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ROYAL AIRCRAFT ESTABLISHMENT

FARNBOROUGH, HANTS

REPORT No: R.P.D.8

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**INFLUENCE OF OPERATING PRESSURE
UPON THE WEIGHT OF LIQUID
PROPELLANT ROCKET MOTORS
FOR MEDIUM RANGE GUIDED MISSILES**

by

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2 ROYAL AIRCRAFT ESTABLISHMENT, FARNBOROUGH

4 The influence of operating pressure upon the weight of liquid propellant rocket motors for medium range guided missiles

by

A.D. Baxter

and

J. Frauenberger
5

SUMMARY

A study of rocket motor weight as affected by thrust in the range 2000 to 4000 lb, total impulse in the range 100,000 to 200,000 lb sec, and combustion chamber pressure in the range 10 to 60 atm has been made both for pressurized tank and turbo-pump motor systems.

It is shown that the optimum operating pressure for the pressurized systems is between 15 and 20 atm and for turbo-pump systems between 30 and 35 atm. In these conditions the turbo-pump system has at all times a considerable advantage in weight for both the filled and empty motor.

Formulae for giving approximate motor weights are also deduced.

-
- 1. Liquid Propellant Rocket Motors I. Baxter, A.D.
 - 2. Guided missiles.

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LIST OF CONTENTS

	Page
1 Introduction	3
2 Method of calculation	3
2.1 Combustion chamber	4
2.2 Propellant tanks	4
2.3 Gas pressure system	5
2.4 Turbo-pump system	5
2.5 Pipes and valves	5
3 Results	5
3.1 Generalized weight estimates	6
3.2 Discussion	6
3.3 Future improvements	8
4 Conclusions	9
References	9
Advance Distribution	10

LIST OF TABLES

	Table
Operating ranges	I
General assumptions	II
Motor weights for 100,000 lb sec impulse	III
" " " 150,000 " " "	IV
" " " 200,000 " " "	V
Weight constants for rocket motor components	VI

LIST OF ILLUSTRATIONS

	Fig.
Layout of rocket motor	1
(a) Pressurized tank system	1(a)
(b) Turbo-pump system	1(b)
Schematic arrangement of combustion chamber and propellant tanks	2
Variation of weight of filled motor with combustion chamber pressure	3
Variation of weight of empty motor with combustion chamber pressure	4
Variation of motor weight with operating time	5
Variation of combustion chamber weight with pressure	6
Proposed pump feed system	7

1 Introduction

The propellant consumption of a rocket motor decreases as the combustion chamber expansion ratio increases and with a given back pressure the expansion ratio is proportional to combustion chamber pressure. Any increase in the latter involves an increase in the weight of certain motor components. Hence the reduction in consumption by increasing the operating pressure of the motor is to some extent off set by an increase in motor weight, and it is likely that an optimum pressure will be reached which gives a minimum all up weight of rocket motor and propellant for a given duty.

In the past calculations have suggested that a chamber pressure of approximately 20 atm is the optimum. However, departures from this are not infrequent as, for example, the V.2 which operated at 15 atm only and recent American designs which have chamber pressures of 50 atm. The actual optimum will be influenced by various factors such as the thrust level, time of operation, and the use of gas pressurized propellant tanks or turbo-pumps for delivering the propellant to the combustion chamber.

There are various advantages which high chamber pressures will give and in the light of recent developments in motor design, it was considered that a review of the earlier conclusions on optimum pressure would be useful. The present report examines the problem, but is only concerned with thrusts and total impulses of the order that may be expected in medium range guided missiles as shown in Table I given below.

Table I

Operating ranges

Operating Conditions	Minimum	Maximum
Thrust (lb)	2,000	4,000
Total Impulse (lb/sec)	100,000	200,000
Combustion Chamber Press. (atm)	10	60
Operating Time (sec)	25	100

From the present investigations it has been possible to deduce generalized formulae for the weight of rocket motors within the operating ranges and to deduce the operating time at which a change from a pressurized system to a turbo-pump system becomes advantageous.

2 Method of calculation

There are two basic motor layouts distinguished by the methods of delivering the propellants to the combustion chamber, viz.

- (a) pressurized tank
- (b) turbo-pump

Both are illustrated diagrammatically in Fig.1, which indicates the main components entering into the calculation of motor weight. These are.

- (i) combustion chamber
- (ii) propellant tanks
- (iii) propellant delivery equipment
- (iv) control valves and pipes.

In general conventional designs are considered for these components and the various assumptions necessary to estimate their weights are discussed in detail in later sections.

Other assumptions made are that the weights of any pistons or bags for controlling the propellants under the influence of lateral or negative acceleration can be neglected as well as the weight of assembly framework and missile skin connecting the propulsion components. In the case of pressurized systems the tanks can sometimes be used as structural members and so reduce the weight debited to the motor. This possibility has not been considered in the present comparisons.

The propellants are taken as white fuming nitric acid and kerosene injected at a mixture ratio of 5 : 1, which is 10% fuel rich. This gives a theoretical specific impulse of 228 sec for combustion at 20 atm and gases expanding down to 1 atm¹. For purposes of calculation, a practical specific impulse of 200 sec has been assumed, that is, 87.7% of the theoretical. This ratio of practical to theoretical specific impulse has been used in calculations for all chamber pressures. The actual values are dependent upon the chamber pressure and are tabulated in Table II given at the end of the text page 11.

2.1 Combustion chamber

It has been assumed that the combustion chamber is regeneratively cooled by nitric acid and that a conventional impinging jet injector head is used. The relative dimensions of the chamber and expansion nozzle are indicated in Fig.2. It will be seen that a value of $L^* = 50$ in, and a cylindrical form of chamber of diameter D with the ratio $L/D = 1.5$ have been chosen. The nozzle throat and exit dimensions are calculated from the usual thermodynamic formulae¹.

A good welding steel is used for both inner and outer jackets of the chamber and, for estimating the wall thickness a stress of 4 tons per sq in is used for the inner jacket and approximately twice this for the outer shell.

2.2 Propellant tanks

The oxidant and fuel tanks are shown diagrammatically in Fig.2. Both are of the same diameter and have dished ends. For the oxidant tank the length/diameter ratio of 4 is selected to produce a minimum weight of the combined tanks². An ullage space of 10% is allowed, to cater for the expansion of the propellants due to temperature changes from 15°C up to 70°C. At the latter temperature the pressure in a fully sealed nitric acid tank would rise from 1 atm to 3.3 atm and in a kerosene tank from 1 atm to 2.0 atm.

The propellant delivery pressure necessary to cater for pressure drops in pipes and across injectors are given in Table II for various combustion chamber conditions. For the pressurized tanks this is the working pressure and test pressures are assumed to be 50% in excess of this. The material is stainless steel of welding quality (BS/STA5/V6A) and the working stress is approximately 25% of the ultimate tensile stress.

For the turbo-pump system the tanks are not pressurized, but allowance is made for a light pressure (up to 3 atm) to be applied to assist pump suction. The material in this case is aluminium alloy. In both systems suitable allowance is made for weight of flanges and bosses for filling and delivery connexions. Light alloy presents no advantage in

the pressurized tanks as the strength at the welds is a limiting factor. The strength here is estimated to fall between 10% and 50% according to the wall thickness. With 10% loss in strength the tank weight is almost the same in light alloy or steel. At 33% loss, the light alloy tank would be almost 25% heavier.

2.3 Gas pressure system

A recent assessment of gas pressurizing systems³ indicates that a cordite or similar powder charge for generating high gas pressure will be the lightest system. Such systems have not yet been fully developed, but it is assumed that the problems of reducing the high gas temperatures to an acceptable figure and ensuring compatibility of the gas and propellant can be overcome without any material increase in weight.

Charge design is based on a method previously published⁴ and similar numerical values of the constants are used.

2.4 Turbo-pump system

The turbo-pump system includes, as shown in Fig.1(b), the turbo-pump itself, a steam generator, H.T.P. supply tank and a nitrogen pressurizing bottle.

The weight of the pump and steam consumed for driving it are calculated from existing data⁵, but an additional arbitrary allowance of H.T.P. to cover starting and idling conditions equivalent to a 3 seconds run at full load is included. A small spherical light alloy (A.W.10) tank is used for storing the H.T.P. It is pressurized to 30 atm, and has a working stress of 0.25 times the ultimate tensile stress of the material. The pressurizing nitrogen is stored at 150 atm, and the size of bottle is based on adiabatic expansion of the gas. A combined reducing and starting valve is included, but the flow rate is so small that the smallest practicable valve covers all conditions.

The steam generator uses silver gauze catalyst packed at 30 layers per in. With a depth of bed of 8 in, this will decompose H.T.P. at a rate of 0.427 lb/sec per sq in. of cross section. The only design variable is, therefore, the diameter.

2.5 Pipes and valves

The lengths of gas and liquid pipes can be estimated from the layout of propellant tanks and combustion chamber shown in Fig.1. The gas pipes are included in the weight of the pressurizing system and only liquid lines are detailed under this heading.

The valves also present no special problems; the main valve is assumed to be a dual unit controlling starting rates and relative lead of one propellant to the other.

3 Results

The results of the component calculations are summarized in Tables III, IV and V (see pages 12, 13 and 14 respectively); curves of the weights of the filled and empty motor are given in Fig.3 and 4 respectively.

Referring to Fig.3 it will be observed that in all cases the pressurized tank system shows a minimum weight at combustion chamber pressures slightly below 20 atm, but the turbo-pump system continues to fall slightly, even at the highest chamber pressures. The decrease in

weight beyond a pressure of 30 atm is very small and it may be concluded that 30 to 35 atm is probably the best operating pressure.

Fig.4 shows a comparison of the empty weight of 3000 lb thrust motors for different values of total impulse or operating time. It can be seen that the empty weight of the turbo-pump system remains relatively constant for different operating pressures. On the other hand the empty weight of the pressurized system increases steadily with increase of pressure which suggests that it might be advantageous to use operating pressures as low as 15 atm. The table also reveals that for the pressurized system the ratio of empty to filled weight lies between 0.3 for high thrust and low impulse and 0.23 for low thrust and high impulse; the corresponding values for the turbo-pump system are between 0.24 and 0.12.

3.1 Generalized weight estimates

The weight of a rocket motor is chiefly dependent on thrust and operating time. The combustion chamber pressure has also an effect as has been shown, but if this is fixed, the weight can be written in the general form

$$W = a + b.F + c.Ft$$

where W is the motor weight lb
 F " " " thrust lb
 t " " " thrust duration sec

and a, b, c are constants

All the components can be dealt with in this form by using appropriate constants. From Tables III, IV and V the constants have been determined for combustion chamber pressures of 20 atm in the pressurized system and 30 atm in the pump system. The results are given in Table VI (see page 15) and lead to the conclusion that for pressurized tank systems

$$W = 11.3 + 0.018 F + 0.0065 Ft \quad (1)$$

and for turbo-pump systems

$$W = 26.7 + 0.028 F + 0.0054 Ft \quad (2)$$

These results are correct to a first approximation only and their validity has not been tested outside the operating ranges stated in Table I, but some extrapolation should be permissible.

3.2 Discussion

From the tables it will be seen that the two systems have identical combustion chambers, propellant pipes and valves, and weight of propellants when operating at the same chamber pressure, but for purposes of comparison, the optimum pressure conditions indicated above should be used.

In this case the turbo-pump uses less propellant because of the higher specific impulse, but the consumption of H.T.P. for driving the turbine is higher in order to cope with the greater power needed to deliver the propellants at the higher pressure. The result is that the gross propellant consumption of the motor with the turbo-pump system is almost identical with that of the motor with the pressurized tank and gas pressurizing charge. It is then apparent that the advantage of the turbo-pump is almost entirely due to the difference in propellant tank weights.

Propellant tanks in the pressurized system increase in weight directly with the operating pressure and with the total impulse, whereas with the turbo-pump system the tank weight decreases slightly with increasing chamber pressure owing to the smaller volume of propellant associated with increasing specific impulse. In the second case the tanks weigh between 5% and 7% of the weight of propellant stored, but in the first case they are 25% of the propellant weight of the optimum motor.

As has been pointed out in the assumptions, the pressurized tanks can take some of the missile structural stresses; hence the apparent weight of the motor with the pressurized tank can be decreased by some undetermined amount which should be debited to the structure. It is unlikely that this will approach 10% of the weight of the filled motor, which is the order of the difference in weight between the two systems, except for motors of the shortest operating times.

In Fig.5 the motor weights are plotted against operating time and these show that the pump motors have a weight advantage beyond 17 sec at 2000 lb thrust and 12 sec at 4000 lb thrust. In practice, the weight allowance for pressurized tanks might increase these times by, say, 10 sec. On the other hand, it must be remembered that for the pressurizing system it has been assumed that a very advanced gas generating system is used, whereas for the pumps only existing component designs are used which present a wide field for improvement. Some of these are mentioned in a later paragraph.

The overall pressure drop between tanks and combustion chamber has been reduced to a lower figure than is present normal practice. This favours the pressurized tanks as any increase in expulsion pressure produces an immediate weight penalty. It is also assumed in estimating the empty weight of the pressure tank system that the gas generated for expulsion is actually exhausted overboard at 'all-burnt', though this will not in fact be the case if a piston or other seal is interposed between it and the propellants.

In neither system have expulsion pistons been included in the weight of the tanks, but the additional weight would be the same for both systems. It might be necessary to supply some slight pressure behind the piston of the motor with the turbo-pump and this would involve an additional weight. It would however, be only slight if exhaust steam from the turbine could be used or gas bled from the venturi nozzle of the chamber.

In examining the change in weight of other components it can be seen that at constant thrust the weight of the combustion chamber decreases slowly with increasing pressure. This is because the greater wall thickness required is more than compensated by the reduction in volume obtained for a constant value of L^* . At the same time, however, the increasing expansion ratio requires a venturi nozzle which becomes a greater proportion of the whole chamber. Ultimately this will produce an increase in overall chamber weight but by the time this condition is reached, limitations in other directions are probable, such as space available in the head for propellant injection. The trend is clearly shown in Fig.6 where the weights of complete chamber, venturi and combustion space are plotted against pressure for a 4000 lb thrust unit.

The gas pressurizing generator and its associated equipment increase in weight directly with operating pressure and with total impulse, but this increase in weight is practically independent of thrust. On the other hand the weight of the turbo-pump pressure equipment depends more on thrust than impulse and has a total weight between two and three

times as great in the range considered. The propellant pipes and valves weigh the same; the only difference is that low pressure pipes of large diameter connect the tanks with the junction of the pump to the system, whereas high pressure pipes of smaller diameter, but of approximately the same weight as those of the other system lead straight through to the tanks of the pressurized system.

3.3 Future improvements

It is not proposed to analyse in detail the possibilities of future reductions in weight, but a brief indication of some lines on which development may show improvement is given here.

The chief advantage of the turbo-pump system in avoiding heavy propellant tanks is somewhat offset by the extra weight of pumps and their driving gear. Any improvements in these would, therefore, be advantageous. Amongst the proposals at present under development are schemes for more efficient pumps⁶ which should reduce both weight and steam consumption by 10-20%. This would give a consequential saving in weight of H.T.P. and nitrogen, and of their containers, as well as in the weight of the steam generator.

Another proposal (not yet reported) by D.J. Saunders is shown in Fig.7. This involves a very small turbo-pump which sucks H.T.P. from a light unpressurized tank and pumps it to the steam generator, the weight involved is that of a small additional quantity of H.T.P., the turbo-pump and a control valve. This weight will be considerably less than that of the original nitrogen pressure bottle, reducing valve and pressurized tank which they replace. As an example such a system applied to a motor of 4000 lb thrust and 200,000 lb sec impulse would reduce the filled weight from 1212 lb to 1190 lb which is 92 lb less than the weight of the motor with the pressurized tank system.

A turbine drive utilizing gases from a high pressure pilot chamber has been proposed in America. With this system no auxiliary gear would be required except starting equipment which could be mounted externally on the missile launching ramp. All the driving gases would be directed into the main chamber and so would be effective in generating rocket thrust. The pilot chamber would involve some additional empty weight, but this would be more than balanced by the absence of H.T.P. tanks, steam generator and other gear. There is, however, a great deal of development work involved in this scheme.

Against these suggested improvements the only likely saving in weight of the pressurized system is by new methods of tank construction, which enable the necessary strength to be obtained with a lower weight, or which combine existing weight with missile structure weight in a still more efficient manner.

The combustion chamber is the other major component of the empty weight of rocket motors and proposals for improvements have been discussed in another report². There are indications that a reduction in weight between 20% and 50% can probably be achieved. This saving in weight would affect both the pump and pressurized systems equally.

Finally, it is obvious that even a small improvement in specific impulse would effect a major saving in filled weight and efforts to achieve this are, therefore, very worth while.

4 Conclusions

It is shown that a rocket motor with a pressurized propellant tank has a minimum weight when the combustion chamber pressure is between 15 and 20 atm. Similarly a motor driven by a turbo-pump operates most effectively between 30 and 35 atm. The first type of motor is considerably heavier than the second mainly on account of the heavier tanks required to withstand the high delivery pressures. The advantage in weight of the second system remains approximately constant throughout the flight of the rocket. Further advantage may be gained if the more advanced pumping systems envisaged are developed.

It has also been shown that the weight of a rocket motor depends partly upon thrust and partly upon total impulse; formulae which should prove of value to missile designers have been derived for calculating the initial weight.

LIST OF REFERENCES

<u>No.</u>	<u>Author</u>	<u>Title, etc.</u>
1	W.H. Williams	Thermodynamic charts for the combustion products of nitric acid and kerosene. R.A.E. Tech. Note No. RFD.33, July, 1950.
2	-	Report of the R.A.E. project group on medium range anti-aircraft guided missiles. Appendix V - Rocket Motors R.A.E. Report No. G.W.6 Part III, Dec. 1949.
3	W.H. Bond	An assessment of rocket propellant systems for R.T.V.2 R.A.E. Tech Note No. RFD.20, Aug. 1949.
4	J.W. Orton	Development of a cordite operated fuel expulsion system for 7.2 in. ram jet. R.A.E. Tech. Note No. RFD.9, Dec. 1948.
5	D.J. Saunders	A method of calculating the weight and dimensions of a turbo-pump for rocket propellants R.A.E. Tech. Note No. RFD.22, Nov. 1949.
6	A.D. Baxter	High pressure pumps for rocket propellants R.A.E. Tech. Note No. RFD.12, Feb. 1949.

Attached:

Table II to VI
 RP.418 to 424

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Table II
General Assumptions

Combustion Chamber Pressure (atm)	10	20	30	40	60
Actual Specific Impulse (sec)	179	200	210	216	226
Propellant Delivery Pressure (atm)	18.0	28.5	40.0	51.5	74.0
Turbo-Pump Steam Consumption lb/sec/lb Propellant sec	0.029	0.043	0.059	0.073	0.099

Table III

Motor Weights for 100,000 lb/sec Impulse

System	Thrust	2000 lb for 50 sec					3000 lb for 33.3 sec					4000 lb for 25 sec				
		10	20	30	40	60	10	20	30	40	60	10	20	30	40	60
Pressurized Tanks	Combustion Chamber Press. atm															
	Comb. Chamber lb	41	33.4	30.6	29.6	29.2	58.8	48	44.7	44.4	43.8	74.5	62.5	59.5	59.2	59.2
	Propellant Tanks lb	93	125	171	214	300	93	125	171	214	300	93	125	171	214	300
	Gas Pressure System lb	13.6	17.2	25.7	35.4	55.5	13.2	16.7	25.2	35.0	55.0	13.1	16.4	25.0	34.8	54.7
	Pipes and Valves lb	13.0	13.0	13.0	13.0	13.0	17.1	17.1	17.1	17.1	17.1	20.4	20.4	20.4	20.4	20.4
EMPTY WEIGHT	Combustion Chamber lb	160.6	188.6	240.3	292.0	397.7	182.1	206.8	258.0	310.5	415.9	201.0	224.3	275.9	328.4	434.3
	Propellants lb	560.0	500	476	463	443	560	500	476	463	443	560	500	476	463	443
	Gas Press. Charge lb	6	8.4	11.4	14.2	18.7	5.8	8.4	11.4	14.2	18.6	5.7	8.4	11.4	14.2	18.4
	FILLED WEIGHT	726.6	697.0	727.7	769.2	859.4	747.9	715.2	745.4	787.7	877.5	766.7	732.7	763.3	805.6	895.7
Turbo-Pump	Combustion Chamber lb	41	33.4	30.6	29.6	29.2	58.8	48	44.7	44.4	43.8	74.5	62.5	59.5	59.2	59.2
	Propellant Tanks lb	36	33.4	32.6	32.3	31.7	36	33.4	32.6	32.3	31.7	36	33.4	32.6	32.3	31.7
	Turbo-Pump System lb	25.7	29.6	33.9	37.9	44.7	35.2	39.4	44.5	49.4	57.5	42.6	47.5	53.2	58.7	67.7
	Pipes and Valves lb	13	13	13	13	13	17.1	17.1	17.1	17.1	17.1	20.4	20.4	20.4	20.4	20.4
EMPTY WEIGHT	Combustion Chamber lb	115.7	109.4	110.1	112.8	118.6	147.1	137.9	138.9	143.2	150.1	173.5	163.8	165.7	170.6	179.0
	Propellants lb	560	500	476	463	443	560	500	476	463	443	560	500	476	463	443
	Turbo-Pump Fluids lb	17.5	24.1	31.5	33.3	49.6	18.1	24.8	32.4	39.2	50.9	18.6	25.5	33.8	40.4	52.4
	FILLED WEIGHT	693.2	633.5	617.6	614.1	611.2	725.2	662.7	647.3	645.4	644.0	752.1	689.3	675.5	674.0	674.4

Table IV

Motor Weights for 150,000 lb/sec Impulse

System	Thrust Combustion Chamber Press. atm	2000 lb for 75 sec					3000 lb for 50 sec					4000 lb for 37.5 sec				
		10	20	30	40	60	10	20	30	40	60	10	20	30	40	60
Pressurized Tanks	Combustion Chamber 1b	41	33.4	30.6	29.6	29.2	58.8	48	44.7	44.4	43.8	74.5	62.5	59.5	59.2	59.2
	Propellant Tanks 1b	130	189	255	318.5	450	130	189	255	318.5	450	130	189	255	318.5	450
	Gas Press. System 1b	18.6	24.0	36.6	51.0	81.6	18.3	23.4	36.6	50.8	80.8	18.0	23.0	35.8	50.6	80.0
	Pipes and Valves 1b	13.0	13.0	13.0	13.0	13.0	17.1	17.1	17.1	17.1	17.1	20.4	20.4	20.4	20.4	20.4
	EMPTY WEIGHT 1b	202.6	259.4	335.2	412.1	573.8	224.2	277.5	353.4	430.8	591.7	242.9	294.9	370.7	448.5	609.6
Turbo-Pump	Propellants 1b	839	750	715	695	664	839	750	715	695	664	839	750	715	695	664
	Gas Press. Charge 1b	9	12.6	17	21.2	28	8.8	12.6	17	21.2	27.8	8.6	12.6	17	21.2	27.6
	FILLED WEIGHT 1b	1050.6	1022.0	1067.2	1128.3	1265.8	1072.0	1040.1	1085.4	1147.0	1283.5	1090.5	1057.5	1102.7	1164.7	1301.2
	Combustion Chamber 1b	41	33.4	30.6	29.6	29.2	58.8	48	44.7	44.4	43.8	74.5	62.5	59.5	59.2	59.2
	Propellant Tanks 1b	45.5	42.6	41.4	40.6	40	45.5	42.6	41.4	40.6	40	45.5	42.6	41.4	40.6	40
Turbo-Pump	Turbo-Pump System 1b	29.1	34.1	40.5	45.5	54.8	39.2	44.3	51	56.8	67.3	46.6	52	59.8	66.3	77.6
	Pipes and Valves 1b	13	13	13	13	13	17.1	17.1	17.1	17.1	17.1	20.4	20.4	20.4	20.4	20.4
	EMPTY WEIGHT 1b	128.6	123.1	125.5	128.7	137.0	160.6	152.0	154.2	158.9	168.2	187.0	177.5	181.1	186.5	197.2
	Propellants 1b	839	750	715	695	664	839	750	715	695	664	839	750	715	695	664
	Turbo-Pump Fluids 1b	25.9	35.6	46.5	56.3	73	26.3	36.2	47.4	57.2	74.3	26.9	36.9	48.9	58.5	75.9
FILLED WEIGHT 1b	993.5	908.7	887.0	880.0	874.0	1025.9	938.2	916.6	911.1	906.5	1052.9	964.4	945.0	940.0	937.1	

Table V

Motor Weights for 200,000 lb/sec Impulse

System	Thrust	2000 lb for 100 sec					3000 lb for 65.6 sec					4000 lb for 50 sec				
		10	20	30	40	60	10	20	30	40	60	10	20	30	40	60
Pressurized Tanks	Combustion Chamber Press. atm															
	Combustion Chamb. lb	41	33.4	30.6	29.6	29.2	58.6	48	44.7	44.4	43.8	74.5	62.5	59.5	59.2	59.2
	Propellant Tanks lb	178	253.2	339	419	590	178	253.2	339	419	590	178	253.2	339	419	590
	Gas Press. System lb	23.6	30.7	47.9	67.3	105.6	23.4	29.7	45.9	66.5	104.7	23.0	29.1	41.9	62.5	100.3
	Pipes and Valves lb	13.0	13.0	13.0	13.0	13.0	17.1	17.1	17.1	17.1	17.1	20.4	20.4	20.4	20.4	20.4
Turbo-Pump	EMPTY WEIGHT	255.6	330.3	430.5	528.9	737.8	277.3	346.0	446.7	547.0	755.6	295.9	365.2	464.4	564.7	773.5
	Propellants lb	1120	1000	952	926	866	1120	1000	952	926	866	1120	1000	952	926	866
	Gas Press. Charge lb	12	16.9	23.7	28.3	36.7	11.9	16.9	23.7	28.3	36.4	11.6	16.9	23.7	28.3	36.2
	FILLED WEIGHT	1387.6	1347.2	1406.2	1483.2	1660.5	1409.2	1364.9	1422.4	1501.3	1678.0	1427.5	1382.1	1440.1	1519.0	1695.7
	Combustion Chamber lb	41	33.4	30.6	29.6	29.2	58.6	48	44.7	44.4	43.8	74.5	62.5	59.5	59.2	59.2
Turbo-Pump	Propellant Tanks lb	54.8	51	49.1	48.3	47	54.8	51	49.1	48.3	47	54.8	51	49.1	48.3	47
	Turbo-Pump System lb	32.7	39.2	46.4	53.1	64.6	42.4	49.1	57.3	64.6	77.1	49.8	56.7	66.5	73.9	87.4
	Pipes and Valves lb	13	13	13	13	13	17.1	17.1	17.1	17.1	17.1	20.4	20.4	20.4	20.4	20.4
	EMPTY WEIGHT	141.5	136.6	139.1	141.0	153.8	173.1	165.2	168.2	174.4	185.0	199.5	190.6	195.5	201.8	214.0
	Propellants lb	1120	1000	952	926	866	1120	1000	952	926	866	1120	1000	952	926	866
Turbo-Pump Fluids lb	34	47.1	61.4	74.2	96.4	34.6	47.7	62.2	75.3	97.6	35.3	48.2	64.1	76.5	99.4	
FILLED WEIGHT	1295.5	1183.7	1152.5	1144.2	1136.2	1327.7	1212.9	1182.4	1175.7	1168.6	1354.8	1238.8	1211.6	1204.9	1199.5	

Table VI

Weight Constants for Rocket Motor Components

System	Constant			
	Component	a	$b \times 10^3$	$c \times 10^5$
Pressurized Tanks (C.C Press. 20 atm)	Combustion Chamber	4.5	14.5	0.0
	Propellant Tanks	-3.0	0.0	128.0
	Pressurizing System	3.8	0.0	13.0
	Pipes and Valves	6.0	3.6	0.0
	Propellants	0.0	0.0	508.4
	TOTAL	11.3	18.1	649.4
Turbo-Pump (C.C Press. 30 atm)	Combustion Chamber	1.5	14.5	0.0
	Propellant Tanks	16.2	0.0	16.4
	Pressurizing System	3.0	9.5	12.5
	Pipes and Valves	6.0	3.6	0.0
	Propellants	0.0	0.0	508.4
	TOTAL	26.7	27.6	537.3

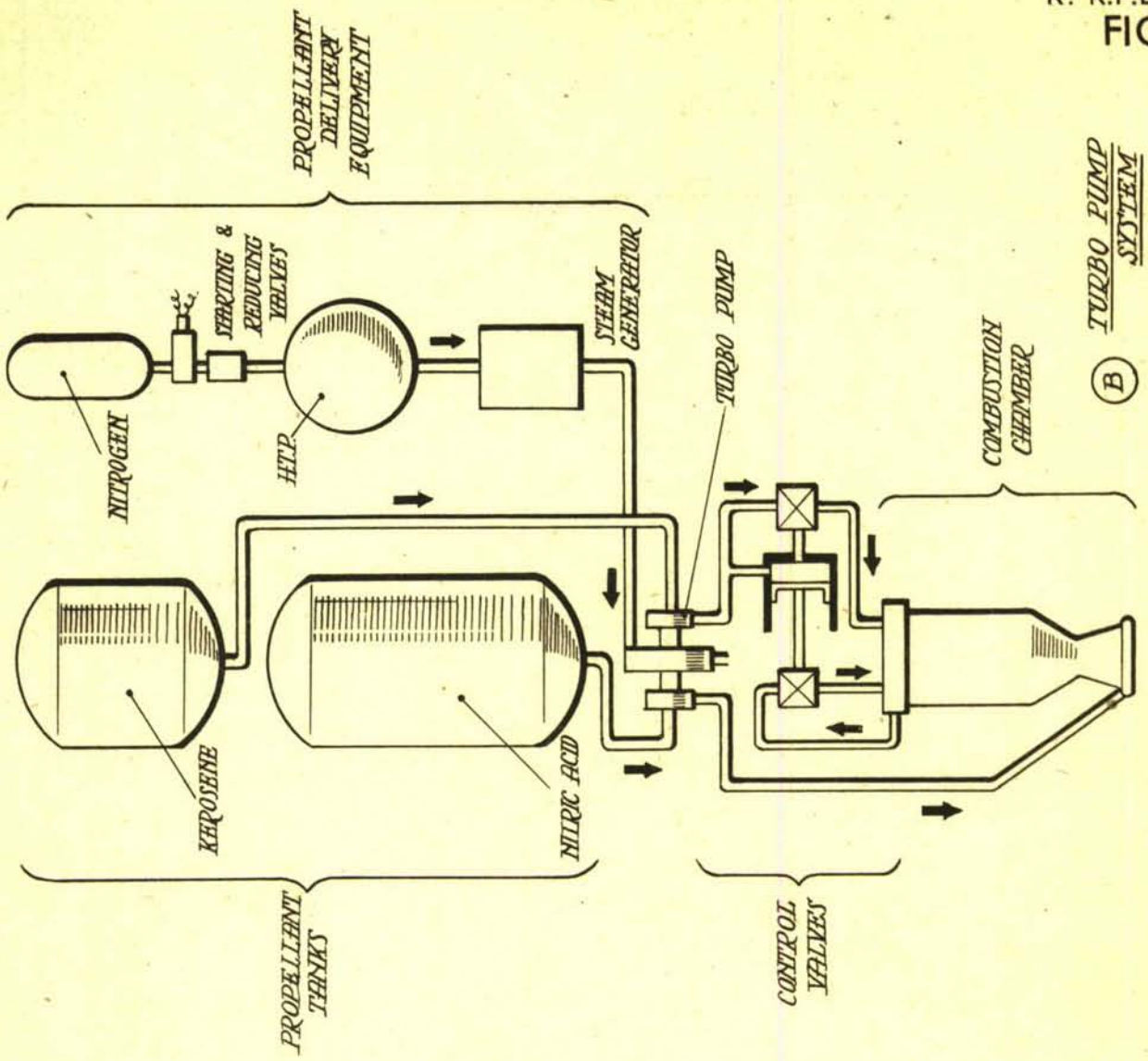
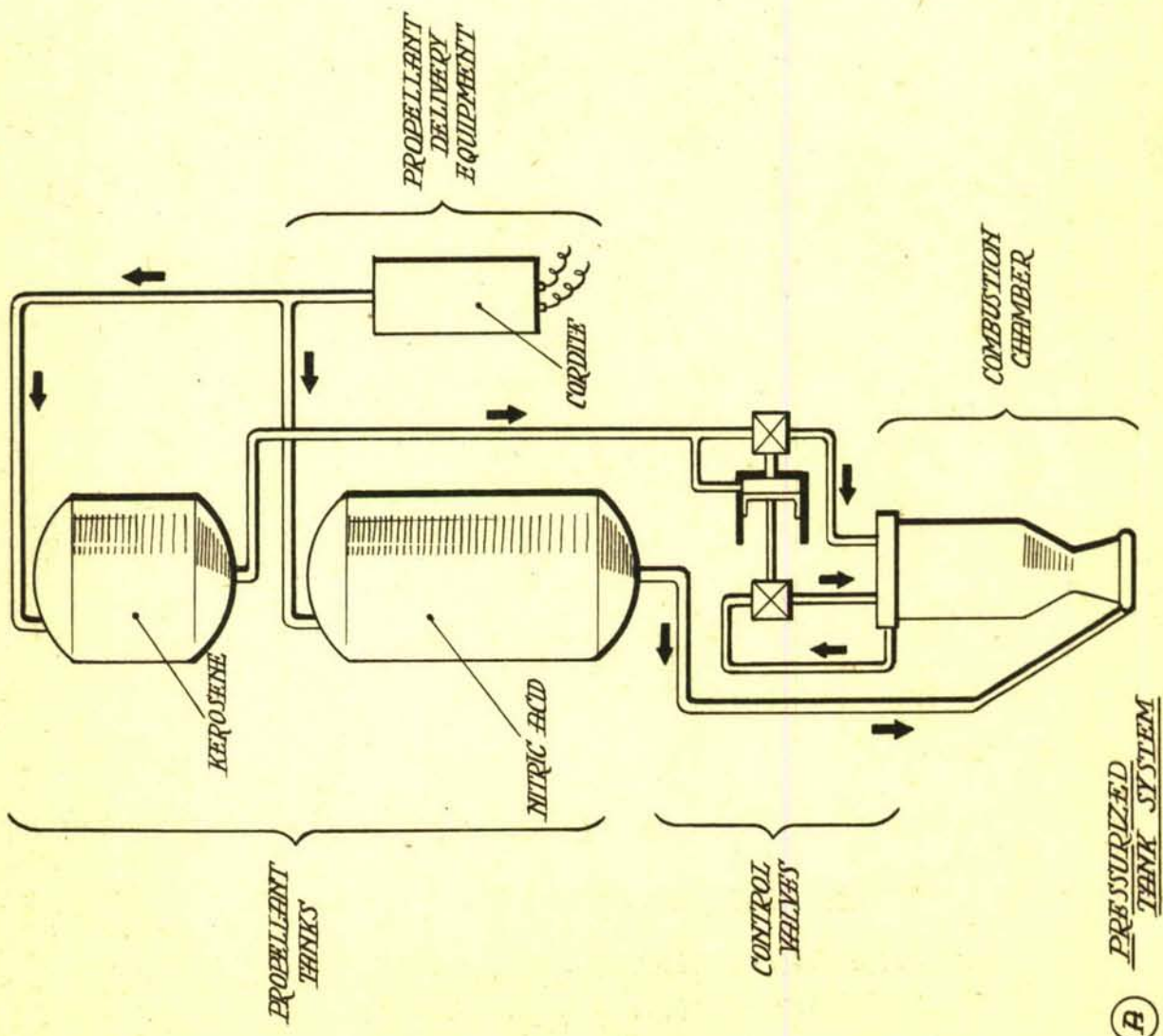
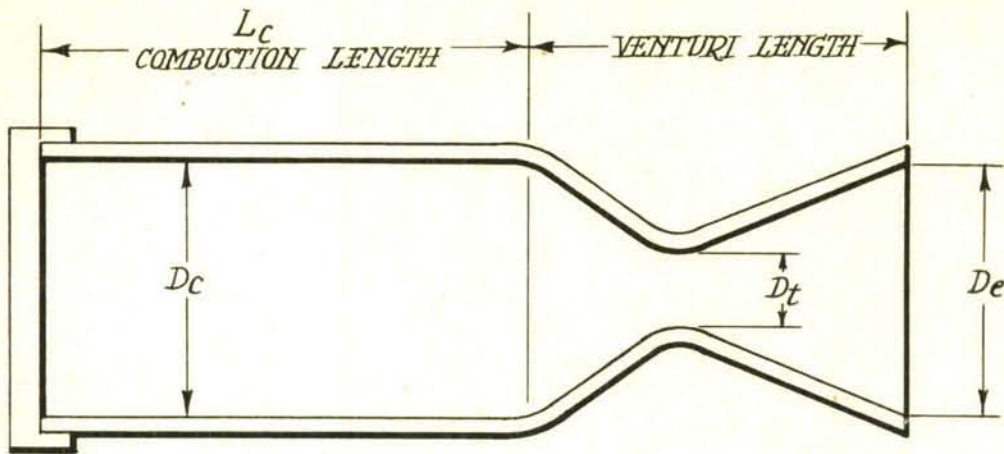


FIG. 1. LAYOUT OF ROCKET MOTOR



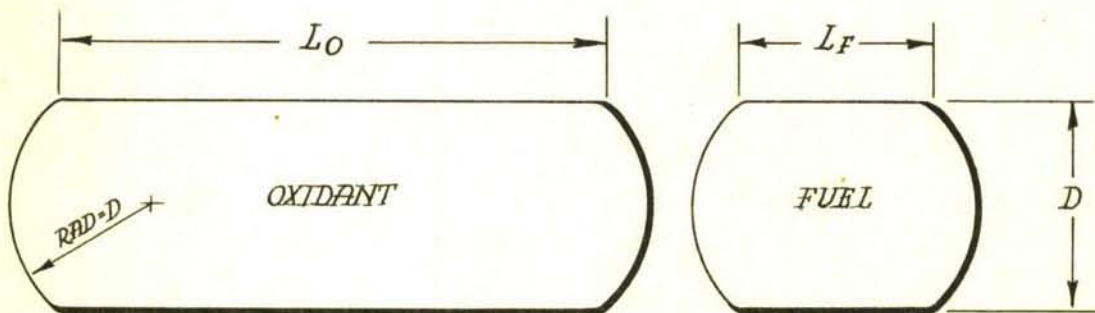


$$L^* = \frac{\frac{\pi}{4} D_c^2 L_c}{\frac{\pi}{4} D_t^2} = L_c \left(\frac{D_c}{D_t} \right)^2 \approx 50 \text{ IN}$$

$$\frac{L_c}{D_c} = 1.5$$

MATERIAL BS/STA.5/V6A ULTIMATE TENSILE STRESS 35/41 TONS/SQ IN
 OUTER SHELL WORKING STRESS 7.6 TONS/SQ IN
 INNER " " " 4.0 TONS/SQ IN

COMBUSTION CHAMBER



$$\text{OXIDANT TANK} \quad \frac{L_o}{D} = 4$$

$$\text{FUEL TANK} \quad \frac{L_f}{D} = 1.14$$

MATERIAL BS/STA.5/V6A ULTIMATE TENSILE STRESS 35/41 TONS/SQ IN
 WORKING STRESS 10.7 TONS/SQ IN

PROPELLANT TANKS

FIG.2. SCHEMATIC ARRANGEMENT OF COMBUSTION CHAMBER
 AND PROPELLANT TANKS

FIG. 3.

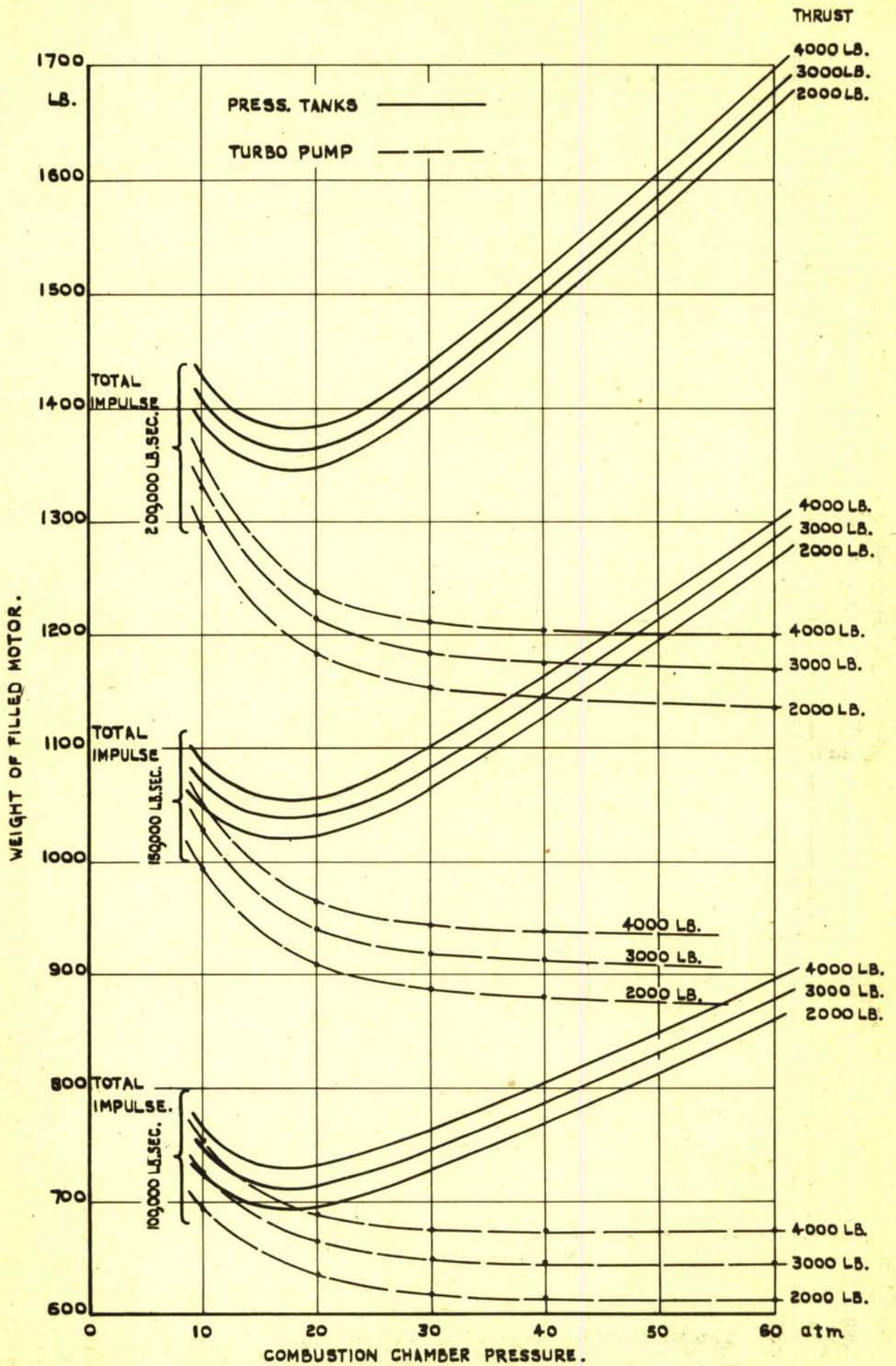


FIG. 3. VARIATION OF WEIGHT OF FILLED MOTOR WITH COMBUSTION CHAMBER PRESSURE.

FIG.4.

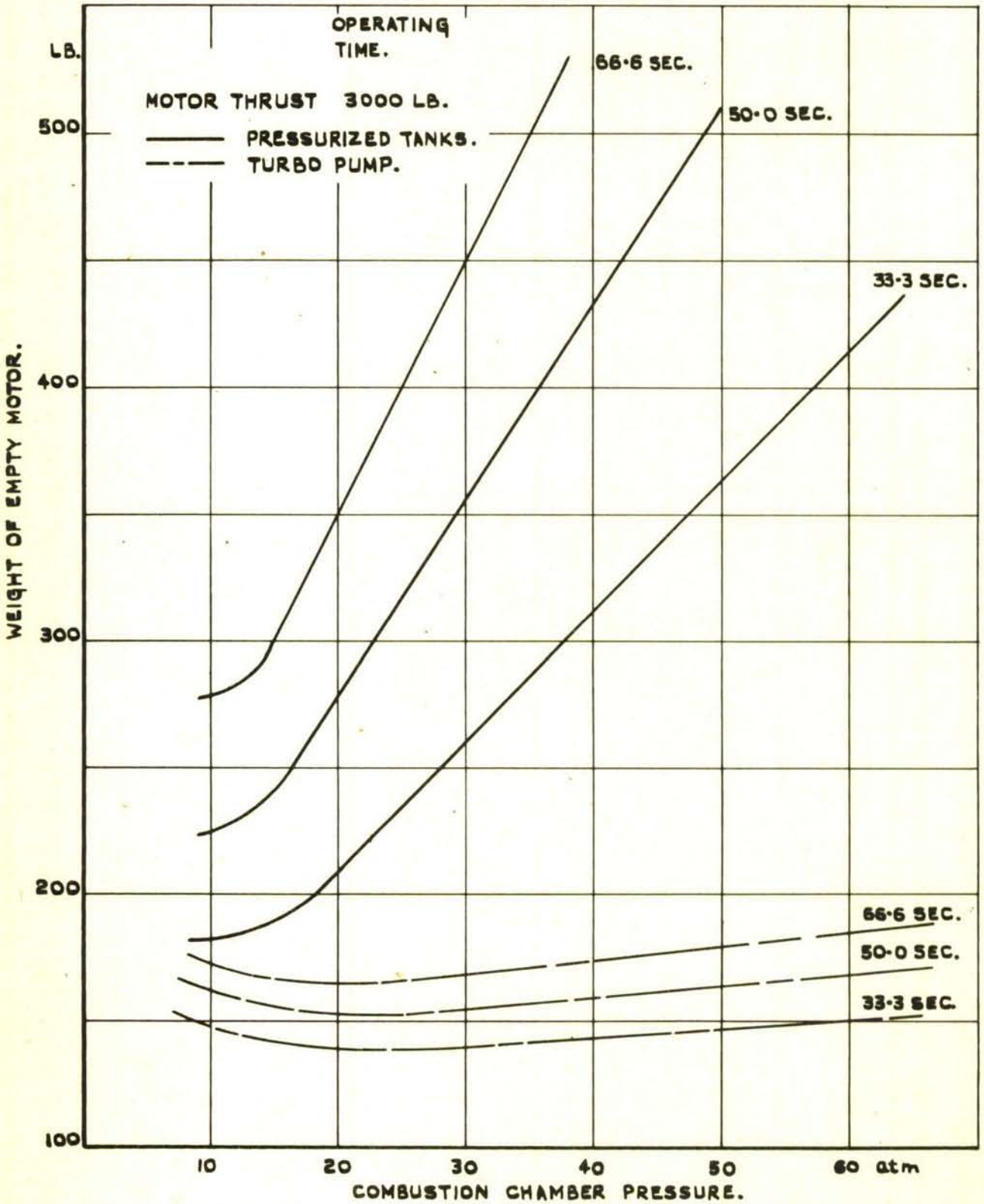


FIG.4. VARIATION OF WEIGHT OF EMPTY MOTOR WITH COMBUSTION CHAMBER PRESSURE.

FIG. 5.

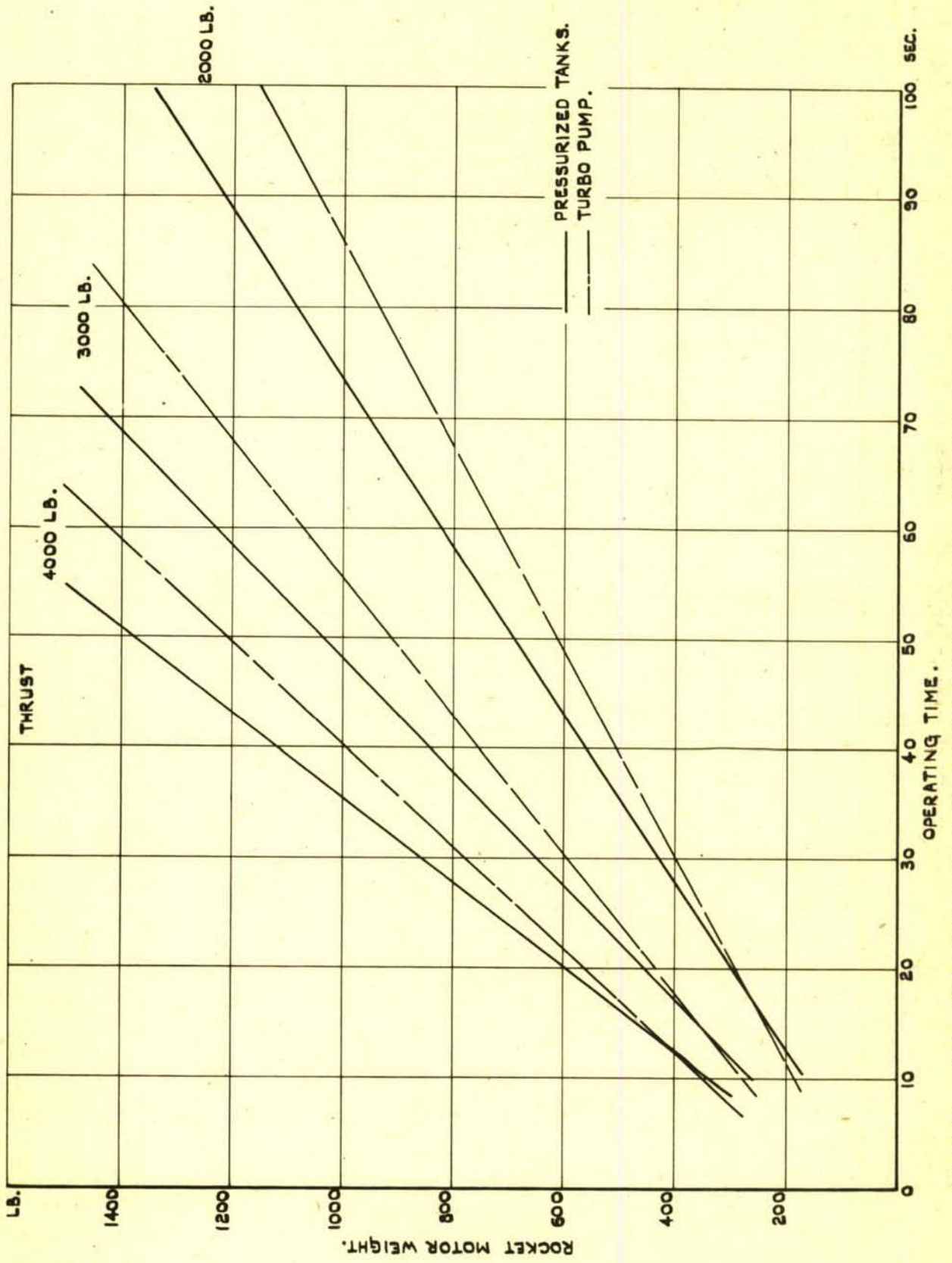


FIG. 5. VARIATION OF MOTOR WEIGHT WITH OPERATING TIME.

FIG.6.

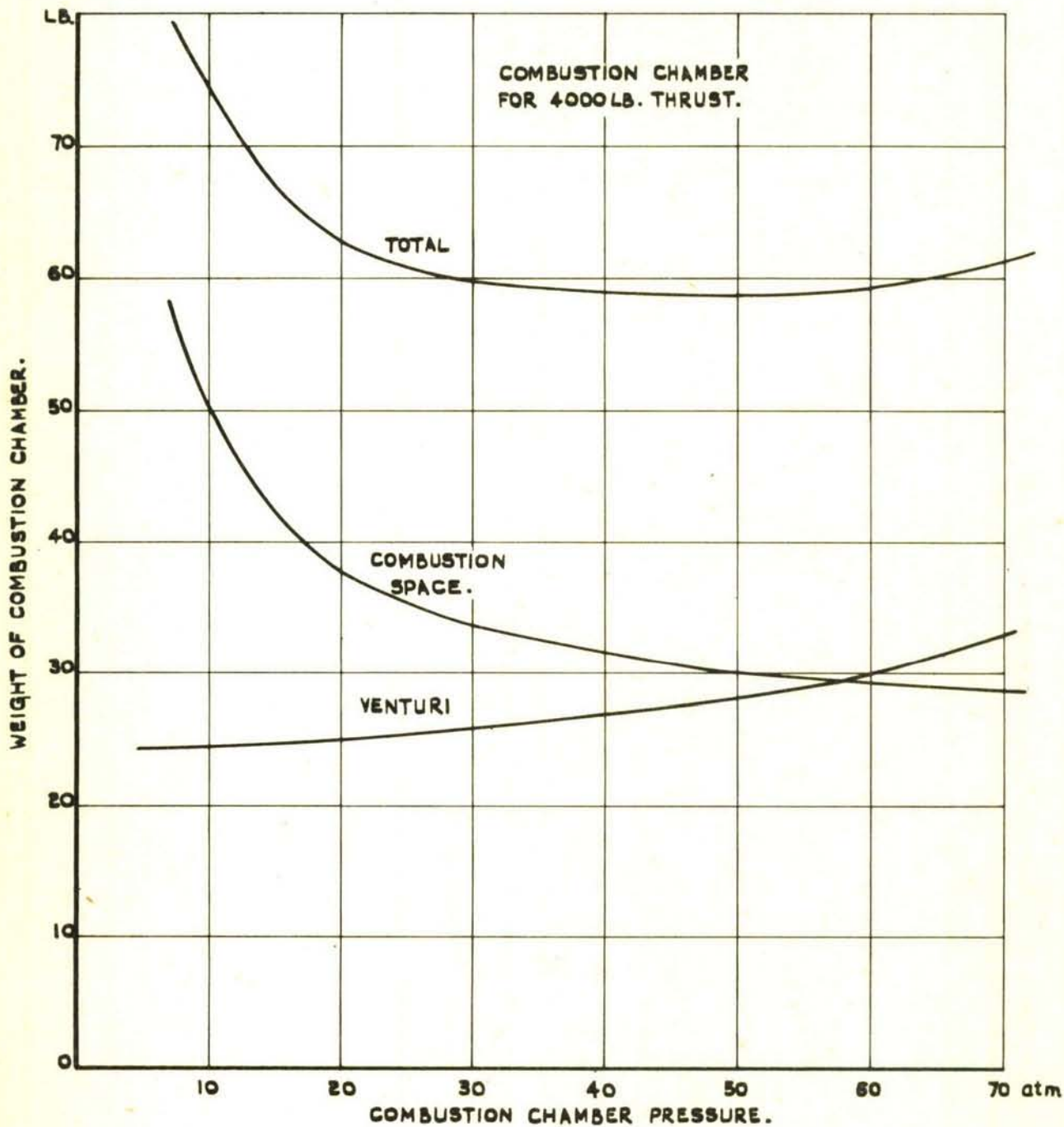


FIG.6. VARIATION OF COMBUSTION CHAMBER WEIGHT WITH PRESSURE.

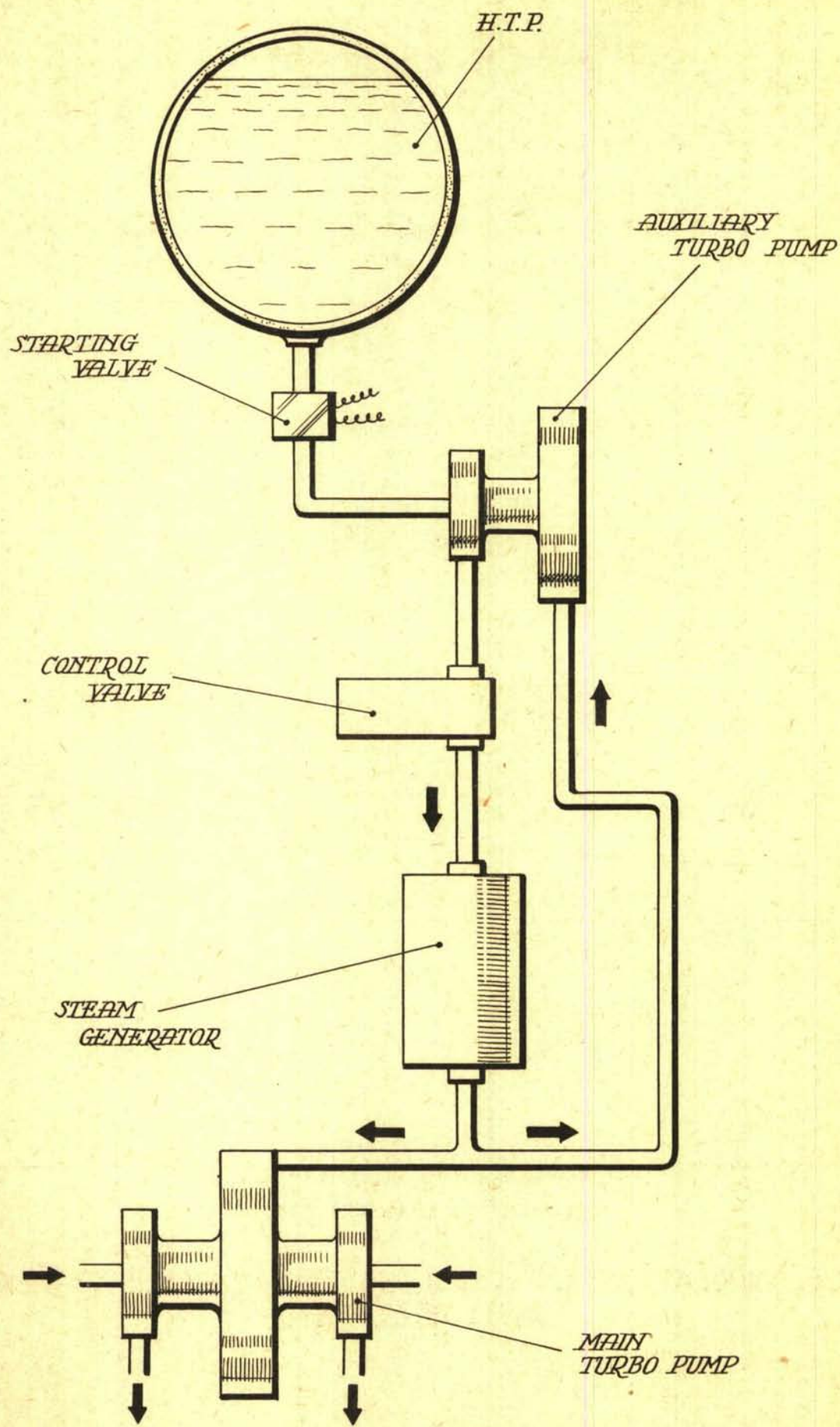


FIG.7. PROPOSED PUMP FEED SYSTEM