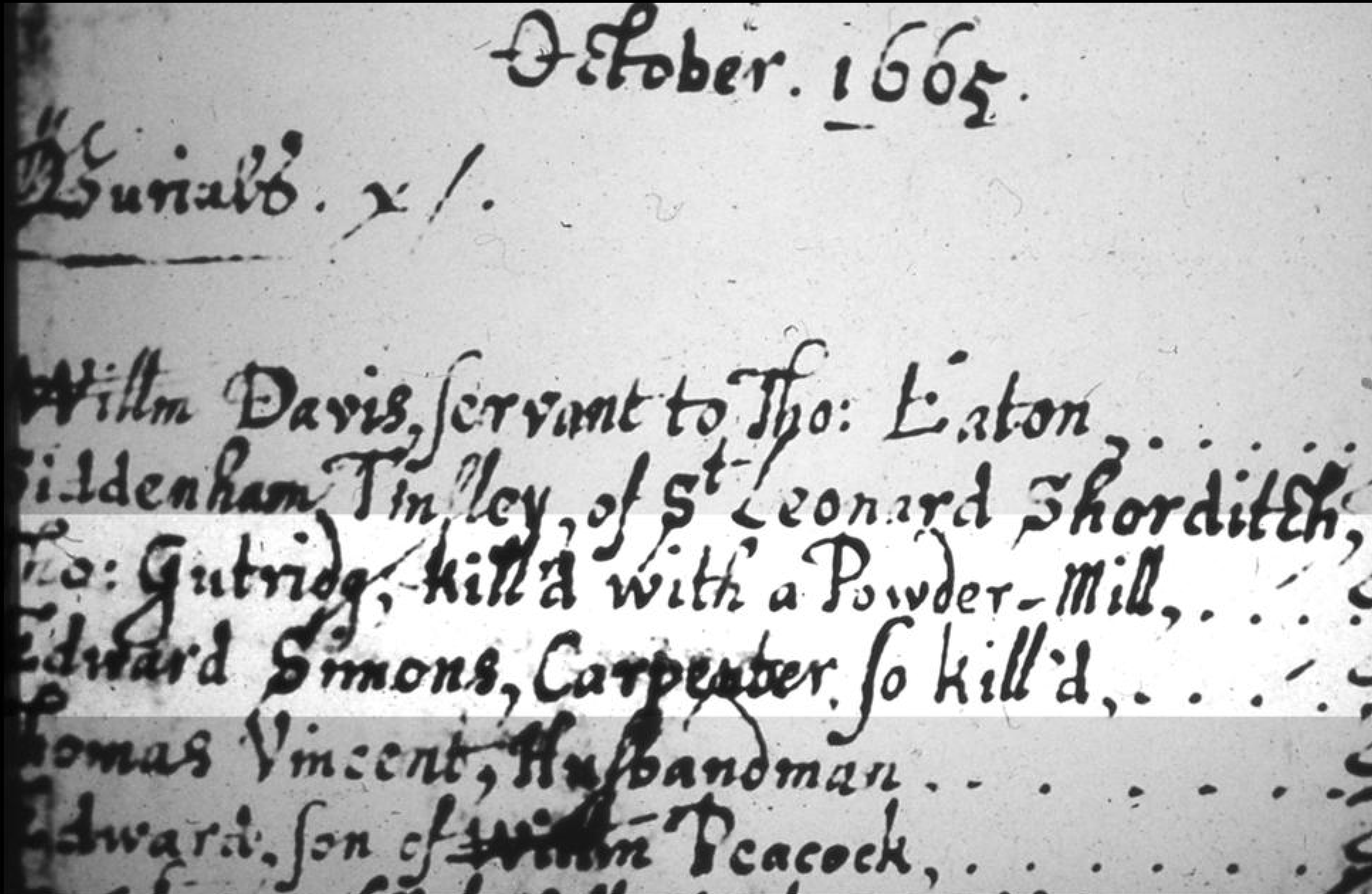
37 series
37/58 commercial silicones as binders
37/607 plastic propallant improvements 1953-1956 ERDE 3/R/57
37/652 slow burning propellants 1959
37/456 plastic propellants based on amm nitrate
37/294 Composite propellants progress to 1954 ERDE 31/M/54
37/243 Plastic propellants present stage ERDE 5/M 51
37/155 Review of plastic propellant 1952-1954

Roger Bacon 13th century Franciscan monk

First illustration of early cannon 1326


1346
Crecy Bombard

Parish Record



October. 1665.

Burials. x /.

Willm Davis, servant to Tho: Eaton

ildenham Tinsley, of St Leonard Shorditch,

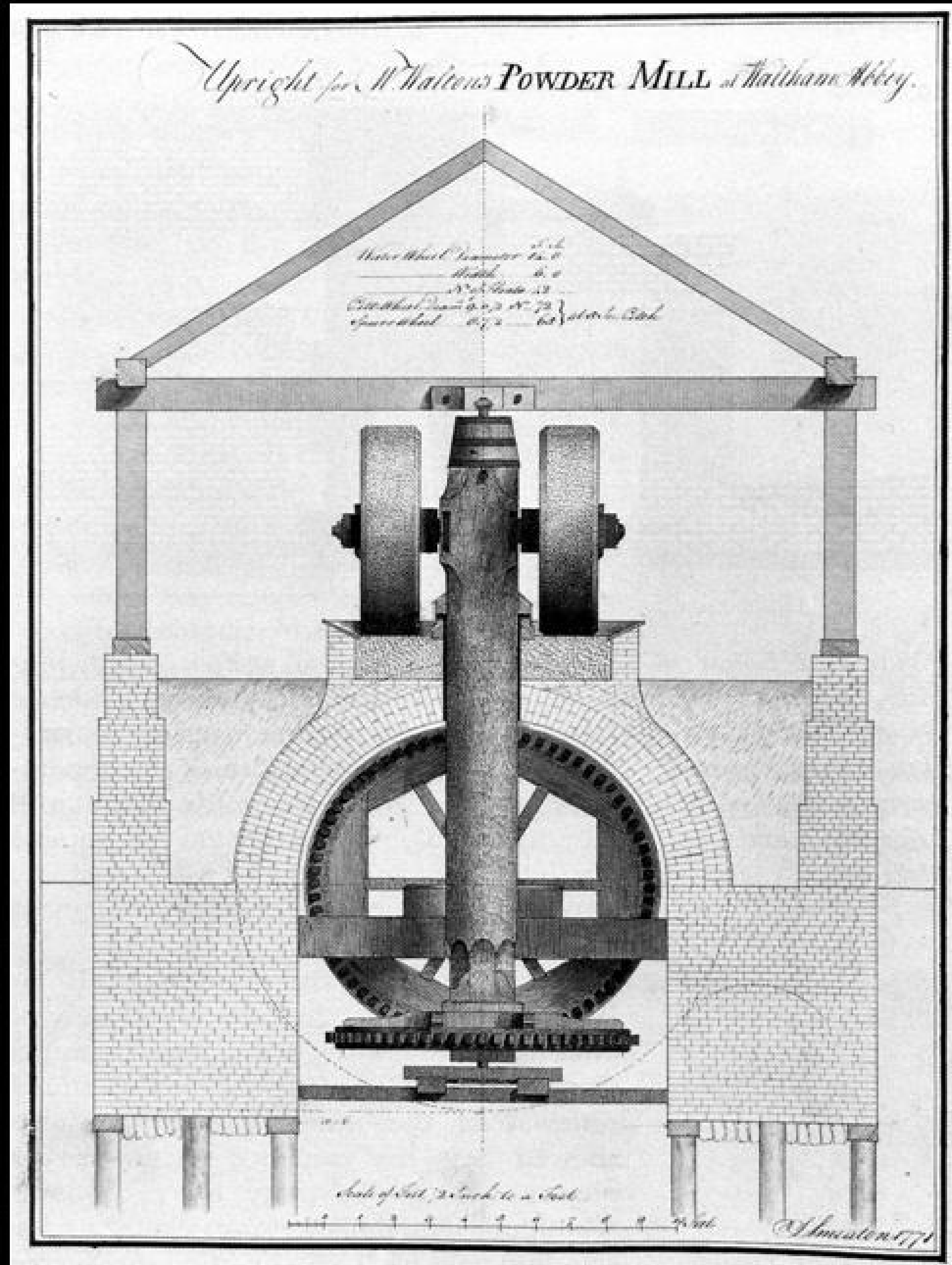
o: Gutridg, kill'd with a Powder-Mill, . . .

dward Simons, Carpenter, so kill'd, . . .

homas Vincent, Husbandman . . . . . .

dward, son of Willm Peacock, ...

Smeaton's design

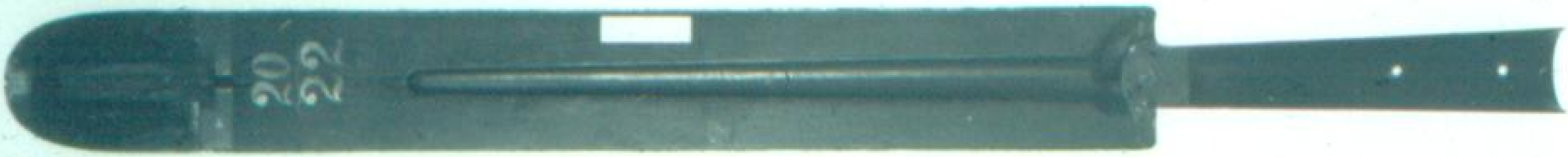



GUNPOWDER PERFORMANCE TRIALS
MARLBOROUGH DOWNS 1809/10
(RANGE IN YARDS - 10"SHELL, 9 LBS GUNPOWDER)
KING'S MILLS
ROYAL GUNPOWDER FACTORY, WALTHAM ABBEY (4430)
ROYAL POWDER MILL, FAVERSHAM (4360)
CONTRACTORS' GUNPOWDER
PIGOU (4270)
BUTTS (4187)
W. TAYLOR (3922)
BRIDGES (3898)
TAYLOR & Co (3861)
KITCHENER (3801)

GUNPOWDER

POTASSIUM NITRATE	75%
CHARCOAL	15%
SULPHUR	10%

24-Pounder Rocket



12-Pounder Rocket

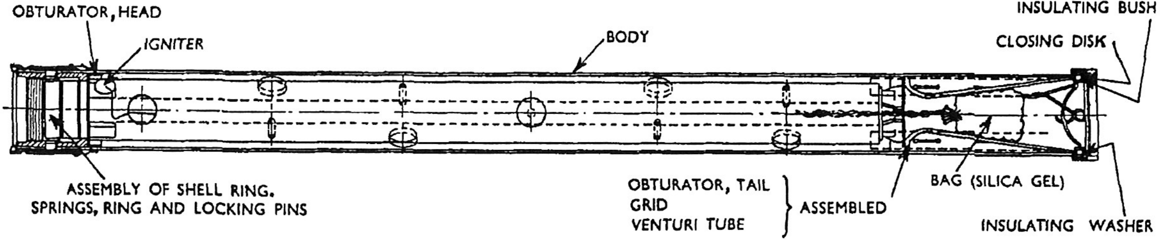
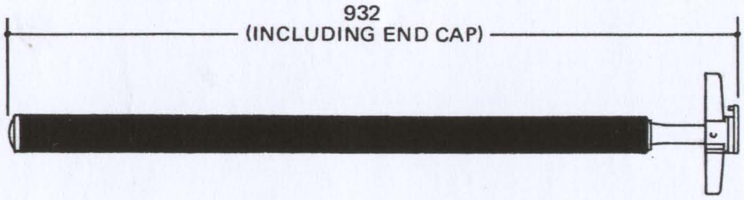
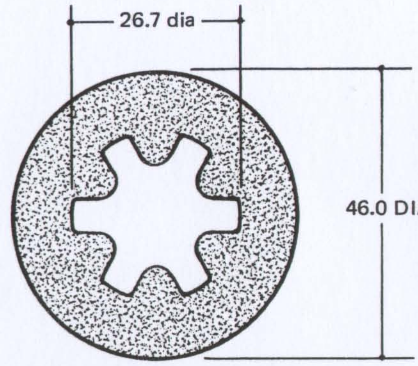


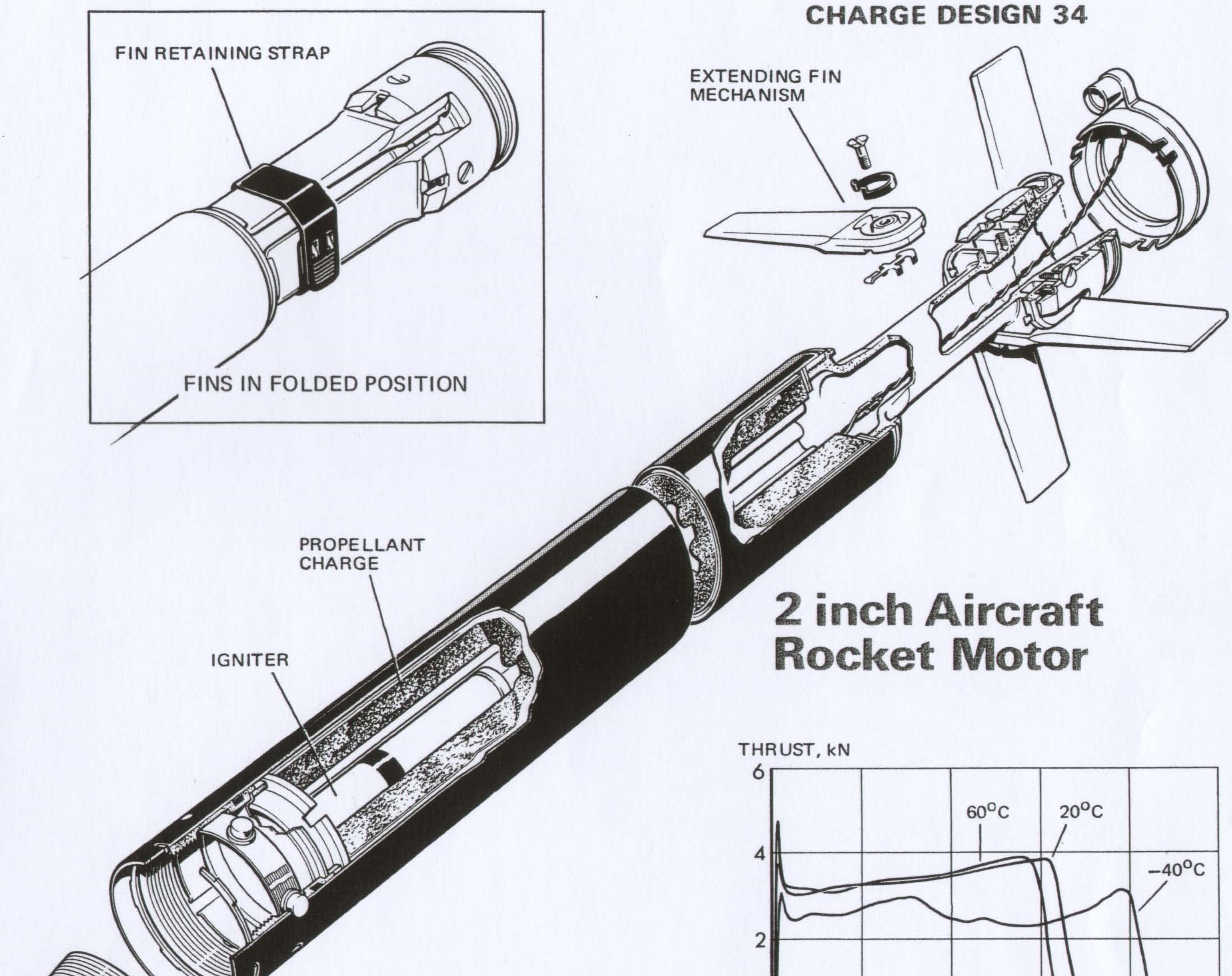
Fig. 2. 2-inch Rocket Motor (Loose Charge)

DIMENSIONS IN mm

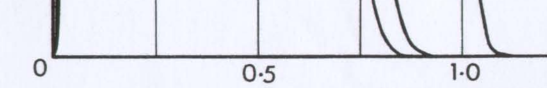


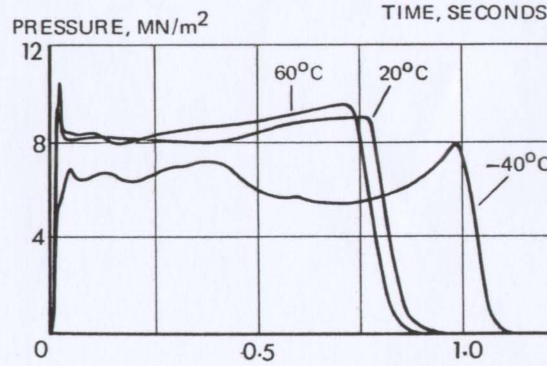


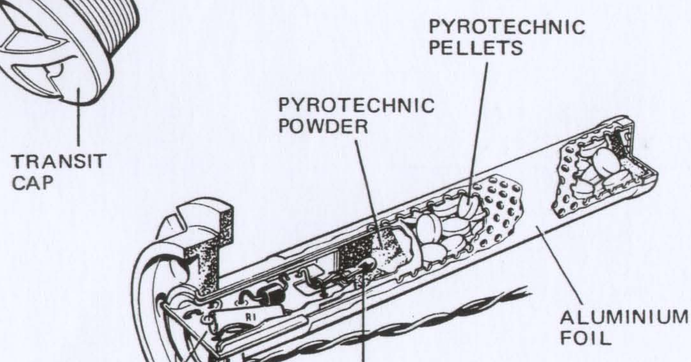
CHARGE DESIGN 34



2 inch Aircraft Rocket Motor







IGNITER

COATED CORDITE CHARGES

TO OBTAIN SPECIFIC PRESSURE - TIME PERFORMANCE
ESSENTIAL FOR FLUID EJECTION AND SUSTAINED REACTION PROJECTS

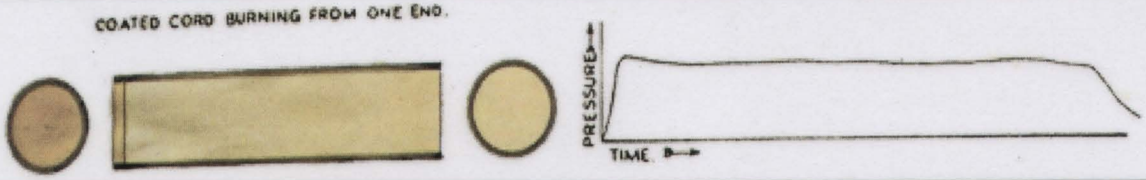
TYPE OF PRESSURE - TIME CURVE | APPLICATIONS | PRESSURE (lbs/sq.in) | TIME (secs)

UNCOATED CHARGE

Curve dependent on application. Maximum time of opertaion - up to 4 seconds

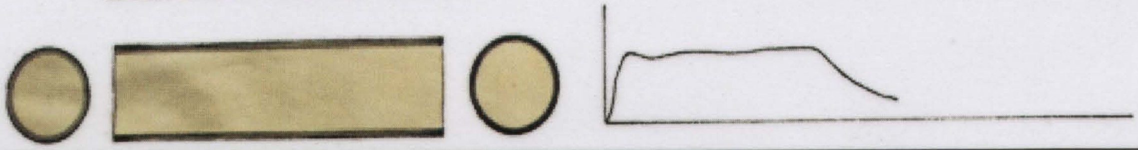
APPLICATIONS	PRESSURE (lbs/sq.in)	TIME (secs)
Aircraft Catapult	1000	1.25
Aircraft Engine Starter	1000	0.75
Fluid Ejection Flame Thrower	250	2.5
Fluid Ejection Shell Sustained Reaction	3000	0.1
Aircraft Assisted Take Off	350	4
Baseball	150	0.1

COATED CORD BURNING FROM ONE END.



APPLICATIONS	PRESSURE (lbs/sq.in)	TIME (secs)
Fluid Ejection Smoke Curtain	400 -1000	30-50
Sustained Reaction (SWALLOW)	750	40
Reaction Assisted Shot	500	5
Rocket Glider Target	350	20-40

COATED CORD BURNING FROM BOTH ENDS.



APPLICATIONS	PRESSURE (lbs/sq.in)	TIME (secs)
Fluid Ejection Flame Thrower	150	12

COATED CORD WITH INITIAL BOOSTING CHARGE.

APPLICATIONS	PRESSURE (lbs/sq.in)	TIME (secs)
Sustained Reaction with Initial Boost	(1400 (400	40
L.A.Device	(900 (250	50

COATED TUBE BURNING FROM CENTRAL HOLE OF SUITABLE SHAPE.

APPLICATIONS	PRESSURE (lbs/sq.in)	TIME (secs)
Sustained Reaction:		
Aircraft Assisted Take Off	800	4
Alternative Rocket Charge	700	2
Propulsion of Explosive Net	600	5

COATED TUBE BURNING FROM CENTRAL HOLE.

APPLICATIONS	PRESSURE (lbs/sq.in)	TIME (secs)
Sustained Reaction:		
Propulsion Explosive Net	400	5

Table 1

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NC	2.6	1.7	1.6
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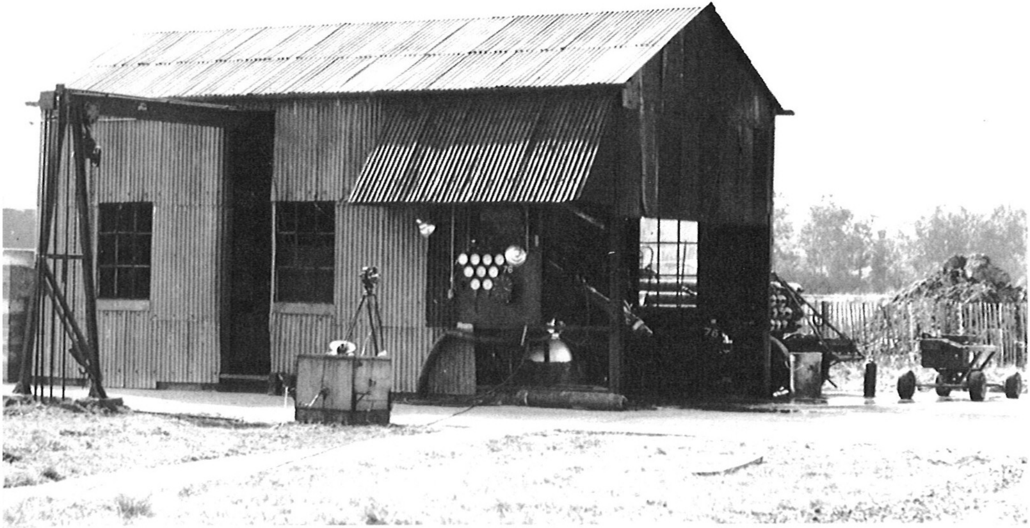

Figure 6 Lizzie Hut 10/08/47

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Cupric Oxide	1	Clay 1

Organisations involved with solid rocket motors

ERDE R and D on new solid rocket propellants

IMI Summerfield (1952) developed bought in CDB technology from the USA. Also developed strip laminate body technology

BAC (1956) became BAJ in 1959 designed and made some motors and made bodies for Westcott and Summerfield

Westcott factory (1946) designed motors, fired motors and pressed plastic propellant charges

ROF Bishopton pressed EDB charges

ROF Bridgwater pressed plastic and later composite charges

ROF Patricroft made some bodies

Triton Oliver made nozzles and insulation

Northern Rubber made rubbery insulation materials