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TECHNICAL MEMORANDUM No. 3/M/63

An Investigation of Materials for Choke Discs and Expansion Nozzles for 2-inch Experimental Rocket Motors

R.S. Smith
G.W. Stocks

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~~Exhaust~~
Nozzles - erosion
Propellants -
Combustion

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6 (5th March, 1964)

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Reference: WAC/151/010

1. SUMMARY

Measurements of the amount of choke erosion in a two-inch solid propellant motor containing approximately $\frac{3}{4}$ lb. of aluminised polyurethane propellant have been made, using as choke materials a wide range of commercial grades of graphite and a limited number of processed grades of graphite supplied by the Metallurgy and Physics Department, R.A.E. Farnborough. The erosion of metal chokes made from tungsten, molybdenum, and tantalum was also measured. Under the conditions of these tests it was found that of the graphites investigated, Nobrac grade M3/HF had the highest resistance to erosion. Tungsten was the only metal tested that was superior to the best grades of graphite.

The throat erosion of expansion nozzles using the same type of motor was also investigated. In this case the study was restricted to nozzles made from four materials, viz. one commercial grade of graphite, a silicon carbide/graphite mixture, a copper-base alloy, and molybdenum. For firings with a propellant containing 5 per cent aluminium the copper-base alloy, Hidurel 6, proved superior to the other materials tested. All the materials tested eroded substantially when fired with propellants containing 20 per cent aluminium.

2. INTRODUCTION

Measurements of rates of burning and specific impulse of experimental propellant formulations are carried out at E.R.D.E. in a two-inch rocket motor (K-round) containing approximately $\frac{3}{4}$ lb. of propellant. When this motor is used for measurement of rates of burning, it is fitted with a carbon disc or choke, drilled to the appropriate size for the desired combustion pressure; for specific impulse measurement, a graphite expansion nozzle, having a nominal expansion ratio of 7:1, is fitted.

The excessive erosion of these carbon chokes and nozzles that occurs with motors containing high-energy polyurethane-propellant formulations causes a marked decrease in chamber pressure with time, and a loss in thrust efficiency. The assessment of propellant ballistics must consequently become more difficult, and less accurate. Gains in performance of a few units in specific impulse are now regarded as significant, consequently, methods of measuring the ballistic properties must be improved.

The primary purpose of this study is to find a choke and a nozzle material that will maintain reasonably constant operating conditions for the brief duration of a K-round firing, normally between 0.5 and 2 seconds. The material must also be reasonably inexpensive and easy to machine, in view of the great variety of sizes needed.

The choice of nozzle and choke materials for this motor had hitherto been confined to three grades of carbon, Nobrac Ltd. M3/50, Morgan Crucible Ltd. EY.9106, and Powell Duffryn Ltd. B.2., all of which were unimpregnated, electro-graphitised, pressed grades with quoted apparent densities of 1.75, 1.66 and 1.60 g/cm³ respectively. These grades were satisfactory with

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plastic propellant of low and medium energy; under slightly more severe conditions the Powell Duffryn grade was marginally superior to the other two. With the introduction of high-energy polyurethane propellants these materials proved less suitable and increases in choke orifice area of up to 30 per cent and occasionally as high as 60 per cent during one firing have been observed.

A trial was carried out to determine whether commercial grades of graphite, other than those in current use, might be more satisfactory as choke and nozzle materials. A number of processed grades (1) supplied by the Metallurgical Department, R.A.E., Farnborough were also investigated. The opportunity was also taken to check briefly the suitability of the high-melting-point metals, tungsten, molybdenum, and tantalum.

Most ceramic materials, despite their high melting points, possess the inherent weakness of having low thermal shock resistance, which with a few exceptions renders them unsuitable as constructional materials for nozzles or chokes. In combination with other materials, however, mostly better thermal conductors, satisfactory results have been achieved. Only one of these materials, a sintered silicon carbide/graphite mixture developed by Hard Metal Tools Ltd., was included in these tests.

Because of the comparatively short burning time, it appeared likely that a metal with a high thermal diffusivity, not necessarily a high melting point, might also render satisfactory service. Transient-heat conduction calculations based on conditions similar to those found with these expansion nozzles have shown the superiority of copper compared with some other metals and alloys. For this reason one high-copper-content alloy, Hidurel 6 (Langley Alloys Ltd.) was examined in these tests in the form of an expansion nozzle.

The majority of these screening tests were confined to various brands of graphite, however, because graphite had in the past proved a useful choke and nozzle material for routine ballistic assessment of propellants; it is readily available at a relatively low cost, and is easy to machine in the many different choke sizes required for ballistic assessment.

In certain circumstances (e.g. where it is necessary for a large number of firings requiring only a small range of choke or nozzle sizes) the use of less amenable, more expensive materials, such as tungsten or molybdenum might be justified, provided that their erosion resistance was superior and the assessment of the propellant performance therefore more accurate than it would have been with graphite nozzles. Possible cases in point would be:

- (a) Control rounds for specific impulse,
- (b) The firing of Phoenix propellant formulations where only two sizes of nozzle are used,
- (c) Firings as a means of production control, possibly applied to the polyurethane propellants.

Most of the tests were carried out with materials machined in the form of choke discs because they were less expensive to produce than expansion nozzles. Hidurel, molybdenum and silicon carbide/graphite were tested in the form of nozzles, however, because these materials were under consideration

/for

for applications (a) and (b) above, for which nozzles only were required.

3. EXPERIMENTAL

3.1 Specimens

The choke materials sampled were machined in the form of discs, 1.385 inches diameter and 0.25 inch thick, with a hole 0.302 inch diameter drilled centrally in each disc, with the exception of a few specimens of molybdenum, tantalum and tungsten which had an outside diameter of 0.750 inch (Table 7, p.15). Each disc was shrunk into a mild steel housing when used as a motor choke (Fig. 1).

A limited number of specimens were machined in the form of expansion nozzles with a throat diameter of 0.302 inch and a nominal expansion ratio of 7:1. The molybdenum and Hidurel nozzles used for this test were machined from solid bars (Fig. 2) whilst the graphite and silicon carbide/graphite nozzles were inserts shrunk into mild steel cases (Fig. 3).

3.2 Measurement of Erosion

A magnified silhouette of the choke orifice or nozzle throat was projected on to half-plate bromide paper, before and after a firing (Fig. 4). The areas of the photographed images were measured with a planimeter and the relative increase in area was used as an index of erosion of the material.

3.3 Procedure

Two aluminised polyurethane propellants U.216/D.6/1.0 and U.241/D.6/1.0, the compositions of which are given in the Table below, were employed in this investigation.

PROPELLANT COMPOSITIONS

Designation	Ingredient	% by Weight	Flame Temperature at 1000 p.s.i., theoretical, K
U.216/D.6/1.0	Ammonium Perchlorate	72.50	3,200°
	Daltorol	14.45	
	Triethyleneglycol-dinitrate (TEGN)	6.75	
	Tolyene 2,4-di-isocyanate (TDI)	1.30	
	Aluminium	5.00	
U.241/D.6/1.0	Ammonium Perchlorate	60.00	3,550°
	Daltorol	13.40	
	TEGN	5.00	
	TDI	1.60	
	Aluminium	20.00	

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The choke specimens were tested in the thin-walled motor (Fig. 5) and the nozzle specimens in the thick-walled motor (Fig. 6).

Before the commencement of this investigation it had been found, during the course of routine ballistic assessment firings, that propellant U.216 eroded graphite chokes more severely than any other propellant developed at E.R.D.E. up to that time, and it was therefore chosen for these tests. After the preliminary screening of a wide range of commercial grades of graphite had been completed, a new propellant, U.241, which had been developed was found considerably more erosive than U.216. The investigation was continued, therefore, using propellant U.241. The results of the tests with both propellants are contained in this Technical Memorandum.

From the initial screening of graphite chokes with propellant U.216 three samples of each of the two best grades, together with some additional grades that became available after the preliminary trial had been completed, were fired with propellant U.241. A limited number of chokes made from the high-melting-point metals were also fired with this propellant. The final assessment of commercial grades of graphite was based on a further series of firings with ten samples of each of six grades, selected on the basis of results obtained in the two preliminary tests. Where differences in erosion of the best grades were marginal, consideration was given to their relative cost in making an assessment.

The nozzle materials were tested with U.216 and U.241 propellant, except in the case of molybdenum from which only one nozzle was made; as it cracked during the firing with U.216 propellant, no further consideration was given to this material. For this investigation Nobrac graphite M3 was used mainly as a control for the tests with the other materials which were, in general, tested as they became available.

Each choke disc or nozzle was used for one firing only throughout these tests, except for the Hidurel 6 nozzle which was used three times, as indicated in Table 8 (p.16).

4. RESULTS

The results of the tests with the processed grades of graphite supplied by R.A.E. are contained in Table 1 (p.6). It was apparent that both the furfuryl alcohol and gas-impregnation processes reduced erosion. Erosion of a sample of EY.9 gas-impregnated graphite resulting in a carbon gain of 8.55 per cent was approximately half that of the untreated sample. It is difficult to explain why the second sample, with a carbon gain of 8.95 per cent, showed little improvement over the untreated sample, but further trials are necessary before any definite conclusions can be reached.

The detailed results of the tests with choke disc materials are contained in Tables 4, 5, 6 and 7, (pp. 9 - 15) and those with nozzle materials in Table 8. Summaries of the results of the tests with the best choke and nozzle materials are contained in Tables 2 and 3, respectively (pp. 7 and 8).

From Table 2 it can be seen that Nobrac graphite, grade M3/HF, showed least erosion under the conditions of the tests, although in one of the preliminary tests (Table 5) it eroded slightly more than the Le Carbone grade

/P.5890

P.5890. This discrepancy can possibly be accounted for by batch to batch variability of a particular grade of graphite, a contingency for which there was no provision in any of the tests. It is also evident, from Table 2, that of the refractory metals investigated as choke disc materials, only tungsten was superior to the best grades of graphite.

The summary of results contained in Table 3 shows that the silicon carbide/graphite nozzles are superior to those made from graphite grade M3, although when used with propellant formulation U.241 the superiority is not as marked as might be expected. Hidurel 6 proved to be very satisfactory when fired with propellant U.216, but not with propellant U.241. As a result of this investigation, nozzles made from Hidurel 6 are in current use at E.R.D.E. with some of the less erosive, high-energy propellants.

5. CONCLUSIONS

5.1 Choke Disc Materials

Under the conditions of these tests it was found that of the graphites investigated, Nobrac grade M3/HF had the highest resistance to erosion. Of the metals tested tungsten was the only one that was superior to the best grades of graphite.

5.2 Expansion Nozzle Materials

For the motors filled with propellant U.216 uncooled nozzles made from Hidurel 6 proved superior to the other materials tested. All materials eroded substantially when exposed to the combustion products of propellant U.241.

6. REFERENCE

1. R.L. Bickerdike, A.R.G. Brown, G. Hughes, W. Johnson and W. Watt, Nuclear Power, 1959, 4, 86.

/TABLE 1

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TABLE 1

Erosion Trial with Graphite Chokes supplied by R.A.E. Farnborough
Propellant formulation U.216 (5 per cent Al)

Source of Graphite	Treatment	Increase in Orifice Area, %	Mean Combustion Chamber Pressure, p.s.i.	Time of Burning, sec
Morgan Crucible (	Untreated	18	1337	1.24
Grade EY.9 (	"	19	1316	1.24
Morgan Crucible (	Furfuryl alcohol impregnated	14	1321	1.25
Grade EY.9 (	Heat treated to 1200°C. Carbon gain 5.45%	14	1289	1.25
Morgan Crucible (	Gas-impregnated Carbon gain 8.55%	9	1494	1.20
Grade EY.9 (	- ditto - 8.95%	18	1379	1.20
Carbonised cloth	Gas-impregnated	62	1105	1.25
Powdered coke	Gas-impregnated Density 1.68 g/c.c.	28	1368	1.21
" "	- ditto - 1.73 g/c.c.	41	1347	1.22

/TABLE 2

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TABLE 2

Summary of Erosion Trials with Graphite and Refractory Metal Chokes

Orifice diameter 0.302 inch. Choke thickness 0.250 inch.

Propellant formulation U.241 (20 per cent Al)

Material	Source and Grade	No. of Firings	Time of Burning, sec	Mean Values		
				Mean Combustion Chamber Pressure, p.s.i.	Combustion Chamber Pressure Drop During Firing, p.s.i.	Increase in Orifice Area, %
Graphite	Nobrac M3	10	1.18	1460	313	22
"	Nobrac M3/28/HF	8	1.21	1339	327	26
"	Nobrac M3/28	9	1.18	1418	412	22
"	Nobrac EF/28	10	1.17	1462	317	21
"	Le Carbone P.5890	10	1.15	1540	267	21
"	Powell Duffryn R2.B	3	1.01	1534	150	22
Graphite	Nobrac M3	10	1.17	1442	279	24
"	Nobrac M3/HF	9	1.15	1522	199	15
Graphite (tantalum carbide coated)	Le Carbone P.5890	3	0.97	1600	365	24
Molybdenum (sintered)	Electro-Alloys	3	1.05	1465	225	30
Molybdenum (cast and forged)	A.R.D.E. (W/HLW)	2	0.99	1457	293	35
Molybdenum (cast)	A.R.D.E. (W/HLQ)	3	0.94	1445	502	50
Tantalum	Murex	1	1.03	1423	674	105
Tungsten (sintered)	Murex	3	0.91	1727	-160 89 34	4

/TABLE 3

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TABLE 3

Summary of Erosion Trials with Graphite and Metal Nozzles

Propellant Formulations U.216 (5 per cent Al) and U.241 (20 per cent Al).

Nozzle throat diameter 0.302 inch, Inlet radius of curvature 1 inch, Expansion ratio 7:1

Material	Source and Grade	Propellant	No. of Firings	Time of Burning, sec	Mean Values		
					Mean Combustion Chamber Pressure, p.s.i.	Combustion Chamber Pressure Drop During Firing, p.s.i.	Increase in Orifice Area, %
Graphite	Nobrac M3	U.216	2	1.28	1218	98	21
Silicon carbide/carbon	Hard Metal Tools Ltd. G.7903	U.216	1	1.22	1372	24	5
*Copper alloy (Hidurel 6)	Langley Alloys Ltd.	U.216	1	1.23	1382	-152	-4
Molybdenum	Murex (sintered)	U.216	1	1.23	1553	-148	-2
Graphite	Nobrac M3	U.241	4	1.21	1311	214	19
Silicon carbide/graphite	Hard Metal Tools Ltd. G.7903	U.241	1	1.19	1377	230	12
*Copper alloy (Hidurel 6)	Langley Alloys Ltd.	U.241	1	1.20	1399	455	16

*Hidurel 6, 98.8 - 99.5 per cent Copper

TABLE 4

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TABLE 4

Initial Screening of Graphite Chokes

Propellant formulation U.216 (5 per cent Al)

Manufacturer	Grade	Increase in Orifice Area		Mean Combustion Chamber Pressure, p.s.i.	Time of Burning, sec
		%	Mean %		
Le Carbone	P.5890	9	6	1338	1.34
" "	" "	3		1654	1.16
" "	" "	7		1660	1.17
National Carbon	Graphite ATJ	12	9	1332	1.35
" "	" "	9		1566	1.14
" "	" "	6		1605	1.19
Nobrac	M3	10	10	1338	1.35
" "	" "	7		1433	1.22
" "	" "	14		1560	1.14
Morgan Crucible	EYX.49	24	17	1128	1.43
" "	" "	13		1447	1.22
" "	" "	15		1419	1.22
Powell Duffryn	B.2	18	23	1445	1.20
" "	" "	18		1393	1.24
" "	" "	33		1315	1.23
Nobrac	M3 (50)	27	24	1375	1.23
" "	" "	17		1403	1.24
" "	" "	28		1290	1.25
Acheson	C.S.	24	24	1244	1.39
" "	" "	-		*	-
" "	" "	-		*	-
Morgan Crucible	EY.9106	23	30	1405	1.22
" "	" "	30		1432	1.15
" "	" "	36		1240	1.29
Powell Duffryn	B.1	29	28	1362	1.23
" "	" "	27		1382	1.20
" "	" "	28		1324	1.25
Powell Duffryn	B.2/R	32	30	1362	1.24
" "	" "	29		1371	1.23
" "	" "	28		1339	1.25
Morgan Crucible	EY.9	32	30	1057	1.44
" "	" "	33		1134	1.30
" "	" "	26		1199	1.31

*Disc fractured.

/TABLE 4 (contd.)

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TABLE 4 (contd.)

Manufacturer	Grade	Increase in Orifice Area		Mean Combustion Chamber Pressure, p.s.i.	Time of Burning, sec
		%	Mean %		
Powell Duffryn	C.3	28	30	1175	1.43
" "	" "	30		1540	1.11
" "	" "	33		1476	1.12
Morgan Crucible	CYX.105	37	36	1210	1.28
" "	(EY.115)	36		1157	1.31
" "	" "	34		1420	1.17
Morgan Crucible	CYX.114	43	42	1175	1.30
" "	" "	43		1184	1.29
" "	" "	39		1245	1.27
Morgan Crucible	CYX.106	53	68	1103	1.34
" "	" "	80		956	1.34
" "	" "	71		1047	1.31

TABLE 5

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TABLE 5

Erosion of Commercial Graphite Chokes

Propellant formulation U.241 (20 per cent Al)

Material	Source of Supply	Grade	Choke Disc Dimensions		Increase in Orifice Area:		Mean Combustion Chamber Pressure, p.s.i.	Time of Burning, sec
			Outside Diameter, inches	Orifice Diameter, inch	%	Mean%		
Graphite	Le Carbone	F.5890	1.385	0.302	19	19	1574	0.87
"	"	"	"	"	20		1535	1.05
"	"	"	"	"	19		1503	1.08
Carbon (tantalum carbide coated)	Le Carbone	F.5890	"	"	23	24	1608	0.90
"	"	"	"	"	28		1622	1.06
"	"	"	"	"	22		1571	0.94
Graphite	Le Carbone	F.2239	"	"	23	26	1574	0.98
"	"	"	"	"	28		1570	1.00
"	"	"	"	"	*		-	-
Graphite	Morgan	EX.82	"	"	*		-	-
"	"	"	"	"	115		1216	1.04

/TABLE 5 (contd.)

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TABLE 5 (contd.)

Material	Source of Supply	Grade	Choke Disc Dimensions		Increase in Orifice Area		Mean Combustion Chamber Pressure, p.s.i.	Time of Burning, sec
			Outside Diameter, inches	Orifice Diameter, inch	%	Mean %		
Graphite	Morgan	EY.9	1.385	0.302	*	*	-	-
Graphite	Morgan	EY.66	"	"	25	25	N.E.	N.E.
"	"	"	"	"	28	28	1544	1.00
"	"	"	"	"	22	22	1424	0.90
Graphite	Nobrac	M3	"	"	32	32	1376	0.96
"	"	"	"	"	29	29	1475	1.00
"	"	"	"	"	30	30	1373	1.10
Graphite	Nobrac	M3/H.F.	"	"	20	20	1557	0.93
"	"	"	"	"	19	19	1549	0.97
"	"	"	"	"	21	21	1450	0.94
Graphite	Powell Duffryn	R.2A	"	"	*	*	-	-
"	"	"	"	"	*	*	-	-
Graphite	Powell Duffryn	R.2B	"	"	25	25	1501	0.97
"	"	"	"	"	21	21	1561	1.06
"	"	"	"	"	20	20	1541	1.00

* = Disc fractured.
N.E. = Not evaluated

/TABLE 6

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TABLE 6

Final Erosion Trial with Graphite Chokes

Propellant formulation U.241 (20 per cent Al)

Manufacturer	Grade	Increase in Orifice Area			Mean Combustion Chamber Pressure, p.s.i.	Time of Burning, sec
		%	Mean %	Standard Deviation		
Nobrac ϕ	M3/28/HF	30.1	26.0	3.9	1288	1.24
		29.5			1312	1.22
		*			*	*
		28.6			1319	1.21
		*			*	*
		27.1			1225	1.23
		18.8			1490	1.17
		28.6			1310	1.21
22.0	1438	1.15				
23.0	1332	1.21				
Nobrac ϕ	M3/28	20.8	22.1	5.4	1387	1.20
		*			*	*
		19.3			1465	1.18
		20.7			1449	1.19
		34.2			1349	1.20
		27.7			1410	1.18
		22.2			1445	1.16
		14.6			1402	1.18
		18.4			1446	1.17
		21.2			1410	1.20
Nobrac ϕ	EF/28	24.2	20.8	2.5	1419	1.20
		20.8			1498	1.18
		18.0			1470	1.18
		18.3			1463	1.18
		20.0			1490	1.16
		22.7			1466	1.17
		24.8			1444	1.16
		20.2			1465	1.16
		17.0			1498	1.16
		21.5			1410	1.19
Nobrac \neq	M3 (Standard)	19.8	23.8	8.7	1404	1.19
		21.6			1446	1.16
		43.1			1297	1.24
		15.4			1498	1.16
		21.6			1425	1.16
		20.4			1472	1.16
		29.7			1475	1.15
		33.9			1401	1.17
		19.5			1475	1.16
		13.0			1530	1.14

/TABLE 6 (contd.)

TABLE 6 (contd.)

Manufacturer	Grade	Increase in Orifice Area.			Mean Combustion Chamber Pressure, p.s.i.	Time of Burning, sec
		%	Mean %	Standard Deviation		
Nobrac [≠]	M3/HF	18.9	15.2	3.5	1519	1.14
		13.3			1510	1.16
		18.0			1497	1.16
		9.4			1571	1.14
		12.8			1531	1.14
		20.0			1480	1.16
		10.1			1525	1.14
		18.3			1540	1.14
		15.8			1525	1.15
Nobrac [∅]	M3 (Standard)	20.2	21.9	6.3	1501	1.16
		30.8			1384	1.21
		28.6			1380	1.20
		17.4			1499	1.18
		25.2			1411	1.19
		10.9			1531	1.15
		20.0			1508	1.18
		13.0			1595	1.14
		23.7			1377	1.19
29.1	1409	1.17				
Le Carbone [∅]	P.5890	23.7	20.8	4.7	1490	1.16
		18.3			1549	1.18
		19.1			1570	1.12
		30.9			1550	1.16
		25.5			1540	1.14
		19.5			1582	1.13
		18.3			1526	1.16
		16.8			1540	1.15
		13.2			1600	1.14
21.8	1451	1.18				

*Disc fractured

[≠]Fired with Batch B propellant

[∅]Fired with Batch A propellant

/TABLE 7

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TABLE 7

Erosion of Refractory Metal Chokes

Propellant formulation U.241 (20 per cent A.I)

Material	Source of Supply	Grade	Choke Disc Dimensions		Increase in Orifice Area		Mean Combustion Chamber Pressure, P.s.i.	Time of Burning, sec
			Outside Diameter, inches	Orifice Diameter, inch	%	Mean %		
Molybdenum	Electro-alloys	Sintered	1.385	0.302	28	30	1532	0.99
"	"	"	"	"	27		1458	1.09
"	"	"	"	"	34		1406	1.08
Molybdenum (W/HLM)	A.R.D.E.	Forged	0.75	"	35	35	1499	0.98
"	"	"	"	"	35		1414	1.00
Molybdenum (W/HLM)	A.R.D.E.	As Cast	"	"	20	50	1566	0.96
"	"	"	"	"	53		1465	0.93
"	"	"	"	"	77		1304	0.93
Tantalum	Murex	"	"	"	78	105	1423	1.03
"	"	"	"	"	131		N.E.	N.E.
"	"	"	"	"	105		N.E.	N.E.
Tungsten	Murex	Forged	"	"	1	4	1688	0.94
"	"	"	"	"	6		1727	0.87
"	"	"	"	"	5		1765	0.92

N.E. = Not evaluated

/TABLE 8

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TABLE 8

Erosion Trial with Graphite and Metal Expansion Nozzles

Propellant formulations U.216 (5 per cent Al) and U.241 (20 per cent Al)

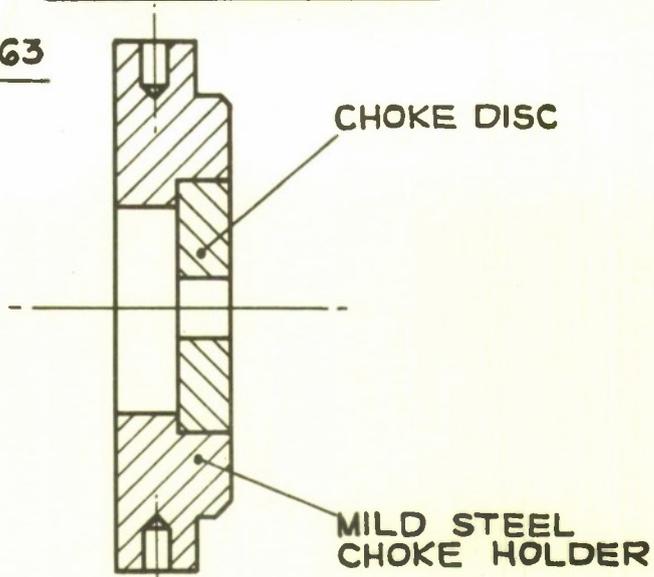
Material	Source of Supply	Propellant Formulation	Increase in Throat Area, %	Mean Combustion Chamber Pressure, p.s.i.	Time of Burning, sec	Remarks	
Molybdenum	Murex	U.216	-2	1353	1.23	Cracked radially	
Graphite M3	Nobrac	"	24	1185	1.29		
Graphite M3	Nobrac	"	17	1251	1.27		
Silicon carbide/ graphite mixture) G.7903	Hard Metal Tools	"	5	1372	1.22		
*Hidurel 6	Langley Alloys	"	-4	1382	1.23		
"	"	"	-2	1414	1.22		
"	"	"	1	1400	1.21		
*Hidurel 6	Langley Alloys	U.241	16	1399	1.20		
Silicon carbide/ graphite mixture) G.7903	Hard Metal Tools	"	12	1377	1.19		
							2nd firing of nozzle
							3rd firing of nozzle
							Throat gouged

*Hidurel 6, 98.8 - 99.5 per cent copper.

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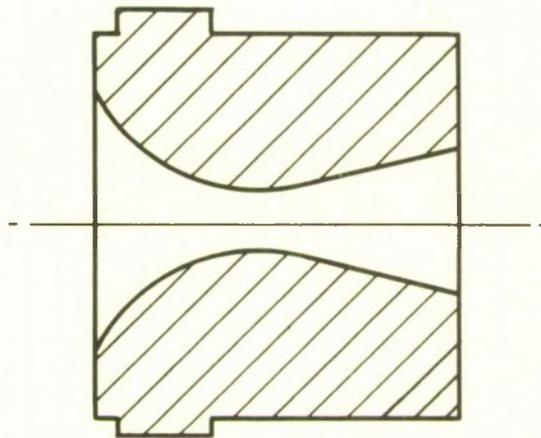
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CHOKE DISC IN CHOKE HOLDER

FIG. 1.



EXPANSION NOZZLE (MOLYBDENUM OR HIDUREL 6)

FIG. 2.

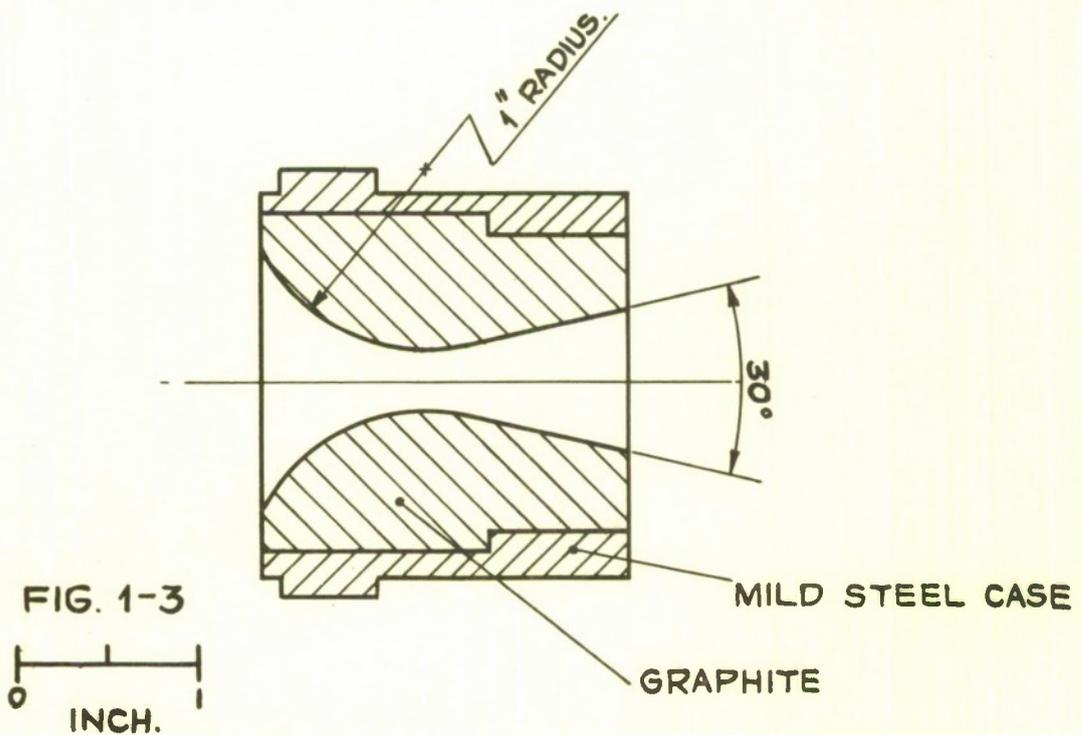
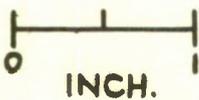


FIG. 1-3



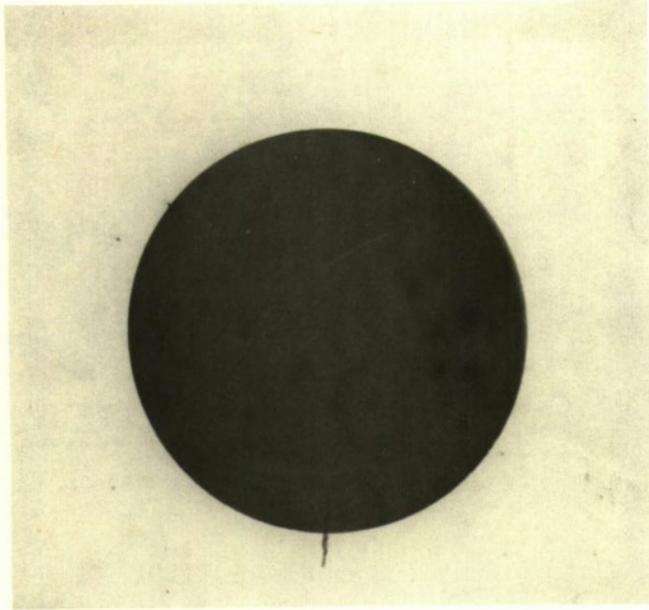
EXPANSION NOZZLE (GRAPHITE INSERT)

FIG. 3.

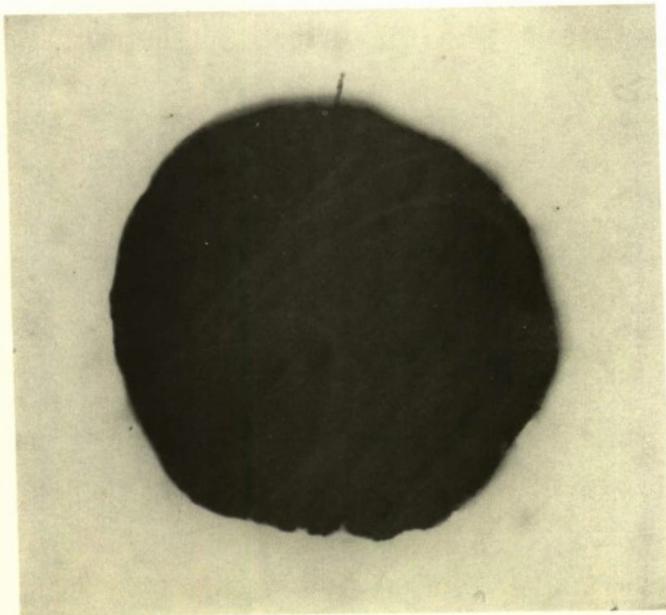
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A.



B.

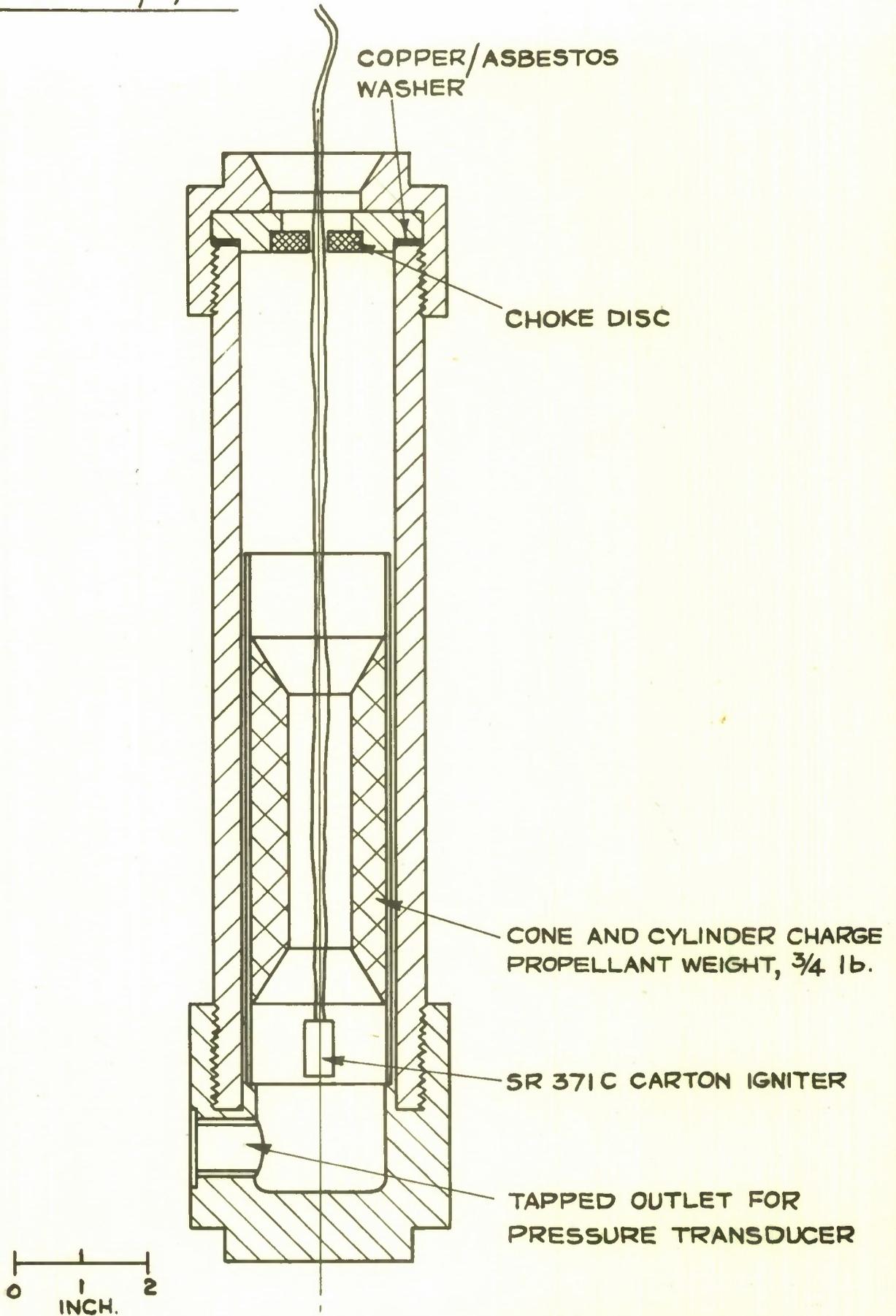
CHOKE ORIFICE SHADOWGRAPHS
BEFORE AND AFTER FIRING.

FIG.4.

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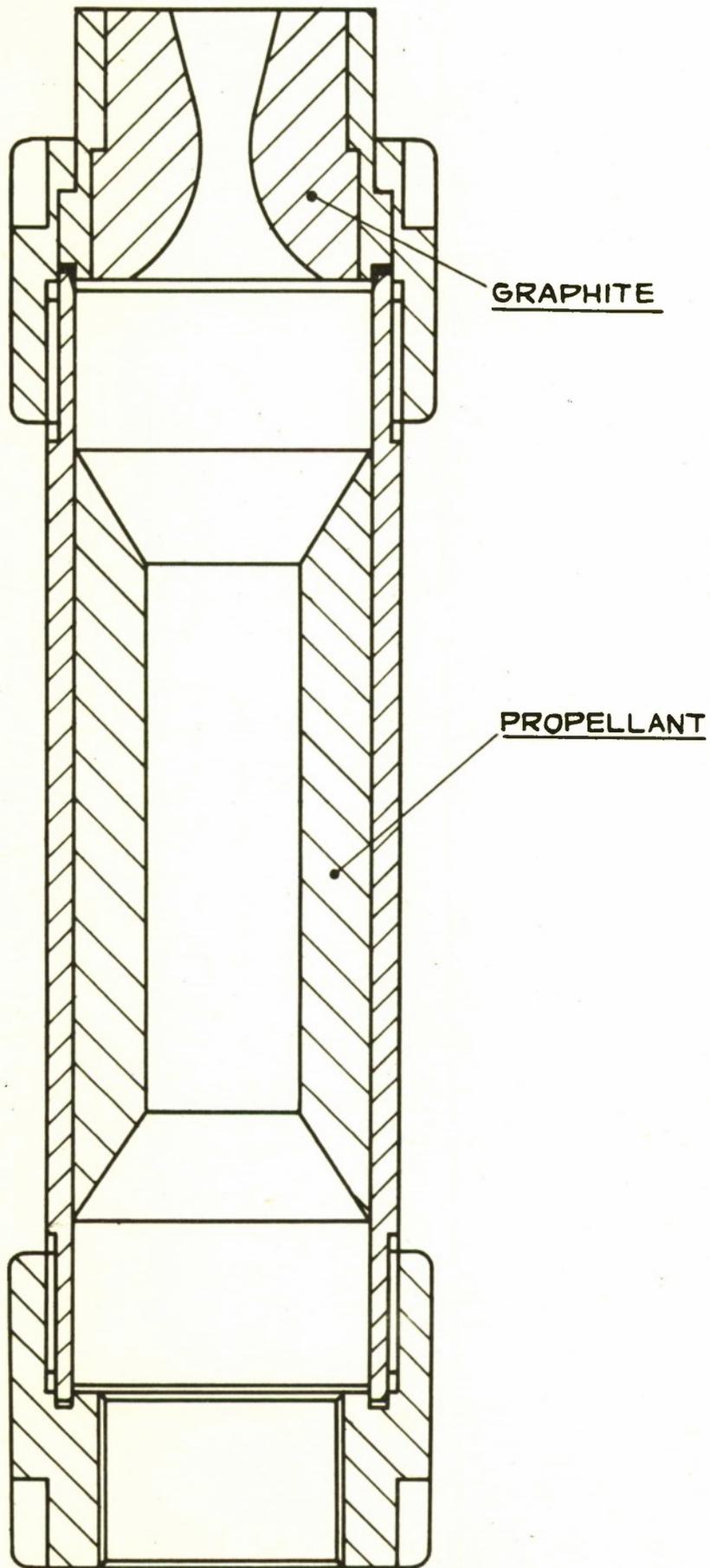
THIN-WALLED K-ROUND MOTOR, ASSEMBLED
FOR RATE-OF-BURNING MEASUREMENT FIRINGS.

FIG.5.

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2 INCH K-ROUND ROCKET MOTOR

SCALE 1/1
0 INCH. 1

FIG. 6.

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Date of Search: 11 December 2008

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