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ROCKET PROPULSION ESTABLISHMENT
WESTCOTT, BUCKINGHAMSHIRE

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R.P.E. TECHNICAL NOTE No: 195

THE DEVELOPMENT OF
THE GOSLING II SOLID
PROPELLENT ROCKET MOTOR

by

E. C. WHITE

OCTOBER, 1960

PICATINNY ARSENAL
TECHNICAL INFORMATION SECTION

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Technical Note No. 195

(October, 1960)

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PROPELLENT ROCKET MOTOR

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SUMMARY

The development of a motor in which the cordite charge of the Gosling I is replaced by a case-bonded plastic propellant is described.

Using the same motor tube an increase of 40% in total impulse was obtained, with a motor operating reliably within the temperature limits -5 to 50°C. These limits are sufficiently wide for a boost motor in the development phases of a guided missile or high speed test vehicle.

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1 INTRODUCTION

This note describes the development of the Gosling II rocket motor which was produced, primarily as a development exercise, at R.P.E. Westcott, but also with the intention of having a design available to meet a possible future use requirement.

The history of ground-to-air missiles has shown a continuing trend towards higher performance boost motors, as shown in the following table:-

<u>Motor</u>	<u>Number of boosts per missile set</u>	<u>Total impulse per set, lb - sec</u>
Demon	8	180,000
Mayfly III	4	208,000
Mayfly IV	4	236,000
Gosling I	4	250,000

In view of this background, the desirability of a boost motor of higher performance, which, if required, would be capable of replacing the Gosling I motor¹ was apparent. The simplest method of effecting this was considered to be by replacing with plastic propellant the cordite charge used in Gosling I and utilising the motor tube of the existing design. A similar procedure had been adopted in developing the Mayfly IV motor which is a plastic propellant version of Mayfly I² and retains the same tube.

Since the new motor was produced purely for development purposes the desired feature was the highest total impulse attainable in the shortest burning time. On examination it was found that the charge conduit design used with the Mayfly IV motor would be suitable for the 10-inch diameter Gosling tube, giving a charge weight of 405 lb. A propellant having a predicted specific impulse of 215 lb-sec/lb would enable a total impulse of 87,000 lb-sec to be developed.

2 MOTOR DESIGN

2.1 Empty components

The Gosling motor tube (Fig.1) is of conventional design comprising a wrapped and welded shell in 16 swg steel to specification SAE4130 to which are welded the head-end pressing and rear-end threaded ring. The tube is subjected to a hydraulic test pressure of 1700 lb/sq in. prior to filling. As indicated above, its use with Gosling II involves no change in external dimensions, which is clearly desirable should a missile contractor wish to install Gosling II motors using missile attachment fittings designed to accept Gosling I. Each missile, however, requires a tube which, although basically the same, differs slightly in minor external dimensions. Details of the different versions of Gosling II motors are shown in Table I.

The steel end-plate to specification DEF13 group 3B is attached to the tube by means of a large diameter screw thread, and has a central hole sufficiently large to accommodate the former required for pressing the propellant charge.

The venturi-nozzle comprises a throat portion fabricated in steel to specification DEF13 group 3B to which is welded a wrapped expansion cone in 12 swg steel. The whole of the internal surface is sprayed with alumina to a thickness diminishing uniformly from 0.020 inch at the throat to 0.005 inch at the exit. A description of this process and the events leading to its introduction in the Gosling II motor are detailed elsewhere³. The axis of

the nozzle is inclined to that of the tube at an angle varying between 0° and 15.5° depending on the application. The nozzle is attached to the end-plate by a ring of set-screws for offset nozzles and by a screw thread for in-line nozzles.

Typical physical and internal ballistic characteristics of the motor are given in Appendix I.

2.2 Propellant charge

The dimensions of the existing former were such as to produce a charge of web thickness 2.01 inch in a 10-inch diameter tube (Fig.2). With a fixed charge design and a pressure limited by the strength of the tube, two characteristics only can be varied; the propellant burning rate and the nozzle-throat size. To attain the shortest burning time the cross-sectional area of the throat must be made as large as possible so that the fastest burning propellant, for a given pressure, may be used. The limiting size for the throat area is reached when the ratio of the cross-sectional area of the conduit to that of the throat is reduced to a point at which propellant erosive burning produces an unacceptably high initial peak pressure. Experience with the Mayfly IV motor had shown that a value of 1.5 : 1 for this ratio produced no appreciable erosive burning and it was considered that a reduction to 1.3 : 1 might be possible. A throat diameter of 4.4 inches required with the conduit area of 20.07 sq in. produced the 1.3 : 1 ratio. The results obtained when attempts were made to reduce this ratio still further will be reported elsewhere.

It was considered that mean and maximum working pressures of 1180 and 1400 lb/sq in. in motors fired at $+15^\circ\text{C}$ would give an adequate margin of safety below the test pressure of the tube (1700 lb/sq in.) when motors were fired at a conditioning temperature of 50°C .

The plastic propellant RD2304G (see Appendix II) was selected as producing a mean pressure of 1180 lb/sq in. when fired with a restriction ratio of 214 : 1. From the known temperature dependance of this propellant, it was calculated that the corresponding mean and maximum pressures at $+50^\circ\text{C}$ would be 1250 and 1500 lb/sq in. respectively. This gives a factor of safety of 1.13 which was considered adequate. The burning rate of RD2304G at 1180 lb/sq in. gives a time of burning of 3.1 seconds at 15°C . The rates of burning of a number of lots of propellant RD2304G determined in the strand burner are given in Table II.

2.3 Igniter

The igniter consists of an aluminium canister containing 100 grams of SR371C pyrotechnic composition which is located at the head end of the motor and is supported either on a separate spider or is attached to the pressure plug. An assembled igniter is shown in Fig.3 and fully described in ref.4.

Some early development firings were carried out using a tubular igniter comprising a paper carton 1 inch diameter by 24 inches long and 100 grams of SR371C (Fig.4). It was believed that this type of construction would reduce the ignition shock and would prove beneficial, particularly at low temperature. Further work^{5,6}, however, showed conclusively that no advantage was gained and its use was discontinued.

3 DEVELOPMENT STATIC FIRINGS

During the development, 40 Gosling II motors were fired at ambient temperature with 100% success. Many of these firings were carried out to

assist the missile contractor in the design of boost harnesses and separation mechanisms, or to simulate and investigate anomalous behaviour in flight rounds such as 'g' pulse in Seaslug and flutter in Red Duster. Early firings at low temperature established that -5°C was a reasonable lower limit and since this motor was not destined for service use, firings at extremes of temperature were kept to a minimum. Such firings as were carried out at temperatures below -5°C were in support of a general investigation into the behaviour of plastic propellant at low temperature and the results have been reported^{5,6}. An upper temperature limit of 50°C was fixed as being adequate to cover the requirements of missiles in research and development phases. Details of a number of these firings are given in Table III. Typical pressure - and thrust-time curves are shown in Fig.5 and 6 respectively. The variation of mean pressure, mean thrust and burning time with operating temperature are shown in Fig.7.

4 PROJECTION FIRINGS

The motor was first required to provide the propulsion for a supersonic vehicle. In this application the conditions of velocity (~ 5000 feet/sec after 3.3 seconds) and acceleration (up to 70g) were severe. The contribution made by Gosling II to this work is reported in Ref.7. In this connection Gosling II successfully formed the second stage of two and three stage vehicles. It is also in current use for trials purposes as a boost motor for the three major surface to air missiles - Thunderbird, Bloodhound and Seaslug.

A total of 293 motors has been supplied for use on these missiles and details are given in Table I.

To date three failures have been recorded.

Two took the form of instantaneous bursts on or near the launcher; these were pressure bursts resulting from failure of the propellant to bond to the metal, the third occurred late in burning following overheating of the rear-end of the tube. The steps taken to overcome the instantaneous failures were:-

- (1) An improved adhesive for bonding the propellant to the tube.
- (2) A more rigorous control of the filling and inspection of the motor.
- (3) The introduction of an ultrasonic method⁸ for detecting the lack of adhesion of the propellant to the tube wall.

The type of failure resulting from detachment of the propellant from the end-plate was obviated by (in addition to the improvements stated above) the insertion of a steel liner at the rear of the tube. This liner, which has a serrated internal surface, has the dual effect of providing a key for the propellant and acting as a heat shield for the tube in the event of lack of adhesion. The method of filling Gosling motors is given in Specifications RPE 1022 and 1029.

5 CONCLUSIONS

- (1) A 10-inch diameter plastic propellant boost motor using a charge of increased performance in an existing tube has been fired successfully on guided missiles and high speed test vehicles under conditions of high acceleration.

- (2) The advantages of plastic propellant are such as to increase the total impulse by 24,500 lb-sec, or 40% over Gosling I. This increase is gained by greater loading density (approx 29% more propellant) and higher specific impulse (about 8%) of the propellant.
- (3) The motor ignites and performs reliably within the temperature limits -5 to +50°C.

REFERENCES

<u>No.</u>	<u>Author</u>	<u>Title, etc.</u>
1	Dickinson, L.A. Morris, N.J.	The development of the cordite-filled Gosling I boost motor (to be published)
2	Dickinson, L.A.	The development of the Mayfly I boost motor and its variants R.A.E. Tech.Memo.No. RPD149 November 1957
3	White, E.C.	Solid propellant rocket motors: thermal insulation of nozzles, Part I R.A.E. Tech.Memo.No. RPD122. April 1957
4	Crook, J.H. Harrison, E.G.	Ignition of solid propellant rocket motors for guided weapons R.A.E.Tech.Memo.No. RPD119 January 1957
5	Hirst, R.C.	The behaviour of plastic propellents in rocket motors at low temperatures R.A.E.Tech.Note No. RPD158 November 1957
6	Rolfe, J.A. White, E.C.	Investigation of factors involved in the failure of plastic propellant motors at low temperature R.P.E.Tech.Note No.180 May 1959
7	Picken, J.	Notes on the progress of free flight trials to measure heat transfer at Mach numbers up to 5 R.A.E.Tech.Note No. Aero 2575 June 1958
8	Lister, R.	An ultrasonic method of detecting lack of adhesion between case-bonded plastic propellant and the tube wall in rocket motors R.A.E.Tech.Note No.RPD156 November 1957

ATTACHED:-

Appendices I and II
Tables I to III
Drgs.No. RP 2837-2840
Detachable abstract cards

ADVANCE DISTRIBUTION:-MOA

CGWL	AD/GW (P & W)	
CM	AD/MXRD (X)	
DG/GW	ADSR (Records)	
D/GW(Air)	D/ERDE	3
D/GW(N)	RAE Farnborough	5
D/GW(Tech)	Sec EDPC	
DMXRD	GW(A)1(b)	70
DI Arm	TIL 1(b)	100

APPENDIX ILeading physical and internal ballistic characteristics
of Gosling II motorWeights (Gosling II Series G taken as typical)

Motor tube	98 lb
End-plate	15 lb
Venturi nozzle	23 lb
Filled igniter and support	4 lb
Empty assembly	140 lb
Charge	405 lb
All-up weight	545 lb

Charge

Propellant	RD2304G
Length	113 inches
Diameter	10.0 inches
Web thickness	2.01 inches
Initial burning surface area	2760 sq.inches
Final burning surface area	3590 sq.inches
Initial cross-sectional area of conduit	20.07 sq.inches

Internal Ballistic Characteristics

Throat diameter	4.36 inches
Throat cross-sectional area	14.92 sq.inches
Initial burning surface area/throat area	185 : 1
Final burning surface area/throat area	241 : 1
Initial cross-sectional area of conduit/throat area	1.34 : 1

Performance

Total impulse	87,000 lb-seconds
Burning time at 18°C	3.1 seconds
Mean thrust at 18°C	26,000 lb
Mean pressure at 18°C	1,180 lb/sq in.
Temperature limits	-5 to +50°C
Firing current	1.5 to 2.0 mA
Circuit resistance	approximately 3.0 ohms

APPENDIX IICharacteristics of propellant RD2304G* Composition

Ammonium percholate	70.5 per cent
Ammonium picrate	15.0 per cent
Polyisobutylene	12.5 per cent
Lecithin	1.0 per cent
Titanium dioxide	1.0 per cent

* Physical properties

Density	1.684 gm/cc
Thermal conductivity, at 30°C	0.0009 cal cm ⁻¹ deg C ⁻¹ sec ⁻¹
at 60°C	0.0011 cal cm ⁻¹ deg C ⁻¹ sec ⁻¹
at 100°C	0.0125 cal cm ⁻¹ deg C ⁻¹ sec ⁻¹
Specific heat	0.293 cal/g deg C

Internal ballistic data

Burning rate at 1000 lb/sq in. and 25°C	0.610 in/sec
Gas temperature, T _c at 1000 lb/sq in.	2350°K
Characteristic exhaust velocity $\int \frac{P \, dt \, A_t}{M} \, g$	4620 ft/sec
Theoretical specific impulse	233 lb-sec/lb
Discharge coefficient(C _d)	0.00675
Mean molecular weight of gaseous products	22.67
Ratio of specific heats	1.27
Equilibrium gas composition	
H ₂ O	28.6 per cent mole fraction
CO ₂	6.3 per cent mole fraction
CO	23.7 per cent mole fraction
H ₂	17.9 per cent mole fraction
H	0.1 per cent mole fraction
N ₂	9.7 per cent mole fraction
HCl	13.7 per cent mole fraction

* Information kindly supplied by D/ERDE, Waltham Abbey

TABLE I

Versions of Cosling II motor for missile boost or vehicle application and numbers supplied

Motor	Venturi offset angle, °	Application	Number of motors supplied by		
			RPE	ROF Bridgwater	Total
Series C	0	Supersonic vehicles, Panther, Puma, Regulus, Tiger I	47	10	57 ⁽¹⁾
D	0	Supersonic vehicle Leopard (forms second stage)	2	0	2
E	15½	Thunderbird	68	48	116 ⁽²⁾
G	11½	Bloodhound	4	50	54
J	15	Seaslug	25	24	49
K	14	Thunderbird	4	8	12
M	4° 55'	Supersonic vehicle, Tiger IV	0	2	2
N	0	Supersonic vehicle; forms second stage of 3-stage vehicle	1	0	1
Totals			151	142	293

Notes: (1) One failure - instantaneous burst just after launch
 (2) Two failures - one instantaneous burst on launcher
 one thermal burst near end of boost burning

TABLE IIBurning rates of propellents RD2304A and RD2304G

Propellant formulation

RD2304A *		RD2304G *							
Lot No.	Rate, in/sec	Lot No.	Rate, in/sec	Lot No.	Rate, in/sec	Lot No.	Rate, in/sec	Lot No.	Rate, in/sec
1	0.597	1	0.613	15	0.603	29	0.602	43	0.604
2	0.601	2	0.616	16	0.613	30	0.616	44	0.601
3	0.605	3	0.620	17	0.617	31	0.617	45	0.611
4	0.627	4	0.619	18	0.611	32	0.605	46	0.608
5	∅	5	0.610	19	0.616	33	0.610	47	0.613
6	0.637	6	0.613	20	0.610	34	0.614	48	0.614
7	0.628	7	0.616	21	0.605	35	0.607	49	0.607
		8	0.617	22	0.610	36	0.611	50	0.607
		9	0.617	23	0.611	37	∅	51	0.607
		10	0.607	24	0.605	38	0.605	52	∅
		11	0.605	25	0.601	39	0.608	53	0.608
		12	0.612	26	0.611	40	0.607	54	0.604
		13	0.613	27	0.608	41	0.602		
		14	0.602	28	0.605	42	0.610		

* Propellents RD2304A and RD2304G are identical in every respect; the change of nomenclature arose from confusion resulting from a clerical error. All propellant was made at ROF Bridgwater.

∅ These lots were re-blended.

All burning rates were determined at ROF Bridgwater or at RPE on strands 4.5 mm diameter at 1000 lb/sq in.

TABLE III
Static firing results

Round No.	Date	Propellant		Charge weight, lb oz	Igniter housing	Ignition delay, second	Burning time, seconds	Total impulse, lb-sec	Specific impulse, lb-sec/lb	Mean thrust, lb	Maximum pressure, lb/sq in.	Conditioning temp, °C	Remarks
		Designation	Lot No.										
10PWE 97	9. 5.57	RD2304A	WA17	406	Metal housed	0.12	3.28	88,900	219	25,200	1470	-5	Initial peak pressure
" 263	7.11.58	"	10	403	"	0.02	3.38	88,400	219	24,300	1390	"	
" 265	7.11.58	"	10	401	"	0.06	3.31	90,600	226	25,600	1367	"	
" 5	12.10.55	RD2304	44-45	412	Tubular (1)	0.04	3.29	72,380	176	20,100	1200	Air	/ choke firing
" 50	19. 3.57	"	7	406	"	0.04	3.19	88,650	218	25,600	1210	"	
" 53	19. 3.57	"	8	406	"	0.04	3.08	87,850	216	26,000	1430	"	
" 79	4. 2.57	"	9	406	"	0.04	3.15	85,200	210	25,000	1370	"	
" 80	28. 3.57	"	9	406	"	0.03	3.07	88,900	218	26,700	1450	"	
" 99	9. 5.57	"	WA17	407	Metal housed	0.09	3.13	89,500	220	26,600	1420	"	
" 100	9. 5.57	"	WA17	406	"	0.14	3.10	90,400	223	27,300	1430	"	
" 116	25. 7.57	RD2304A	WA1	404	Tubular	0.03	3.09	88,500	219	25,300	1290	"	
" 117	25. 7.57	"	WA2	402	"	0.03	3.11	89,000	222	26,600	1500	"	
" 118	25. 7.57	"	WA3	403	"	0.03	3.12	88,800	220	26,400	1450	"	
" 187	31. 1.58	"	WA7	408	"	0.04	3.20	87,900	214	25,700	1220	"	
" 188	31. 1.58	"	WA7	402	"	0.04	3.16	88,400	220	26,500	1417	"	
" 213	30. 4.58	RD2304G	1 & 2	407	"	0.04	3.10	88,900	217	26,400	1377	"	
" 223	10. 7.58	"	3 & 4	406	"	0.04	3.04	89,600	221	27,400	1357	"	
" 233	8. 9.58	"	5 & 6	405	"	0.02	3.09	90,300	223	27,100	1441	"	
" 252	5. 9.58	"	7, 8 & 9	402	Metal housed	0.02	3.12	82,600	206	24,300	1479	Not recorded	
" 264	3.11.58	"	10	402	"	0.02	3.20	89,500	222	25,700	1378	"	
" 283	6. 1.59	"	11 & 12	403	"	0.07	3.11	89,200	221	26,000	1399	"	
" 288	2.12.58	"	7 to 14	405	"	0.02	3.16	88,500	219	25,200	1387	"	
" 289	23.12.58	"	13 & 14	402	"	0.06	3.28	88,400	220	25,000	1370	"	
" 294	5. 1.59	"	13 & 14	402	"	0.03	3.28	86,000	215	24,300	1452	"	
" 304	11. 4.60	"	15 & 16	405	"	0.04	3.15	88,000	217	26,200	1457	"	
" 312	23. 1.59	"	17 & 18	399	"	0.07	3.13	87,500	218	26,100	1361	"	
" 330	12. 3.59	"	19 & 20	405	"	0.04	3.23	87,000	214	25,600	1348	"	
" 350	9. 4.59	"	19 & 20	402	"	0.06	3.21	89,600	220	26,000	1400	"	
" 361	30. 4.59	"	21 to 25	403	"	0.075	3.23	89,500	220	25,700	1430	"	
" 373	29. 7.59	"	24 to 26	403	"	0.06	3.22	88,700	218	24,400	1329	"	
" 390	17. 9.59	"	24 to 26	403	"	0.10	3.22	89,000	220	25,600	1436	"	
" 391	17. 9.59	"	24 to 26	403	"	0.07	3.18	89,000	219	25,900	1360	"	
" 395	21. 9.59	"	24 to 26	406	"	0.07	3.08	88,700	218	26,300	1368	"	
" 410	14.12.59	"	30	407	"	0.11	3.19	85,900	213	24,200	1330	"	
" 421	14. 1.60	"	39	403	"	0.10	3.11	88,830	213	25,580	1352	"	
IIE BGW 28	10. 3.60	"	38, 40, 41	402	"	0.08	3.18	88,680	220	26,160	1478	"	
" 1	30. 4.59	"	22, 23	403	"	0.07	3.16	87,860	219	25,900	1390	"	
" 2	30. 4.59	"	22, 23	402	"	0.04	3.11	88,980	219	26,670	1480	"	
IIG BGW 11	17. 7.59	"	27, 28, 29	405	"	0.06	3.16	89,570	220	26,760	1380	"	
" 11	30. 9.59	"	31, 32, 33	407	"	0.06	3.12	88,380	218	26,000	1384	"	
" 25	3. 11.59	"	34, 35, 36	405	"	0.10	3.20	88,870	220	25,520	1326	"	
IIM BGW 1	13. 4.60	"	45, 46, 47	402	"	0.09	3.30	89,470	212	25,200	1320	"	
IIL BGW 5	18. 3.60	"	42, 43, 44	410	"	0.10	2.82	-	-	-	1500	50	Instrumentation failed
10 FWE 98	30. 5.57	RD2304A	WA17	406	"	0.03	2.87	91,200	222	30,000	1590	"	
" 151	6.11.57	"	WA17	411	Tubular	0.02	2.97	84,700	211	26,300	1450	"	
" 262	3.11.58	RD2304G	10	402	Metal housed	0.02	2.89	89,500	223	28,200	1530	"	
" 266	3.11.58	"	10	402	"	0.09						"	

All igniters contained 100 grams of SR 371C pyrotechnic composition except (1), which contained 150 grams.

All motors were fitted with 4.36 inch diameter nozzles.

Motors prefixed 10PWE were produced at RPE Westcott; those prefixed BGW at ROF Bridgwater.

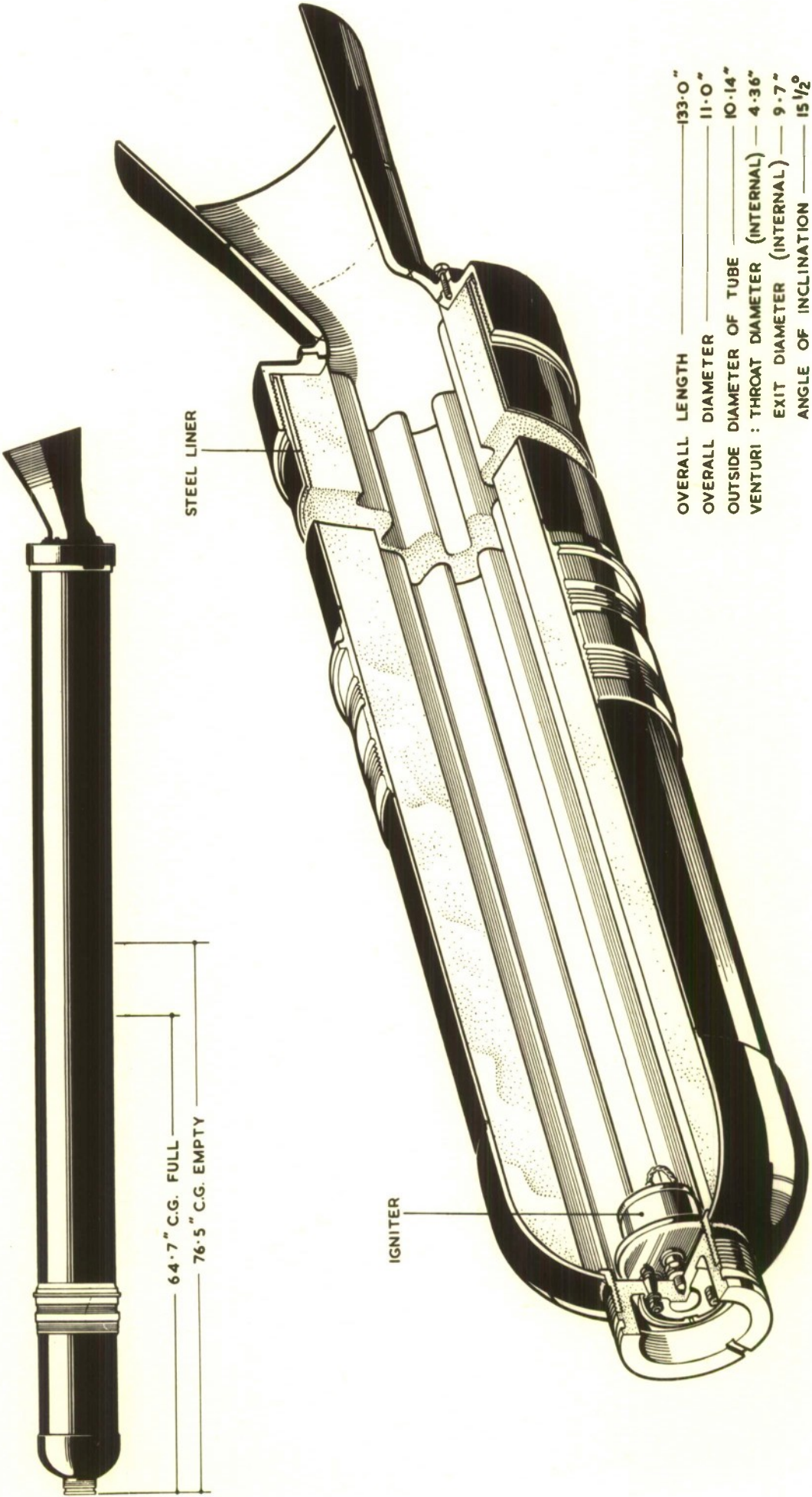


FIG. 1 ASSEMBLY OF GOSLING II MOTOR

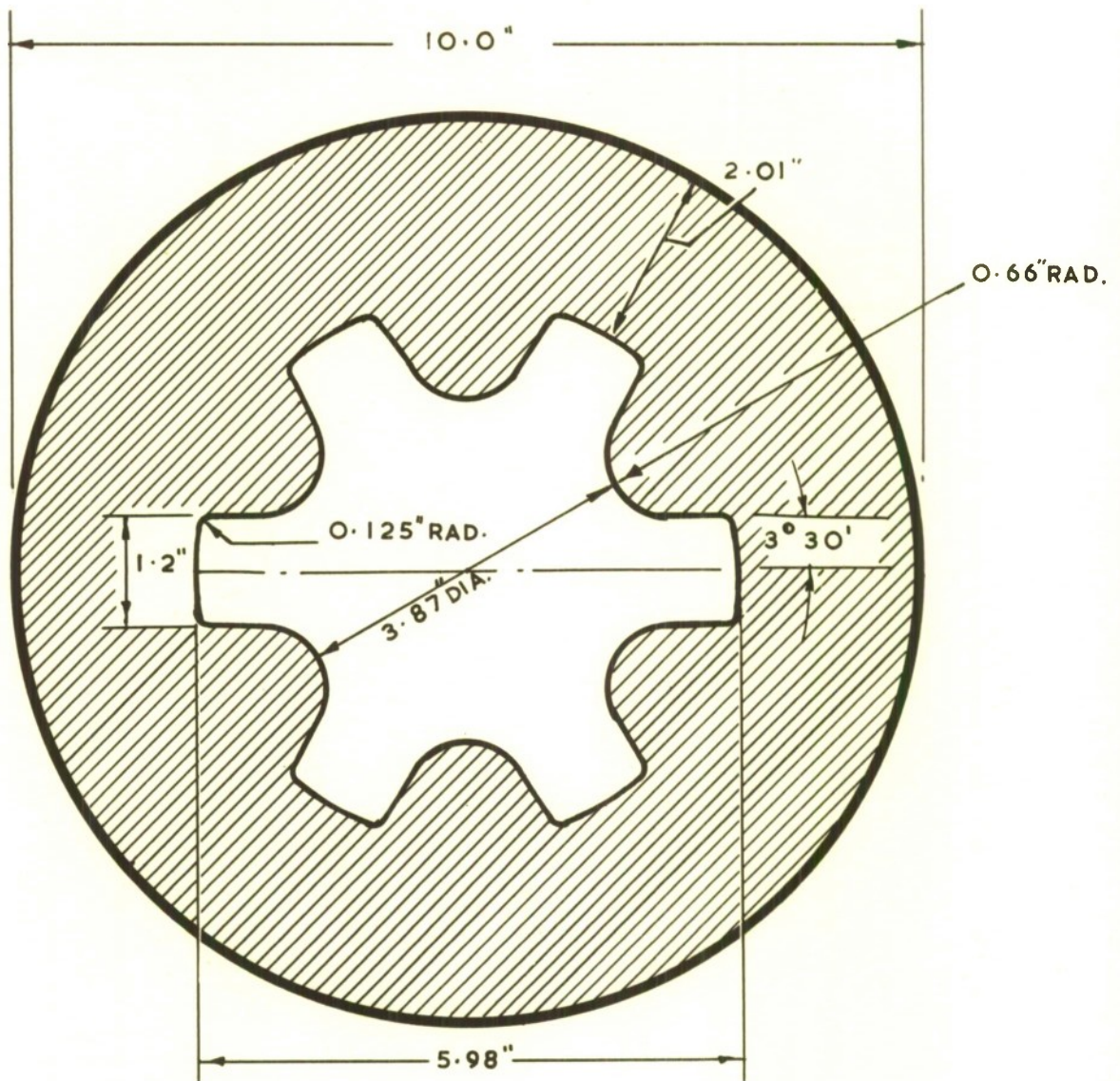


FIG. 2 CHARGE DESIGN C D 43

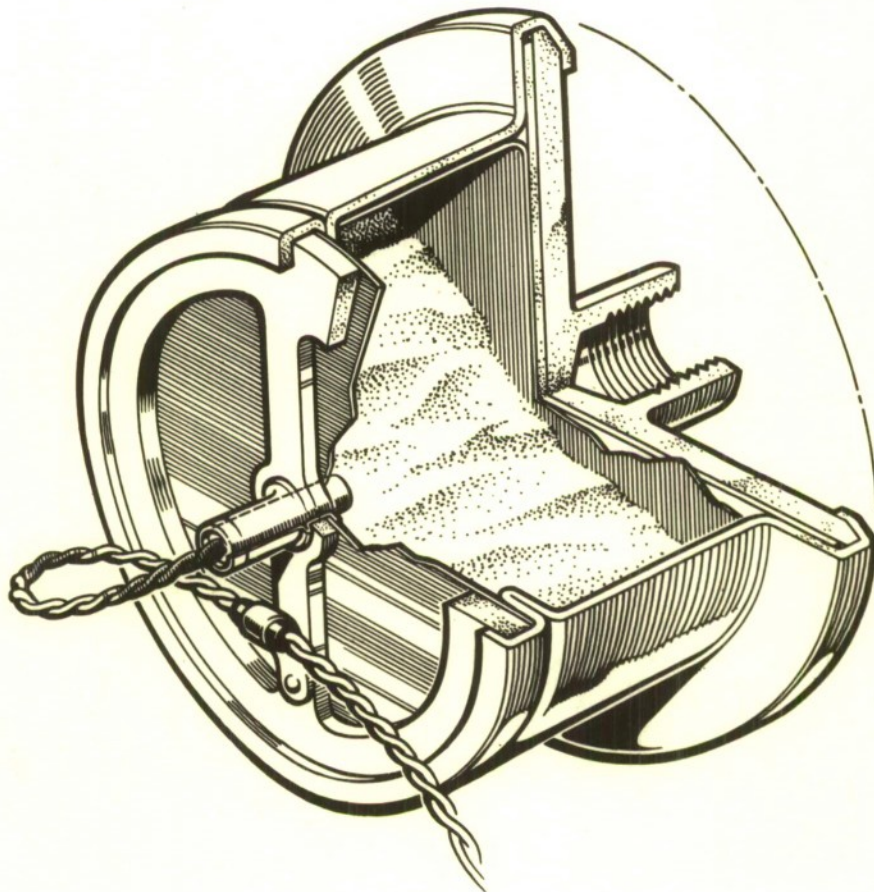
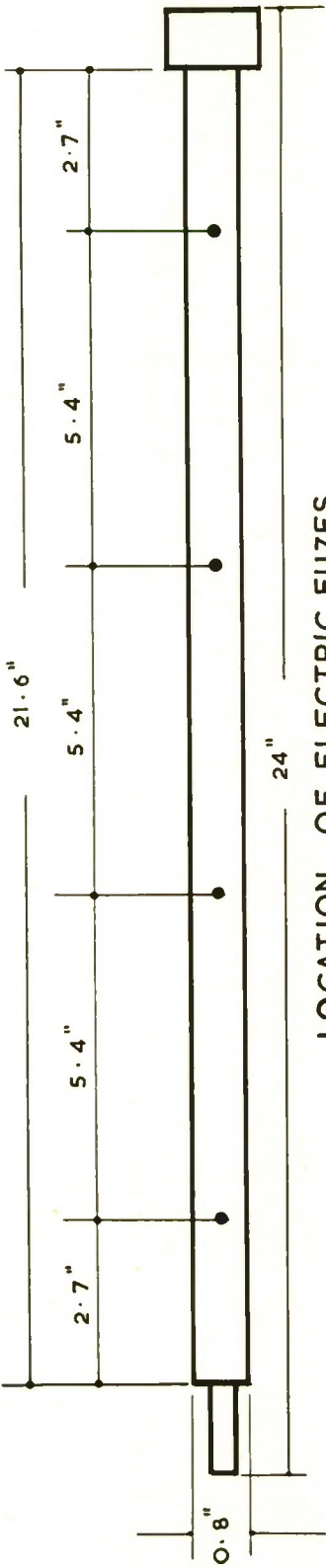


FIG. 3 METAL HOUSED IGNITER



LOCATION OF ELECTRIC FUZES

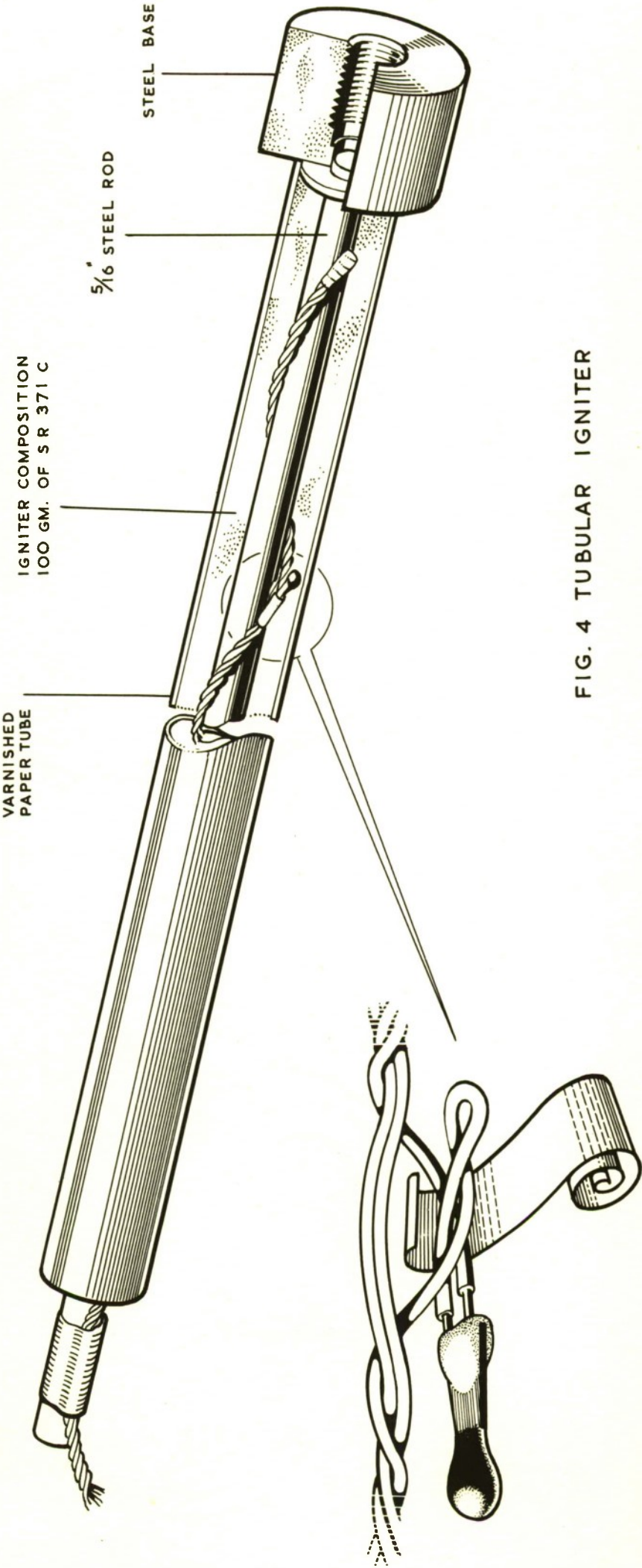


FIG. 4 TUBULAR IGNITER

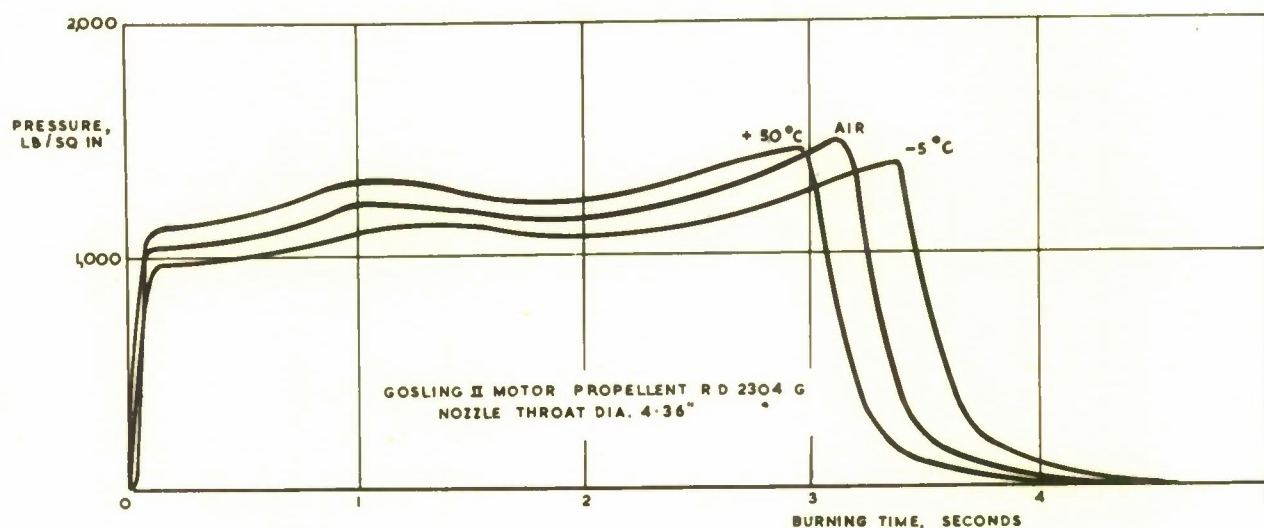


FIG. 5 TYPICAL PRESSURE - TIME CURVES

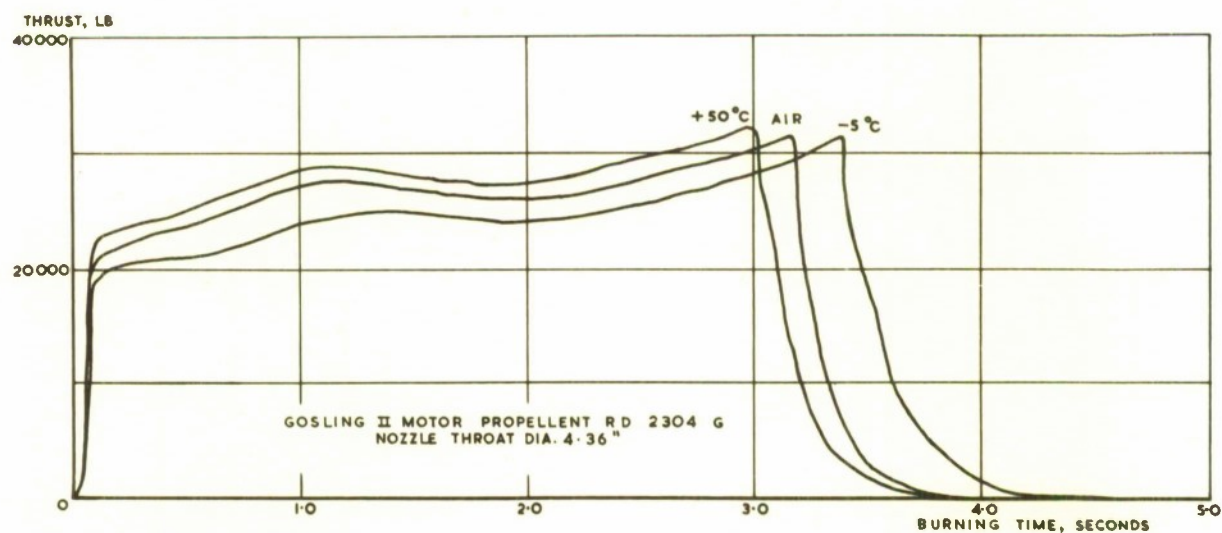


FIG. 6 TYPICAL THRUST - TIME CURVES

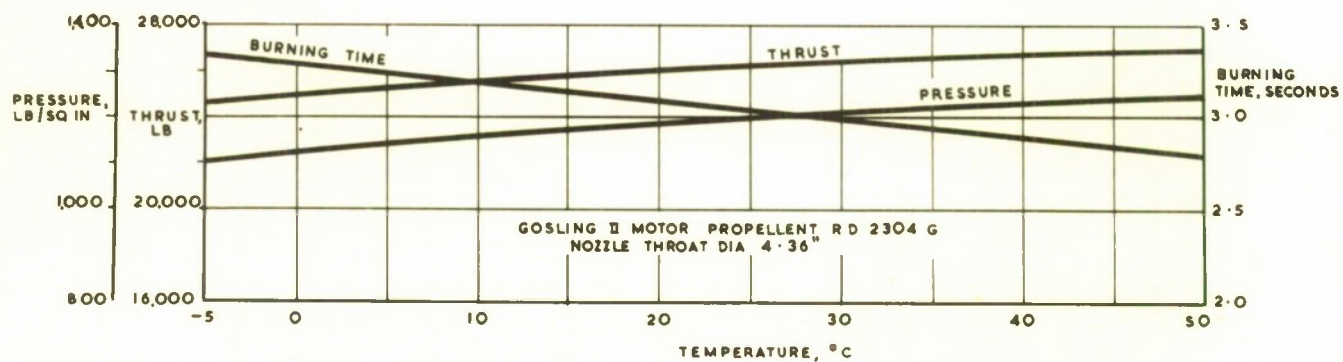


FIG. 7 VARIATION OF MEAN PRESSURE, THRUST & BURNING TIME WITH OPERATING PRESSURE

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