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ROYAL AIRCRAFT ESTABLISHMENT

FARNBOROUGH, HANTS

TECHNICAL REPORT No: A.D.E.2/52
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DEVELOPMENT OF 7.5-inch BOOST MOTOR

by

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ARMAMENT DESIGN ESTABLISHMENT
and J.H.CROOK, R.A.E./R.P.D.

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SUMMARY

The difficulties involved in designing a light alloy rocket motor with an internal burning charge similar to the American 'Deacon' boost are discussed. Static firing trials have shown that the early design of a motor with obturation of the charge at both ends was not satisfactory. The disastrous effects resulting from overheating of the tube wall by gas-wash have been eliminated by filling the annular gap between the charge and tube wall with liquid. The annulus is thereby pressurized simultaneously with the inside of the charge and therefore the charge shows no tendency to burst within the motor tube. A motor of this design, with Vistac as filling liquid, has proved satisfactory in both static and projection firings.

1. Booster rockets

I Litton, J.C.C.
II Deacon
III Vistac
IV Seaslug

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LIST OF CONTENTS

APPENDIX

Table of results of static firings

LIST OF ILLUSTRATIONS

1 Introduction

In May 1948, the G.W. Department of R.A.E. Farnborough stated a requirement for a rocket motor with a total impulse of approximately 20,000 lb sec as a boost for the Seaslug weapon then under consideration. Considerably influenced by information just becoming available on the American "Deacon", it was felt by G.W. Department that a similar solid propellant motor would meet their requirements. Since R.P.D. Westcott, at that time, had practically no facilities for solid propellant development, C.E.A.D. was asked to undertake the work.

First discussions indicated that a few slight modifications to the performance and dimensions of the "Deacon" would provide a boost which would more nearly meet the requirement. These were a reduction in burning time and in overall length, the latter being more important.

The Deacon had a single externally inhibited star-centred cordite charge which was housed in a light alloy tube. The overall dimensions of the motor were 106.75 inches in length and 6.8 inches in diameter. Although techniques[1] had been developed for inhibiting the outer surfaces of cordite charges, the largest size which had been coated previously was 4.3 inches in diameter by 38 inches in length. This charge had been fired only in a steel tube, as an experimental 5-inch A.T.O. motor (Projectile Development Establishment, Aberporth[2]). There was therefore little previous British experience with a cordite charge of this type of the size required, nor of the difficulties likely to be encountered in obtaining reliable functioning with such a charge in a light alloy tube.

From the experience gained at the Projectile Development Establishment, Aberporth, with plastic propellants in a 5-inch light alloy motor[3] it was to be expected that difficulties might arise if the hot gases from the burning cordite charge gained access to the light alloy walls.

With plastic propellant it was fairly easy, in the absence of air inclusions in the propellant, to ensure that no exposure of the light alloy occurred during the burning of the charge, but in the case of a cordite charge there must of necessity be an annular gap surrounding the charge at all temperatures below some arbitrary maximum. Unless special precautions were taken, therefore, a possibility of overheating of the motor wall existed.

The only star-centre charge previously made and fired in this country of dimensions comparable with those now required was the plastic propellant charge in the 8-inch steel motor developed at P.D.E. Aberporth[2]. The limited number which were produced functioned satisfactorily at normal air temperatures and it was, therefore, concluded that ballistically no special difficulties should arise with the large cordite charge now proposed.

2 General design considerations

2.1 Propellant charge

No precise equivalent of the propellant H.9 used in the Deacon was available in this country, so that the choice of propellant was largely conditioned by ease of supply. The ballistic properties of propellant SU/K were considered to be satisfactory and, therefore, this propellant was chosen since its major undesirable feature, viz. its low Young's modulus, was of small consequence in a development such as this where accelerations were likely to be small.

In designing the charge, efforts were made to meet the wishes of the users for a shorter round. Since no significant improvement in specific impulse or density of loading over the "Deacon" could be anticipated, a shorter round meant a larger charge diameter. A charge was, therefore, designed with outside diameter 6.05 inches (see cross-section, Fig.1). In the theoretical charge calculations[4] it was found that the star points had to be truncated appreciably to compensate for the erosion experienced with such a long charge. By this means the theoretical initial peak was made small, and in practice it has been found that no initial peak appears at charge temperatures below 120°F.

2.2 Motor tube and components

With the specified charge and coating (thickness 0.075 inch) it was considered that a tube of $6\frac{3}{8}$ inches internal diameter was required to give sufficient clearance under the worst conditions for filling (viz. bent charges and tube). It was first proposed to manufacture this tube by an extrusion process. The material was DTD.693 and the contractor considered that he could maintain the required tolerances. After the first batch of tubes had been extruded, however, it was discovered that close tolerances were not maintained after heat treatment. In order to cut down the time involved in a fresh order, it was agreed to accept a few tubes extruded to a thickness sufficiently great to allow full machining on both external and internal surfaces. By this means it was possible to obtain the required tolerances on the bore and thickness.

This process was obviously uneconomical in both time and material, and immediate efforts were made to obtain an alternative. After consultation with tube manufacturers, it was agreed that the best solution would be to use a drawn tube in a slightly lower grade alloy, DTD.464 which, it was anticipated, could be used in the drawn condition without any machining other than that required for the screw threads. This was tried, and proved to be satisfactory. The rear end of the tube carried an internally threaded mild steel adaptor or extension into which the mild steel venturi was screwed. The main purpose of the adaptor is to provide a "heat-break"* between venturi and tube and also, in effect, to substitute for the light alloy a short piece of steel tube at a point where there is some possibility of access of hot gases to the motor wall.

Similarly the forward end was terminated by means of a mild steel extension (or shell-ring) threaded internally and carrying a charge retaining ring. The latter was intended to obturate the forward end of the propellant charge by compressing a neoprene washer against it so that complete closure of the annular gap could be effected. Similar obturation had been found necessary in the "Deacon" motor but the precise details of the methods used were not available when the present design was being evolved. It was fully realized that rigid longitudinal clamping of the propellant could only be used in experimental firings because of the large differential coefficient of expansion between the propellant and tube. Nevertheless, it was considered that the arrangement would be good enough to enable the principle of charge/tube obturation to be investigated.

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* Defined as a discontinuity in so far as conduction of heat is concerned. In effect there are air gaps between the tube and adaptor and also between adaptor and venturi.

2.3 Ignition

Ignition was originally effected by means of two standard 3-inch cartons filled with SR.371C and connected in series. This arrangement was satisfactory at ambient temperatures, but resulted in ignition delay at temperatures of -5°F. The number of cartons was, therefore, increased to three, although an even larger quantity of SR.371C may be required if functioning at very low temperatures is to be fully reliable.

3 Charge preparation and filling

From the initial stages of the development, it was realised by C.E.A.D. that, in order to solve the problems likely to arise in charge preparation, coating and filling, it would be necessary to make use of the experience gained from similar, though smaller, charges at the Projectile Development Establishment, Aberporth. Discussions were, therefore, held with C.S.A.R. (S.B.R.) where the staff remaining after the disbanding of the Projectile Development Establishment was concentrated. It was agreed that C.S.A.R. would give any necessary advice, and would provide the facilities required during the coating and other preparation of the charge, the filling operation, and the static firings during development.

Since the heaviest charge in this cross-section which could be extruded from existing 15-inch presses was about 70 lb weight, it was considered most convenient to 'composite' 50 lb sections (i.e. half lengths) to make up the full charge. Occasionally smaller pieces were first 'composited' to produce the half lengths so that the resulting charges contained more than one joint.

The "stress-relief" technique[1] was selected as being the most suitable one for inhibiting the burning of the outer cylindrical surface. Cellulose acetate of wall thickness 0.075 inch was used for preliminary work, but it was the intention to change over to ethyl cellulose should storage considerations make this desirable.

As the largest machine available for the stress-relief process could not accommodate charges longer than about 4 ft, the coating process had to precede the compositing of the halves. This was considered to be undesirable in some respects since it was known from previous work that a reliable butt-joint in an inhibitive coating was difficult to achieve under normal working conditions. The joint was, therefore, wrapped with cellulose acetate tape (0.01 inch thick) using cement PDE.100 or acetone as adhesive. This was done in the hope of being able to prevent ignition of the propellant below any gaps which might be present in the joint in the restrictive coating.

Designs for a larger coating machine and expansion moulds were laid down because of the advantages of applying one continuous coating to the charges.

The filling operation consisted initially of inserting the composite charge into the tube and using an obturating neoprene washer at the forward end. The igniters were placed in the conduit of the charge at the forward end and were tied to a strip of mill-board lying across the end of the charge to keep them in position.

4 Static firing results

4.1 Charges with obturation at both ends

The first round (6W-1), filled as described above, was fired statically at air temperature and burst almost immediately. Most of the propellant caught fire after the burst, but a few of the fragments recovered showed that burning had taken place on surfaces of fracture, which indicated that the charge had probably been disrupted in the rocket tube because of the difference in pressure between the star perforation and the outer obturated annulus. The pressure-time curve is shown in Fig.2 from which it is clear that the pressure developed was more than double the anticipated value. As the tube did not fail at the pressure peak, it is possible that overheating also occurred and was a contributory cause of failure[5].

4.2 Charges without obturation

In order to throw further light on the reasons for the failure a second round was filled, but this time obturation was omitted and in order to ensure rapid equalization of pressure between the star perforation and the outer annulus the two halves were not composited and instead spacers were inserted to facilitate the passage of gases between the two sections. On this occasion no attempt was made to record the pressure or thrust because of the damage done to the equipment during the first firing.

This round was also fired at air temperature, and appeared to function correctly for about one second, as judged aurally, and then stopped burning; after about a minute the charge re-ignited and hence no propellant residue remained for examination. The motor tube was found to have burst, but it was mainly in two halves; both the head and venturi end plates had blown off and the threaded portions were funnelled out. Although the fragments had every appearance of being the result of a burst due to excessive pressure, the firing was normal, apparently, except for the short time of burning. It could not be concluded with certainty, in the absence of a pressure recording, whether the failure was due to overheating of the light alloy tube or to excessive pressure which might have been caused by the removal of the inhibiting coating by gas-wash.

Since it appeared desirable to obviate the effects both of differential pressure (unavoidable with obturation of both ends of the charge) and of gas-wash over both the tube and inhibitive coating (unavoidable without obturation), means of resolving these apparently conflicting requirements had to be considered.

4.3 Rounds with liquid filling in annulus

The simplest method seemed to be to fill the annulus between the charge and wall with a relatively incompressible fluid such as water, which would both transmit the pressure to the outside of the charge and at the same time prevent gas-wash in the annular space.

A round (6W-3) was, therefore, fitted up in this way and an attempt was made to prevent the water from leaking by rather crudely sealing off both ends of the charge with luting. As this was not completely effective the water was replaced by a $\frac{3}{4}$% aqueous agar solution which was poured in at 60°C (140°F) and set on cooling to a rather weak gel. This motor functioned correctly when fired statically and a satisfactory pressure/time curve was obtained which is shown in Fig.3. The light alloy tube remained relatively cool and was found to be in perfect condition and capable of re-use. The inhibitive coating to which a good deal of the agar gel was still adhering was also in remarkably good condition and was merely charred slightly on the inside.

Two further motors (6W-4 and 6W-5) filled in the same way also functioned satisfactorily and both pressure and thrust/time curves were obtained (see Fig.4 and 5).

4.31 High and low temperature firings

In order to check the ballistics of the charge in firings at more extreme temperatures $\frac{3}{4}$% aqueous agar solution at 60°C (140°F) was poured into three rounds (at air temperature) which were then placed in a heating chamber at 37.8°C (100°F). The annulus surrounding the charge was left open so that the displaced gel could escape until a uniform temperature had been obtained throughout. The charge retaining ring was then screwed home against the neoprene washer and the annulus sealed off. All the rounds (6W-6, 6W-7, 6W-8) functioned correctly when fired at 37.8°C (100°F) and satisfactory pressure and thrust/time curves were obtained (see Fig.6, 7* and 8).

Two further rounds (6W-9, 6W-10) were cooled to 1.7°C (35°F) and at that temperature were filled with hot agar solution. A further period was allowed in the cold chamber so that the agar solution could cool, and uniformity of temperature could be attained. The rounds functioned satisfactorily on static firing. The curves are shown in Fig.9 and 10.

4.4 Charges fitted with end spacers

4.41 Light alloy tubes

Although the annular filling appeared to be entirely successful, it was considered desirable to investigate all possible alternatives in order to avoid the complications arising from the use of a liquid filling. A charge was, therefore, prepared in which six spacing tabs approximately $\frac{1}{2}$-inch long with their axes parallel with the axis of the charge were cemented around the circumference of the charge on each end face in order to ensure the passage of the gases to the outside of the charge at both ends and so permit the rapid pressurization of the annulus. It should be noted that none of the spacing tabs projected into the annulus and therefore did not centralise the charge within the tube.

A second charge was fitted with this type of spacer, but at the venturi end only, the other end being sealed by the neoprene washer, already referred to, which was screwed down hard onto the end of the charge. Both rounds (6W-11, 6W-12) were fired at air temperature and pressure recordings were taken; both rounds burst. The first one survived for 0.52 second, and the second one failed after 0.35 second. The records shown in Fig.11 and 12 indicated that no abnormal pressure was developed; in fact the initial level of pressure was somewhat below normal, probably owing to the greater free volume available and the cooling effect of the motor walls on the propellant gases. Although the appearance of the metal fragments from both of the above bursts suggested excessive pressure, it was clear from the recording that failure could only have been due to overheating of the light alloy. This experiment established beyond doubt that at air temperature, provided the annulus was open at one or both ends, the outside of the charge could be pressurized sufficiently rapidly to prevent any disruption of the charge by the internal gas pressure such as occurred when the two ends were obturated.

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* No explanation can be suggested for the peak which appears on this curve, but such phenomena are common with solid propellant rocket motors.

It had been proposed to complete this series of firings with one round where the spacer was at the head end of the charge, and the other end of the annulus was sealed to prevent continuous gas flow. In view of the results of the first two firings and the general shortage of components, it was decided not to expend any further efforts on this type of assembly, and the last firing was, therefore, cancelled.

4.42 Steel tubes

Repeat firings were next carried out in two steel tubes with loose charges arranged in exactly the same way as in the two previous motors. The pressure/time curves are shown in Fig.13 and 14. Both rounds burnt for over one second with a progressive rise in pressure until at 1800 to 1900 lb/sq in. the venturi was ejected from its retaining ring. Fragments of the recovered propellant showed that gas-wash had completely stripped large areas of coating from the charges. The additional burning surface thus exposed was responsible for the progressive pressure-rise observed. It was suspected that ignition may have occurred below the butt joint in the coating, since one or two fragments of propellant showed excessive burning from the outer cylindrical surface along a line corresponding with the butt joint. Hence it was clear that the gas flow over the coating had been augmented by gases arising from the joint. However, the seriousness of the latter phenomenon was not fully appreciated for some considerable time, when the firings were repeated with charges inhibited by means of a continuous coating free from joints. Charges of this type will function quite satisfactorily in steel tubes, particularly if one end is obturated. These experiments will be described more fully in a subsequent report.

5 Discussion of results of the first stage of development

It may be useful at this point to summarize the main conclusions of the work up to this stage in so far as they relate to charges of the composition and dimensions given, since a decision had to be made at that time as to how the design should proceed. The main points are as follows:-

5.1 Charges with single-ended or no obturation

Light alloy tubes filled with charges having either single-ended or no obturation were incapable of resisting the normal working pressure for more than about 0.5 second owing to overheating as a result of the gas flow necessary to pressurize the annulus between the charge and the wall of the tube. The flow is continuous because of the cooling of the gases in contact with the tube.

5.2 Charges with obturation at both ends

If the annulus were sealed off the charges burst, since they were being treated as pressure vessels. The extra burning surface exposed then caused a catastrophic rise of pressure which the tube would have been incapable of withstanding even if it had remained cool; the tube could not, however, remain cool since the protection afforded by the charge disappeared the instant it broke up.

It should be noted here that a light alloy motor would function quite satisfactorily if the charge could be made an exact fit in the tube, since there would then be no annulus to pressurize and hence no gas flow would occur over the walls of the tube. Such a solution is, however, impracticable because of the much greater coefficient of thermal expansion of the propellant relative to that of the metal tube. For example, if a charge were an exact fit at air temperature an annular gap would appear at lower temperatures while plastic deformation would occur at elevated temperatures. This would not be serious in itself, but subsequent cooling of the motor would produce an annular gap which would lead to failure when the rocket was fired.

5.3 Motors with charges possessing thicker inhibiting coatings

Satisfactory results could not be obtained even in steel tubes with charges coated by the equipment available at the time this work was carried out. The possibility of using thicker inhibiting coatings was considered, but this method would have meant considerable delay, since a new die and fresh extrusions would have been required. Moreover, an appreciably thicker coating could only have been accommodated at the expense of a reduction in the charge diameter with resulting degradation of the performance of the rocket motor.

5.4 Motors with charges of larger diameter

The charge as originally ordered was 6.05 inches in diameter with the intention of using a coating 0.1 inch thick in a tube of $6\frac{3}{8}$ inches bore. It was thought that the mean clearance of approximately 0.125 inch on diameter was the smallest that would allow easy assembly of most charges. In practice, the first charges came out at less than 6 inches outside diameter and the coating used was only 0.075 inch thick, so that the clearance was considerably greater than anticipated. This possibly accentuated the troubles with charge cracking under internal pressure. After discussions with R.N.P.F. Caerwent, it was agreed to open out the die and thus achieve a charge of greater overall diameter, up to about 6.10 inches. Later charges were somewhat bigger (note greater charge weights in last firings reported), but no trials were carried out without the fluid in the annulus to check any alteration in behaviour.

6 Further development of motors with liquid filling in annulus

Since none of the above four designs afforded a convenient solution of the problem, it appeared that the only possibility left was a design in which the annular gap between the charge and the wall was filled with a liquid, whereby instantaneous pressurization of the outside of the charge was secured without subjecting either the inhibiting coating or the light alloy walls to high temperature gas-wash.

Because of the large coefficient of thermal expansion of the propellant relative to that of the motor tube, as already explained, it was clearly necessary to make provision for receiving the liquid filling as it became displaced owing to rise in temperature and similarly to provide a reservoir from which liquid could be drawn in order to maintain the annulus completely full as it became enlarged with fall in ambient temperature. In the present case, if a temperature range of -40 to +60°C (-40 to +140°F) is to be covered, then a reservoir capable of accommodating approximately 3 litres of liquid is required.

The main design problem, therefore, was to provide adequate seals against the leakage of liquid to the exterior of the rocket motor and also into the conduit where ignition of the burning surface might be prevented or delayed. In addition a suitable housing for the reservoir or expansion bag had to be provided.

6.1 Annulus filled with ethylene glycol

Two rounds were, therefore, fitted with football bladders situated in the forward end-space (see Fig.15). Initially these contained about 500 cc of ethylene glycol the bulk of which passed into the annulus when the motor was cooled down to -5°F. The first round (6W-15) which was fired at this temperature with two 3-inch carton igniters gave an ignition delay, so that no record was obtained, but functioning was otherwise correct. The second round (6W-16) in which a third 3-inch igniter was inserted yielded a satisfactory pressure/time curve (see Fig.16).

The liquid selected for use as a filling for the annulus should, of course, possess a sufficiently low freezing point and high boiling point to enable the required temperature range to be covered. Furthermore such a liquid should have little or no solvent effect on the inhibiting coating and should not be capable of diffusing through the coating in amounts sufficient to modify the ballistic properties or affect the chemical stability of the propellant.

Of the available liquids ethylene glycol (melting point about -17.8°C (0°F)) diluted with a little ethyl alcohol appeared to be convenient for preliminary work and gave a satisfactory result when tested for solvent-effect on the coating material.

A further problem arose at this stage since during projection firing there will be two forces tending to expel the liquid filling:-

(1) the differential pressure between the front and rear ends,

and (2) the set-back forces as the rocket is projected.

In the first static firings expulsion of the liquid filling was prevented by clamping the charge longitudinally, but in later firings the differential pressure tending to force the charge against the venturi-plate was relied upon to effect the necessary sealing against liquid-loss, and this method appeared to be effective. Smoke produced towards the end of burning, however, indicated that just before 'all burnt' appreciable quantities of liquid were expelled. No failures in static firing tests resulted from this cause, although recovered coatings were not in quite such good condition as when longitudinal clamping was used. Two ways of reducing the loss of liquid during firings were tried. The first method was to fit venturi-end washers of soft neoprene, or similar material, which would compress under load and thus form a liquid-proof seal. The second method was to select a liquid of much higher viscosity which would leak only slowly, even under conditions of bad sealing. Both methods have been used successfully, although a viscous liquid makes the filling operation rather slow and difficult. The liquid polymers of isobutylene (Vistac) have proved satisfactory, but necessitate filling at an elevated temperature.

A 'regularity series' of five rounds (6W-18 to 6W-33), using an ethylene glycol filling without reservoir, was fired statically at each of the temperatures 0, 18 and 37.8°C (32, 65 and 100°F). In each case the glycol was brought to the same temperature as the round before being poured in and was sealed in position by the neoprene washer pressed hard against the end of the charge, as previously described. The thrust/time curves for these firings are given in Fig.17 to 31. All the rounds functioned correctly, except one of two (6W-30 see Fig.29 and 6W-31), which were inadvertently fired at 49°C (120°F) instead of at 37.8°C (100°F) and gave rather high initial-peak pressures causing the ejection of the venturi in the case of one round (6W-31). This charge was recovered and although broken by impact after ejection, it was free from any burning defects. The pressure at which ejection occurred was of the same order as that obtained in the experiments with steel tubes described above, which indicated that the venturi end-ring was the weakest part of the assembly and incapable of withstanding more than about 1800 lb/sq in.

One further round (6W-33) was fired satisfactorily at 37.8°C (100°F) and a total of four records was obtained at this temperature (see Fig.27, 28, 30 and 31).

The variation of thrust and time of burning of this motor with temperature is shown in Fig.32; mean thrust/time curves are given in Fig.33.

Details of the empty assembly are shown in Fig.34.

6.2 Secondary peaks

The American "Deacon" employs an anti-resonance rod, but so far there has been no evidence of secondary peaks with the SU/K charge, although firings at extremes of temperature with the latter have been on a very small scale.

7 Conclusions

It has been shown that, although cordite is an excellent thermal insulator, a star-centre charge of this propellant provides only partial protection to the walls of a rocket motor during firing. This results primarily from the large difference between the coefficients of thermal expansion of cordite and metal, such that the desirable close fit of the one within the other can be maintained only over a very narrow temperature range. The main conclusions to be drawn from experiments designed to improve the effectiveness of the protection given by the charge to the tube are as follows:-

(1) Obturation of the charge at both ends in order to seal off the annulus against the flow of hot gases is not satisfactory below a certain temperature. This is because the differential pressure bursts the charge, thermal insulation breaks down, and the extra burning surface produces a rise in pressure.

(2) Gas-wash causes failure of the light alloy wall if only one end of the charge is obturated, or if the obturation is omitted. The probability of failure is greater the lower the temperature of firing and the smaller the charge diameter.

(3) Functioning is satisfactory over a wide temperature range when the annulus is filled with a liquid (e.g. Vistac). A reservoir for the liquid is also necessary.

(4) There is no evidence of any tendency for the charge to break-up owing to differential pressure in any assembly tested except that described under (1) above.

(5) When a liquid filling is used for the annulus the solid inhibitor apparently serves little or no useful purpose. Experiments in which the latter has been successfully omitted will be described in a subsequent Technical Note. Meanwhile, however, the solid inhibitor should be regarded as an insurance against possible failure elsewhere.

(6) In approximately six hundred projection firings of this motor up to the present, the failure rate from all possible causes has been of the order of 2%. However, it is considered that the reliability of a light alloy rocket motor will, in general, be less than that of an equivalent version using a steel tube.

Acknowledgements

The authors wish to express their appreciation to Mr. W. Blackman S.S.W.R. for his interest in the work, part of which was carried out in the Armament Research Establishment, Woolwich by one of us (J.H.C.) while a member of the staff of that Establishment. Thanks are also due to Mr. J.R. Price who carried out the static firings and to Mr. H.A.J. Prentice who assisted in this work.

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4	G.F.P. Trubridge	"Basic internal ballistics of rockets" P.D.E. Aberporth Report No. 1945/13, February 1945.
5	The Aluminium Development Association	"The properties of aluminium and its alloys" Bulletin No.2, p.40, December 1949.

Attached:-

Appendix

Drg. Nos:- RP.713-724, 726-743, 853, 854, 880.

Advance Distribution:-

PDSR(A)
PDSR(D)
DWGRD
GW3 - 6/70
DWRD
CEGW (Cdr. Mitchell)
CEAD(CT1)
Eng RD6
DMXRD
DGOF
CSR
ERDE (Waltham Abbey)
TPA3/TIB - 180 (100)

DDRAE(E)
Guided Weapons - 3
Armament
Library

APPENDIX

Table of static firing results

Round No.	Cordite lot	Date of Firing	Charge weight lb oz	Charge Length in	Temperature °F	Time of burning sec	Initial peak Pressure lb/sq in	Initial peak Thrust lb wt	Pressure time curve see Fig.	Notes
Charge sealed at both ends										
6W-1	RNP 128S	1/12/48	104 - 3	91	Air	0.223	2325	-	2	Forward end sealed with neoprene washer. Burst at 1910 lb/sq in pressure.
Charge without end-seals										
6W-2	RNP 128S	14/12/48	105 - $4\frac{3}{4}$	92	Air	Not recorded		-	-	Charge in two halves separated by tabs 0.1 in thick to allow communication between conduit and annulus. Burst after about 1 second.

APPENDIX (Continued)

Table of static firing results

Round No.	Cordite lot	Date of Firing	Charge weight lb oz	Charge Length in	Temperature ^{o}F	Time of burning sec	Initial peak		Perf Index	Pressure and thrust/time curves see Fig.	P.max lb/sq in	T.max lb wt	P.mean lb/sq in	T.mean lb wt	Time to ½ M.T.
							Pressure lb/sq in	Thrust lb wt							
Annulus filled with $\frac{3}{4}$ % aqueous agar solution															
6W-3	RNP 128S	12/1/49	104 - 9½	91.3	Air	3.85	-	-	-	3	1020	-	-	-	-
6W-4	RNP 128S	25/1/49	105 - 2¾	91.5	Air	3.71	1060	7960	204	4	1025	8,080	770	5,790	2.82
6W-5	RNP 128S	25/1/49	104 - 3	91.1	Air	3.74	1045	7760	203	5	1020	8,000	751	5,656	2.87
6W-6	RNP 128S	21/4/49	104 - 10	91.5	100	2.90	-	-	210	6	1420	11,470	954	7,580	2.11
6W-7	RNP 128S	21/4/49	104 - 7½	91.5	100	2.96	1695	-	-	7	-	-	938	-	-
6W-8	RNP 128S	21/4/49	103 - 5¾	91.5	100	2.98	-	-	205	8	1380	11,000	922	7,100	2.17
6W-9	RNP 128S	26/4/49	103 - 15½	91.5	35	3.76	970	6730	197	9	950	7,120	713	5,380	3.01
6W-10	RNP 128S	26/4/49	104 - 10¾	91.5	35	3.88	-	-	202	10	980	7,600	722	5,476	2.99

APPENDIX (Continued)

Table of static firing results

Round No.	Cordite lot	Date of Firing	Charge weight lb oz	Charge Length in	Temp. ^{o}F	Time of burning sec	Initial peak Pressure lb/sq in	Initial peak Thrust lb wt	Pressure time curve see Fig.	P.Max	Notes
Charges fitted with spacer tabs											
6W-11	RNP 128S	6/5/49	103 - $14\frac{1}{4}$	91.1	Air	0.520	-	-	11	860	Light alloy tube, spacer tabs at both ends of charge. Tube failed near head-end screw thread.
6W-12	RNP 128S	6/5/49	104 - $0\frac{1}{2}$	91.5	Air	0.350	1,055	-	12	995	Light alloy tube, spacer tabs at venturi-end of charge. Burst.
6W-13	RNP 146S	31/5/49	-	91.5	Air	1.35	-	-	13	1,900	Steel tube. Spacer tabs at both ends of charge. Venturi plate blown off.
6W-14	RNP 146S	14/6/49	104 - $1\frac{3}{4}$	91.5	Air	1.58	795	-	14	1,790	Steel tube. Spacer tabs at venturi-end of charge. Venturi plate blown off.

APPENDIX (Continued)

Table of static firing results

Round No.	Cordite lot	Date of Firing	Charge weight lb oz	Charge length in	Temperature °F	Time of burning sec	Initial peak		Perf index	Pressure and thrust/time curves see Fig.	P.max	Time to $\frac{1}{2}$ M.T. (sec)
							Pressure lb/sq in	Thrust lb wt				
Annulus filled with ethylene glycol and fitted with reservoir												
6W-15	RNP 146S	17/6/49	104 - $3\frac{3}{4}$	91.5	-5	No record		-	-	-	-	-
6W-16	RNP 146S	1/7/49	104 - $2\frac{3}{4}$	91.5	-5	4.57	885	-	(Calculated) 204	16	625	3.51
Round with extruded tube for motor body												
6W-17	RNP 146S	28/7/49	104 - 8	91.5	Air	3.40	1100	7740	204	-	1220	T. max 9380

APPENDIX (Continued)

Table of static firing results

Round No.	Cordite lot	Date of Firing	Charge weight lb oz	Charge length in	Temp. °F	Time of burning sec	Initial peak		Perf Index	Pressure and thrust/time curves see Fig.	P.max lb/sq in	T.max lb wt	Time to ½ M.T.	Notes
							Pressure lb/sq in	Thrust lb wt						
Annulus filled with ethylene glycol, (without reservoir.) 'Regularity series'														
6W-18	RNF 164S	27/9/49	106 - 10	91.4	Air(66)	3.52	1110	7,680	203	17	1,170	9,160	2.69	
6W-19	RNP 164S	27/9/49	107 - 4	91.5	Air(66)	3.50	1080	7,860	205	18	1,110	8,815	2.67	
6W-20	RNP 164S	29/9/49	106 - 7	91.4	Air(65)	3.60	1045	7,920	-	19	1,160	8,800	2.69	
6W-21	RNP 164S	29/9/49	104 - 10	91.5	Air(65)	3.54	-	-	204	20	1,130	8,680	2.68	
6W-22	RNP 164S	10/10/49	107 - 8	91.6	Air(62)	3.65	-	-	204	21	1,135	8,660	2.81	
6W-23	RNP 164S	11/10/49	107 - 12	91.8	32	3.95	-	-	198	22	-	7,795	3.04	
6W-24	RNF 164S	13/10/49	107 - 4	91.4	32	3.95	975	7,020	200	23	1,005	7,380	3.16	
6W-25	RNP 164S	13/10/49	108 - 3	91.8	32	4.08	990	7,120	202	24	1,005	7,955	3.18	
6W-26	RNP 164S	20/10/49	108 - 9	91.8	32	4.30	-	-	202	25	910	7,385	3.48	
6W-27	RNP 164S	20/10/49	108 - 10½	91.4	32	4.15	-	-	199	26	-	7,520	3.28	
6W-28	RNP 164S	25/10/49	108 - 12	91.8	100	3.15	1310	9,760	202	27	1,310	10,190	2.32	
6W-29	RNP 164S	25/10/49	108 - 8	91.8	100	3.10	1420	10,490	203	28	1,380	10,680	2.24	
6W-30	RNP 164S	27/10/49	107 - 14	91.6	120	2.72	1820	13,095	208	29	1,480	11,840	2.05	Inadvertently fired at 120°F
6W-31	RNP 164S	27/10/49	108 - 4	91.8	120	0.14	1800	12,360	-	-	-	-	-	Inadvertently fired at 120°F. Venturi ejected
6W-32	RNP 164S	1/11/49	108 - 2	91.7	100	3.21	1360	9,840	209	30	1,300	10,085	2.33	
6W-33	RNP 164S	1/11/49	108 - 8	91.8	100	3.20	-	9,830	209	31	-	10,480	2.31	

FIG. 1

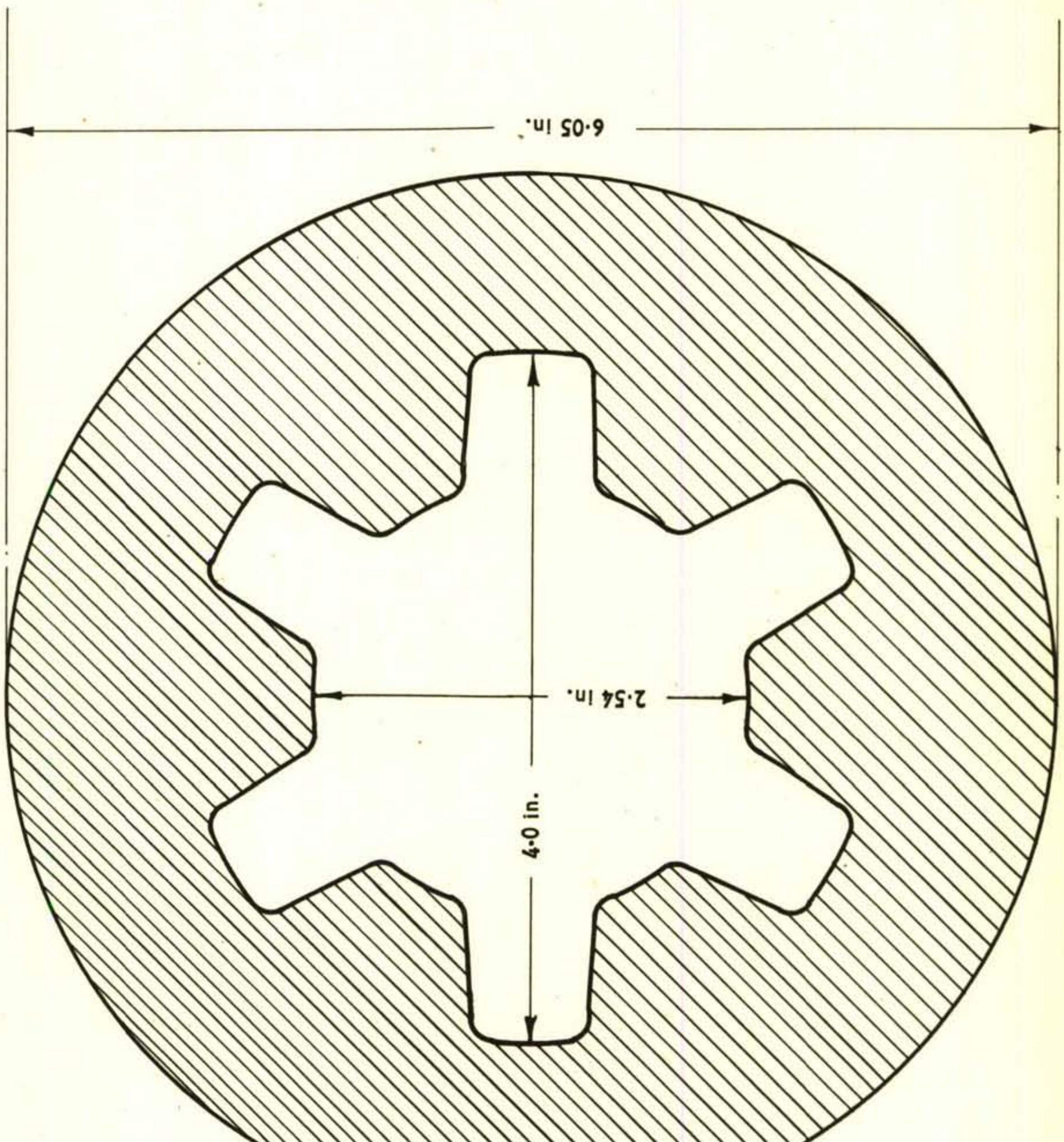


FIG.1. CROSS SECTION OF CHARGE [SU/K]

FROM D8(L)2914/98

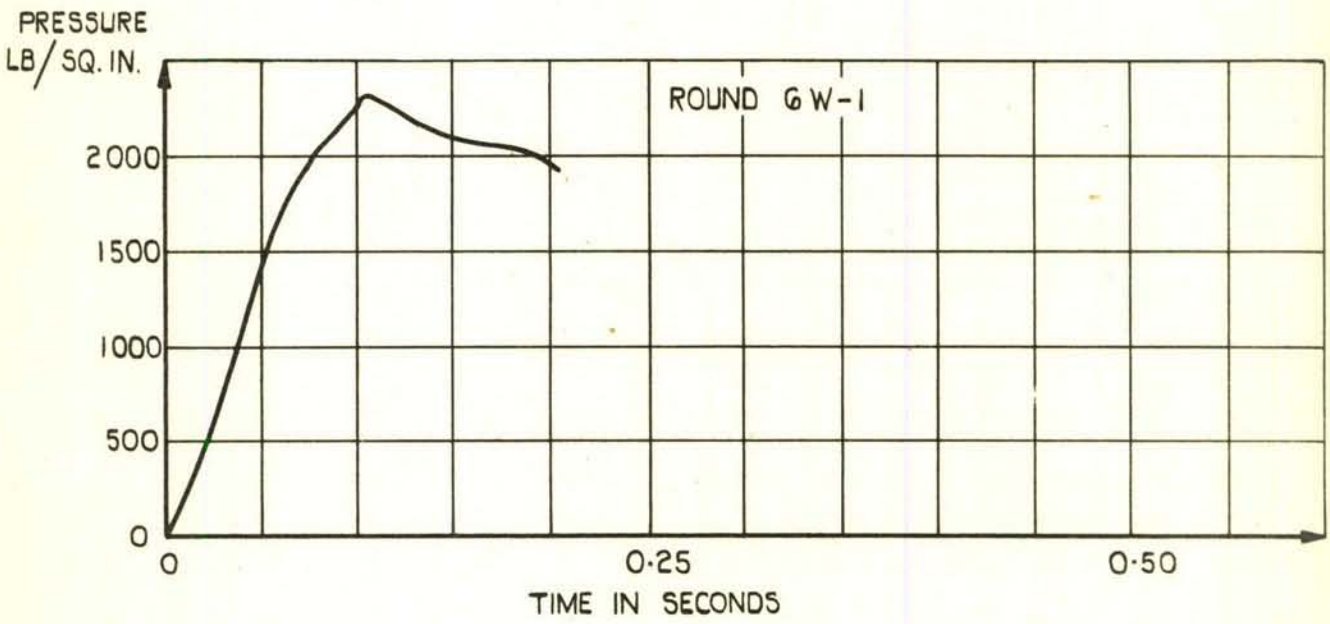


FIG. 2 PRESSURE/ TIME CURVE — ANNULUS SEALED AT BOTH ENDS, FIRING AT AIR TEMPERATURE.

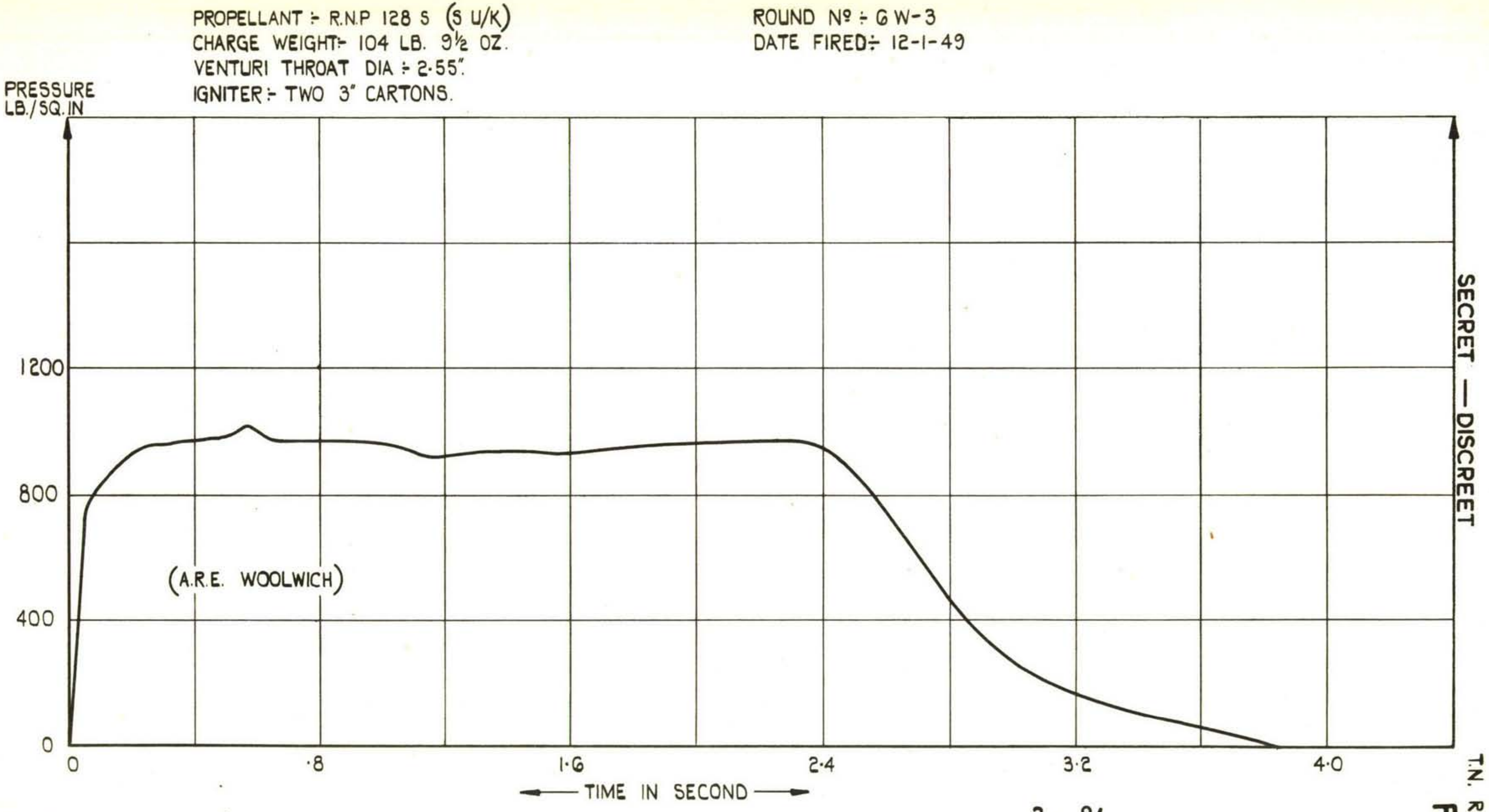


FIG.3 PRESSURE / TIME CURVE — ANNULUS FILLED WITH ¾ % AQUEOUS AGAR SOLUTION, FIRING AT AIR TEMPERATURE.

FIG.4

SECRET — DISCREET

PROPELLANT ÷ R.N.P. 128 S. (S.U/K)
CHARGE WEIGHT ÷ 105 LB. 2 ¾ OZ.
VENTURI THROAT DIA ÷ 2·55"
IGNITER ÷ TWO 3" CARTONS.

ROUND Nº ÷ G W - 4
DATE FIRED ÷ 25-1-49
PERFORMANCE INDEX ÷ 204

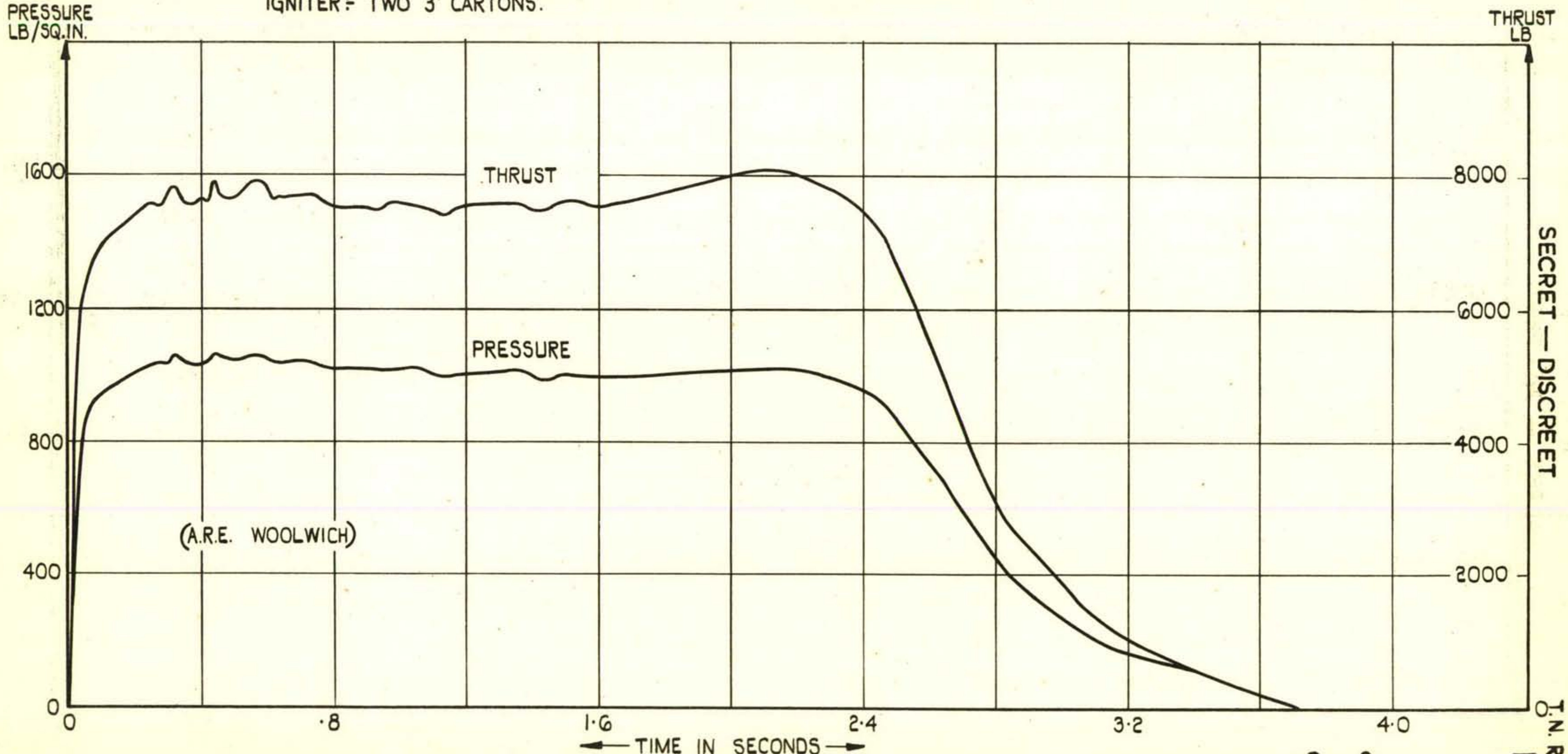


FIG.4 PRESSURE AND THRUST / TIME CURVES — ANNULUS FILLED WITH ¾ % AQUEOUS AGAR SOLUTION, FIRING AT AIR TEMPERATURE.

PROPELLANT ÷ R.N.P. 128 S (SU/K)
CHARGE WEIGHT ÷ 104 LB. 3 OZ.
VENTURI THROAT DIA. ÷ 2·55"
IGNITER ÷ TWO 3" CARTONS

ROUND Nº ÷ G W-5
DATE FIRED ÷ 25-1-49
PERFORMANCE INDEX ÷ 203

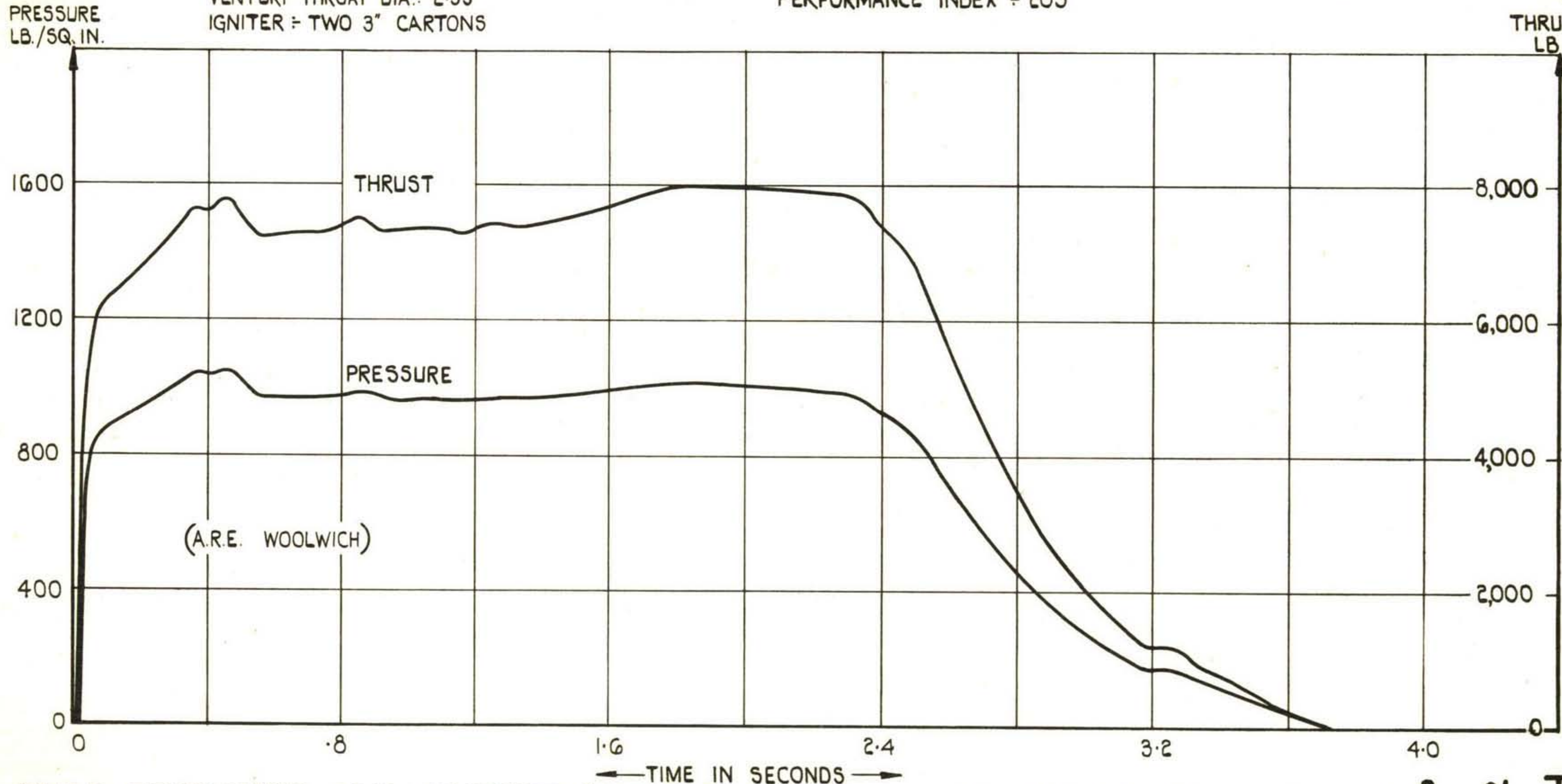


FIG.5 PRESSURE AND THRUST / TIME CURVES — ANNULUS FILLED WITH 3/4 % AQUEOUS AGAR SOLUTION, FIRING AT AIR TEMPERATURE.

FIG.6

PROPELLANT ÷ RNP 128 S (SU/K)
CHARGE WEIGHT ÷ 104 LB. 10 OZ.
VENTURI THROAT DIA.÷ 2·55"
IGNITER ÷ TWO 3" CARTONS

ROUND Nº ÷ GW-G
DATE FIRED ÷ 21-4-49
PERFORMANCE INDEX ÷ 210

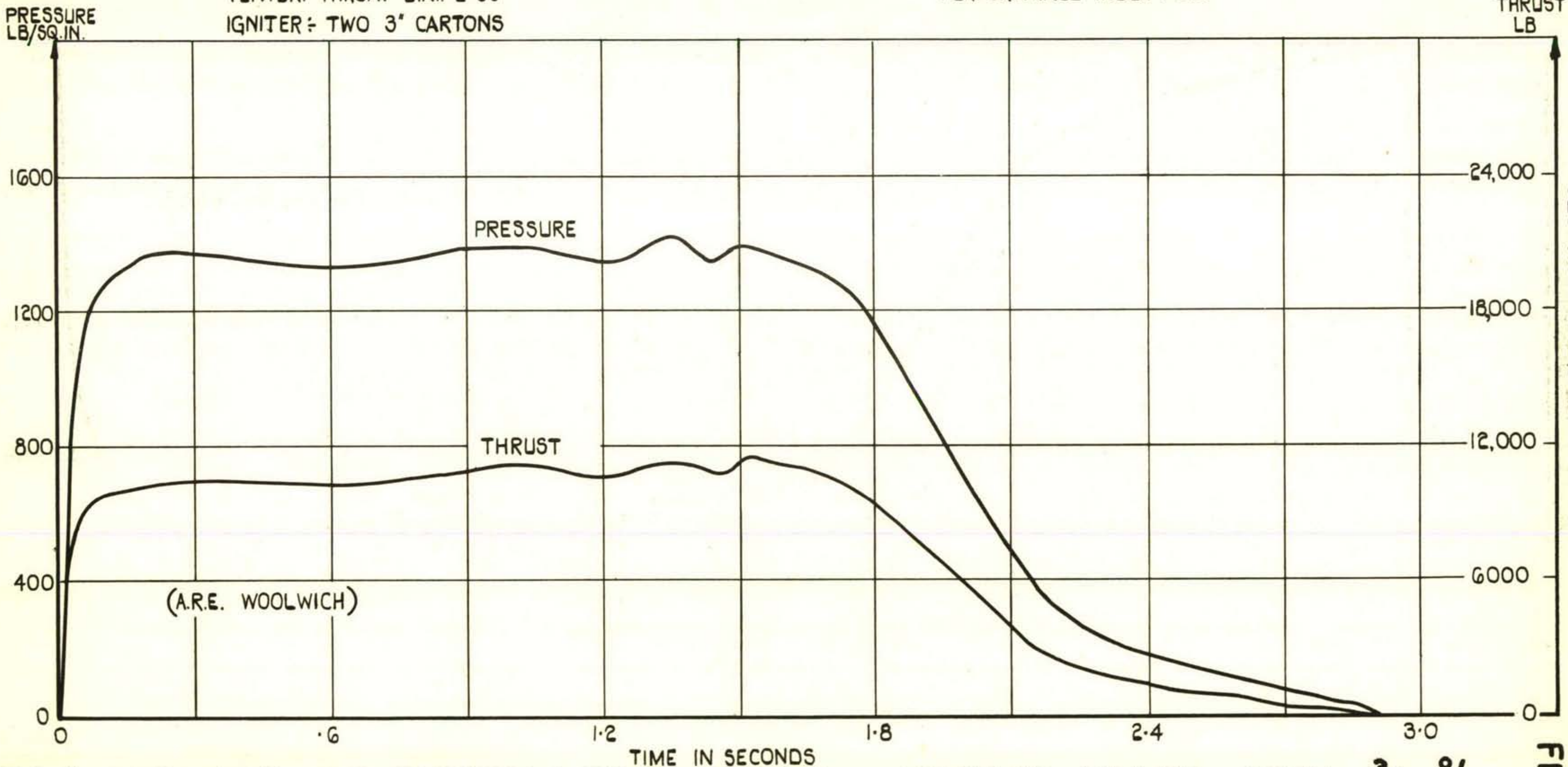


FIG.6 PRESSURE AND THRUST / TIME CURVES — ANNULUS FILLED WITH 3/4 % AQUEOUS AGAR SOLUTION. FIRING AT 100° F.

FIG.7

PROPELLANT ÷ RNP. 128 S. (SU/K)
CHARGE WEIGHT ÷ 104 LB 7½ OZ
VENTURI THROAT DIA ÷ 2·55"
IGNITER ÷ TWO 3" CARTONS

ROUND Nº ÷ G W-7
DATE FIRED ÷ 21-4-49

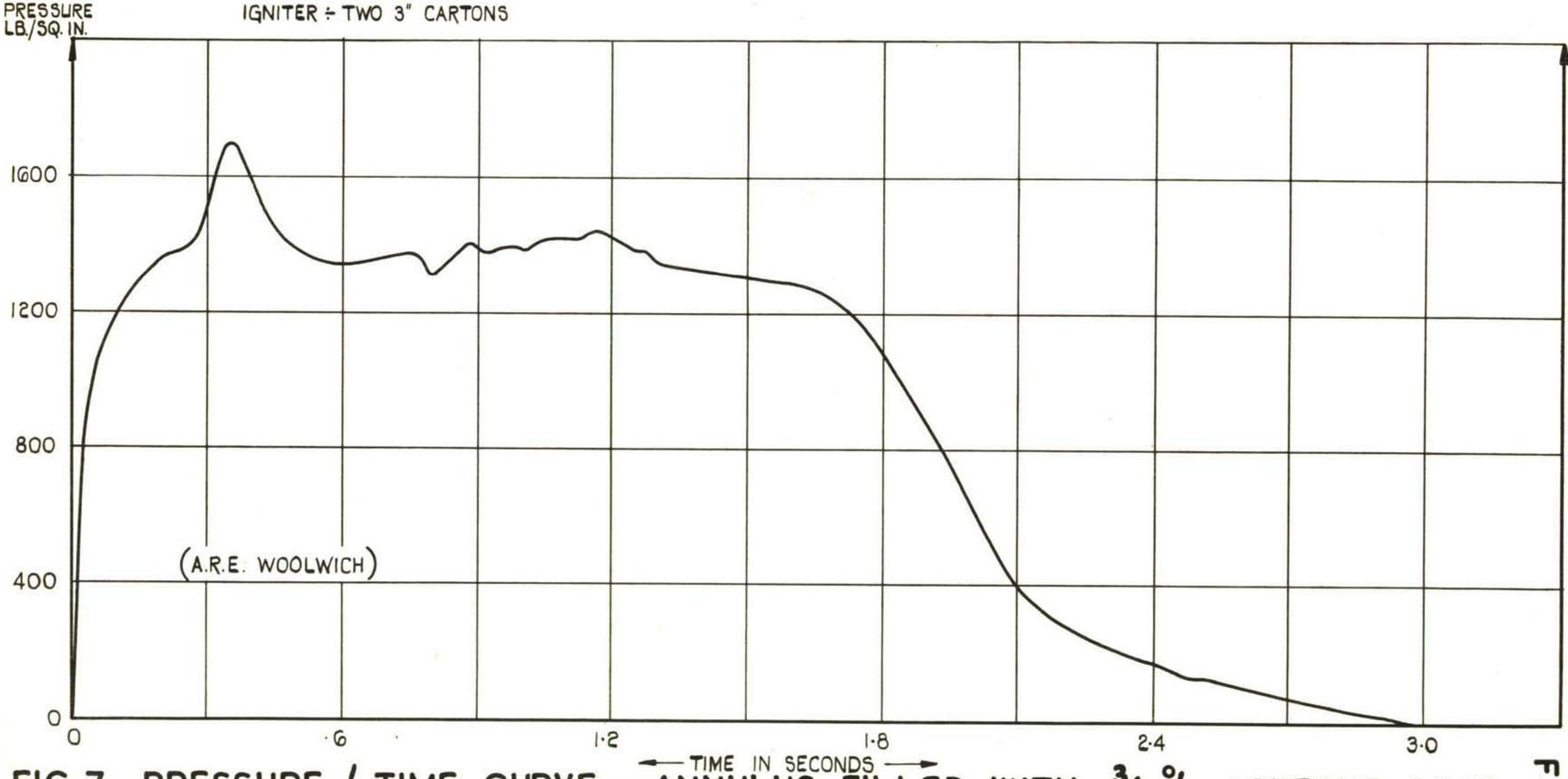


FIG. 7 PRESSURE / TIME CURVE — ANNULUS FILLED WITH ¾ % AQUEOUS AGAR SOLUTION, FIRING AT 100° F.

FIG.8

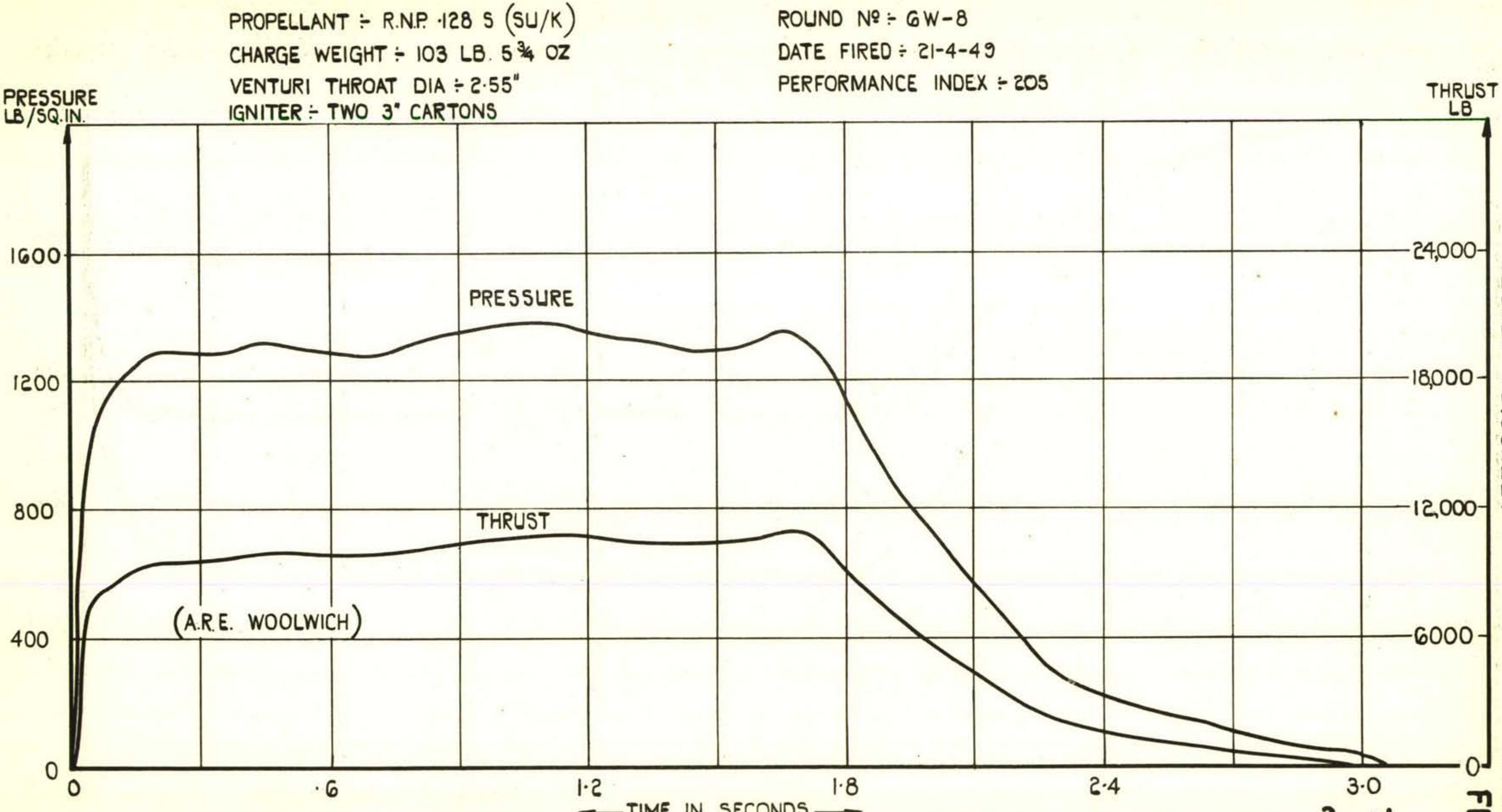


FIG.8 PRESSURE AND THRUST / TIME CURVES — ANNULUS FILLED WITH ¾ % AQUEOUS AGAR SOLUTION, FIRING AT 100° F.

SECRET — DISCREET

PROPELLANT ÷ R.N.P. 128 S (SU/K)
CHARGE WEIGHT ÷ 103 LB. 15½ OZ
VENTURI THROAT DIA ÷ 2·55"
IGNITER ÷ TWO 3" CARTONS

ROUND Nº ÷ G W-9
DATE FIRED ÷ 26-1-49
PERFORMANCE INDEX ÷ 197

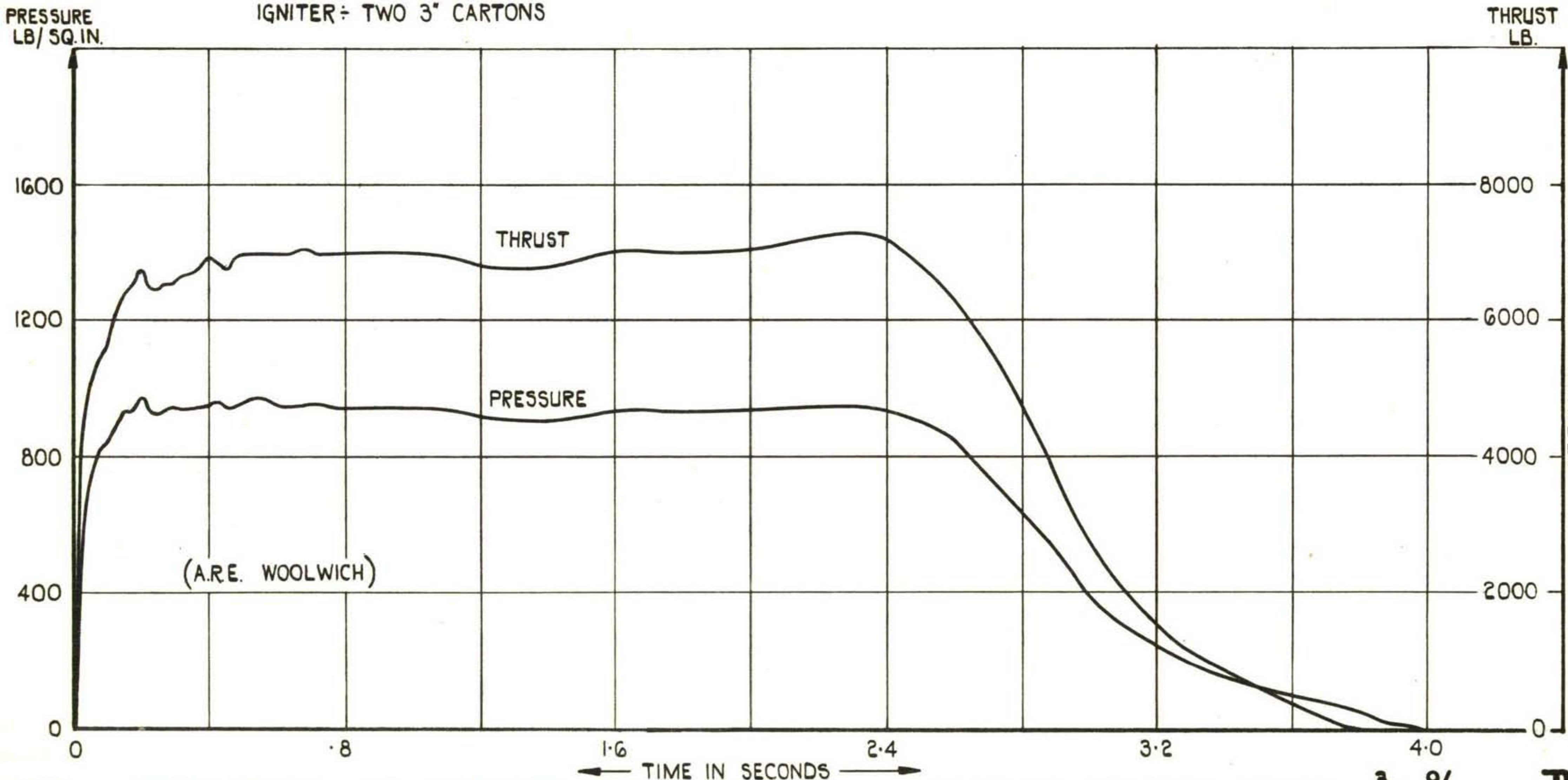
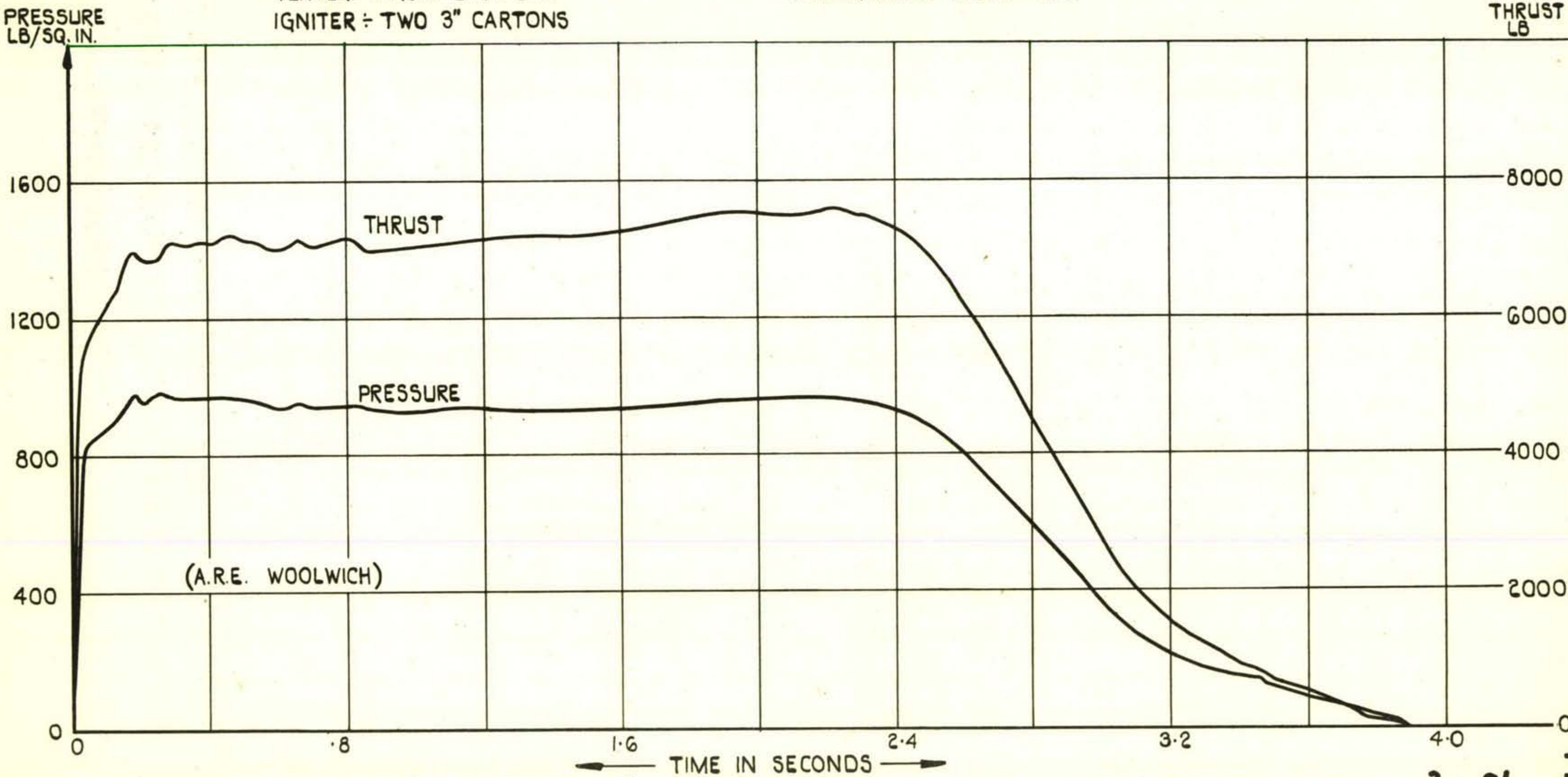


FIG.9 PRESSURE AND THRUST / TIME CURVES — ANNULUS FILLED WITH ¾ % AQUEOUS AGAR SOLUTION, FIRING AT 35° F

PROPELLANT ÷ R.N.P. 128 S
CHARGE WEIGHT ÷ 104 LB. 11 OZ.
VENTURI THROAT DIA ÷ 2·55"
IGNITER ÷ TWO 3" CARTONS

ROUND Nº ÷ G W - 10
DATE FIRED ÷ 26-4-49
PERFORMANCE INDEX ÷ 202



SECRET - DISCREET

T.N. R.P.D. 67
FIG.10

FIG.10 PRESSURE AND THRUST / TIME CURVES — ANNULUS FILLED WITH 3/4 % AQUEOUS AGAR SOLUTION, FIRING AT 35° F

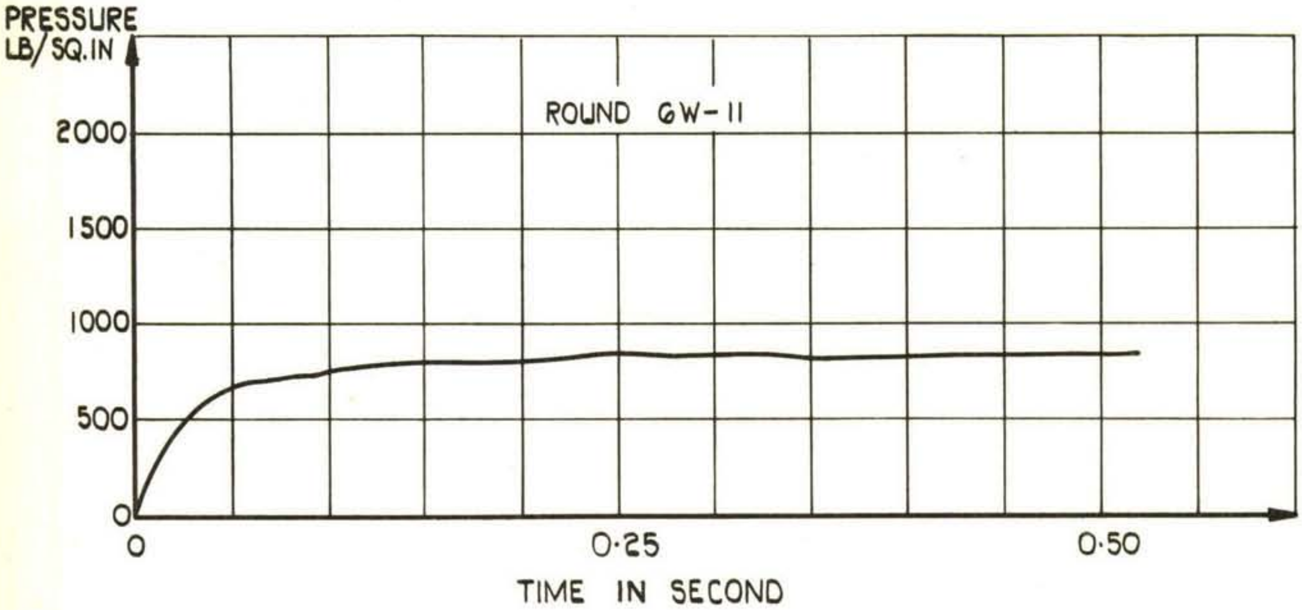


FIG. 11 PRESSURE / TIME CURVE — CHARGE FITTED WITH SPACER TABS AT EACH END, FIRING AT AIR TEMPERATURE.

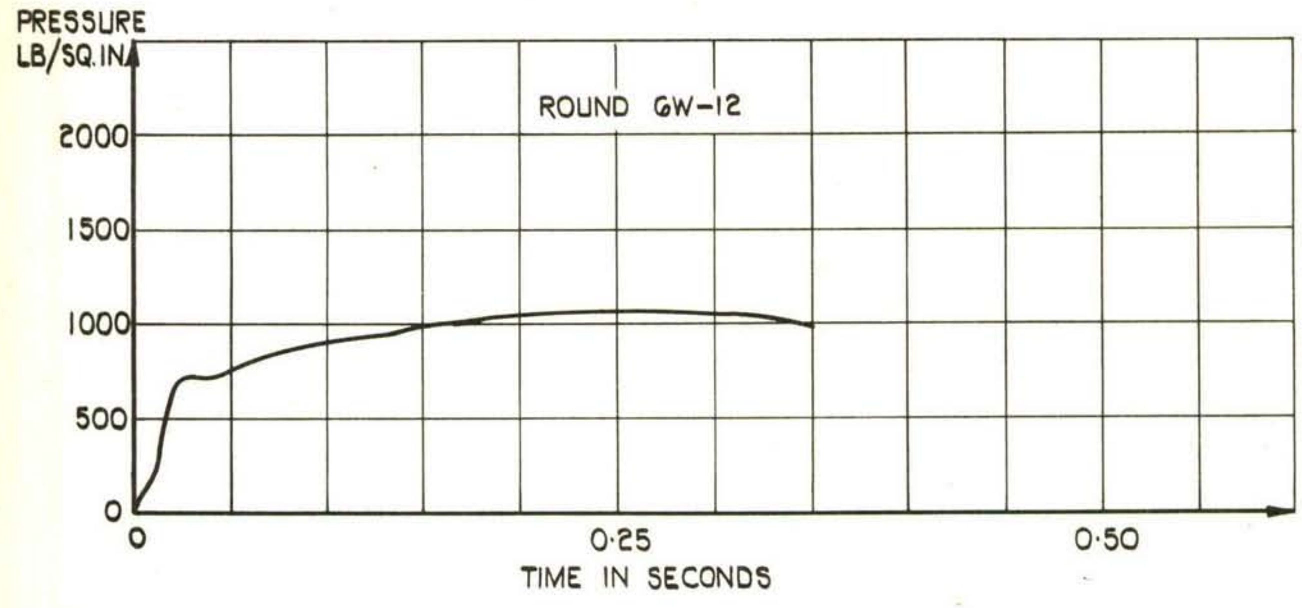


FIG. 12 PRESSURE / TIME CURVE — CHARGE FITTED WITH SPACER TABS AT VENTURI END, FIRING AT AIR TEMPERATURE.

CORDITE LOT Nº ÷ R.N.P. 146 S
IGNITER ÷ TWO 3" SR 371 C IN SERIES
VENTURI THROAT DIA. ÷ 2·55"

ROUND Nº ÷ G W-13
DATE FIRED ÷ 31-5-49

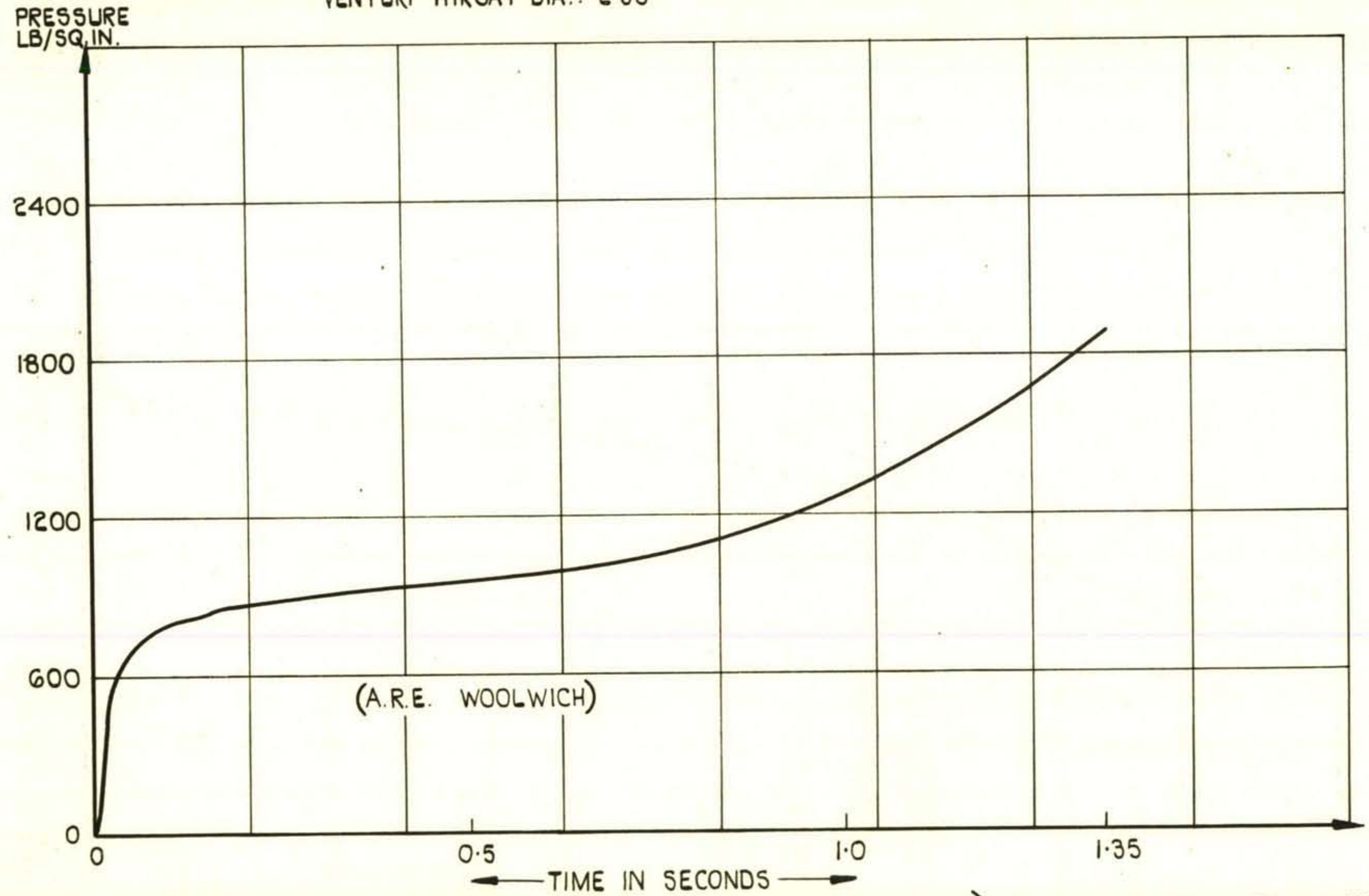


FIG.13 PRESSURE / TIME CURVE —(STEEL TUBE) CHARGE FITTED WITH SPACER TABS AT BOTH ENDS, FIRING AT AIR TEMPERATURE.

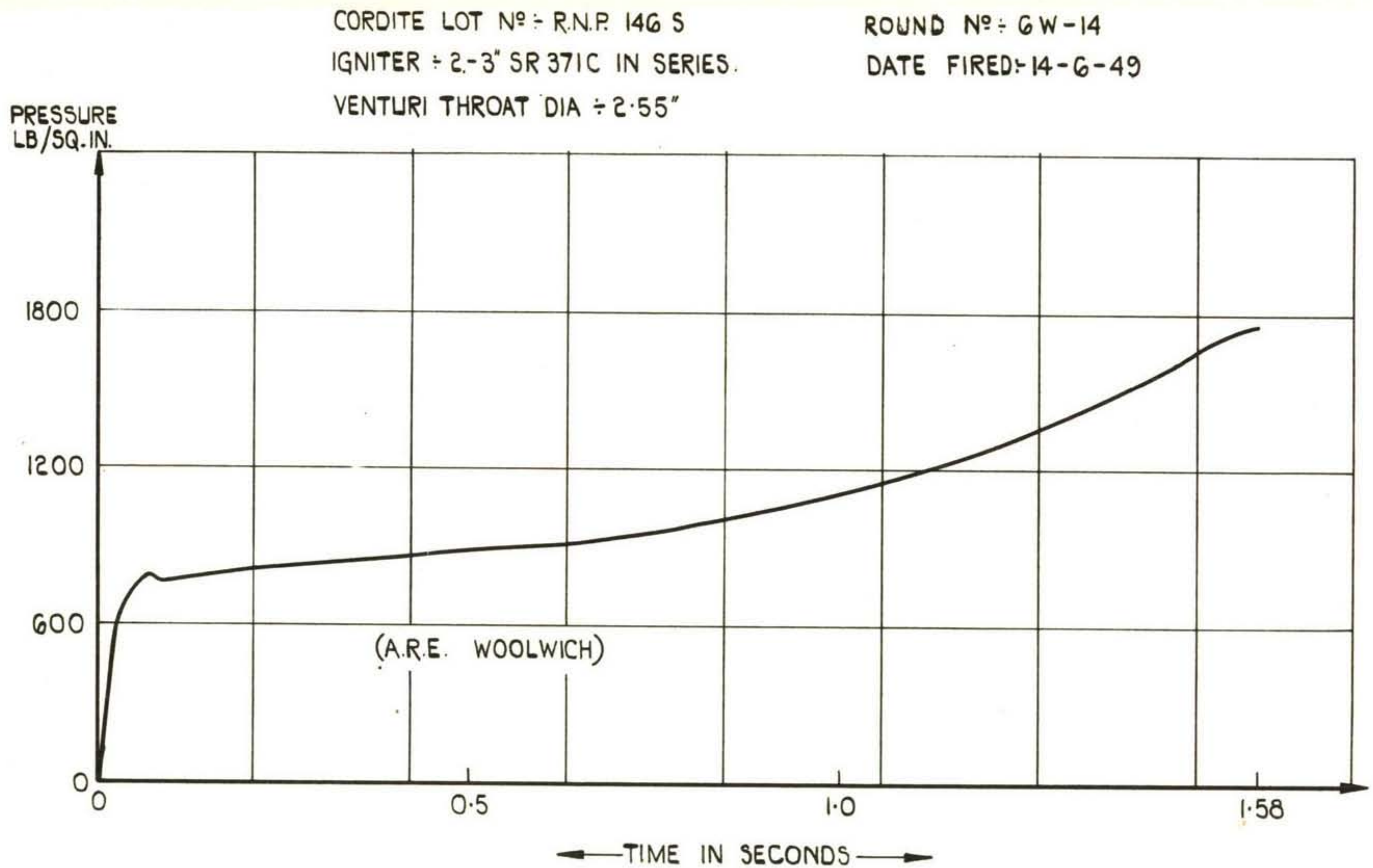


FIG. 14 PRESSURE / TIME CURVE — (STEEL TUBE) CHARGE FITTED WITH SPACER TABS AT VENTURI END, FIRING AT AIR TEMPERATURE.

FIG. 15

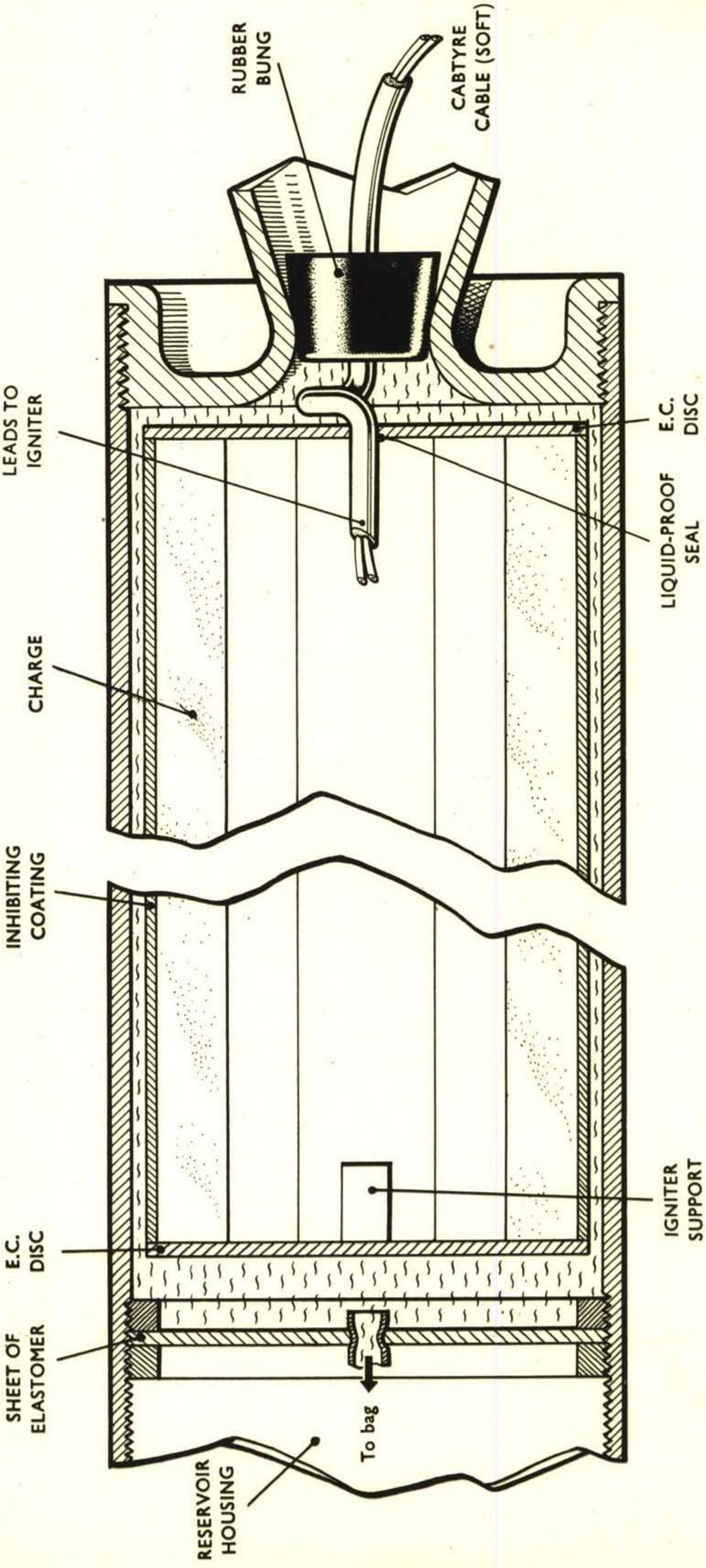


FIG.15. LONGITUDINAL SECTION OF ROUND FITTED WITH RESERVOIR IN FORWARD END SPACE

MECHANICAL DETAILS DIAGRAMMATIC ONLY

SECRET — DISCREET

PROPELLANT ÷ R.N.P. ÷ 146 S
CHARGE WEIGHT ÷ 104 LB. 2¾ OZ
VENTURI THROAT DIA ÷ 2·55″
IGNITER ÷ THREE 3″ CARTONS

ROUND Nº ÷ G W-16
DATE FIRED ÷ 1-7-49
PERFORMANCE INDEX 204 (CALCULATED)

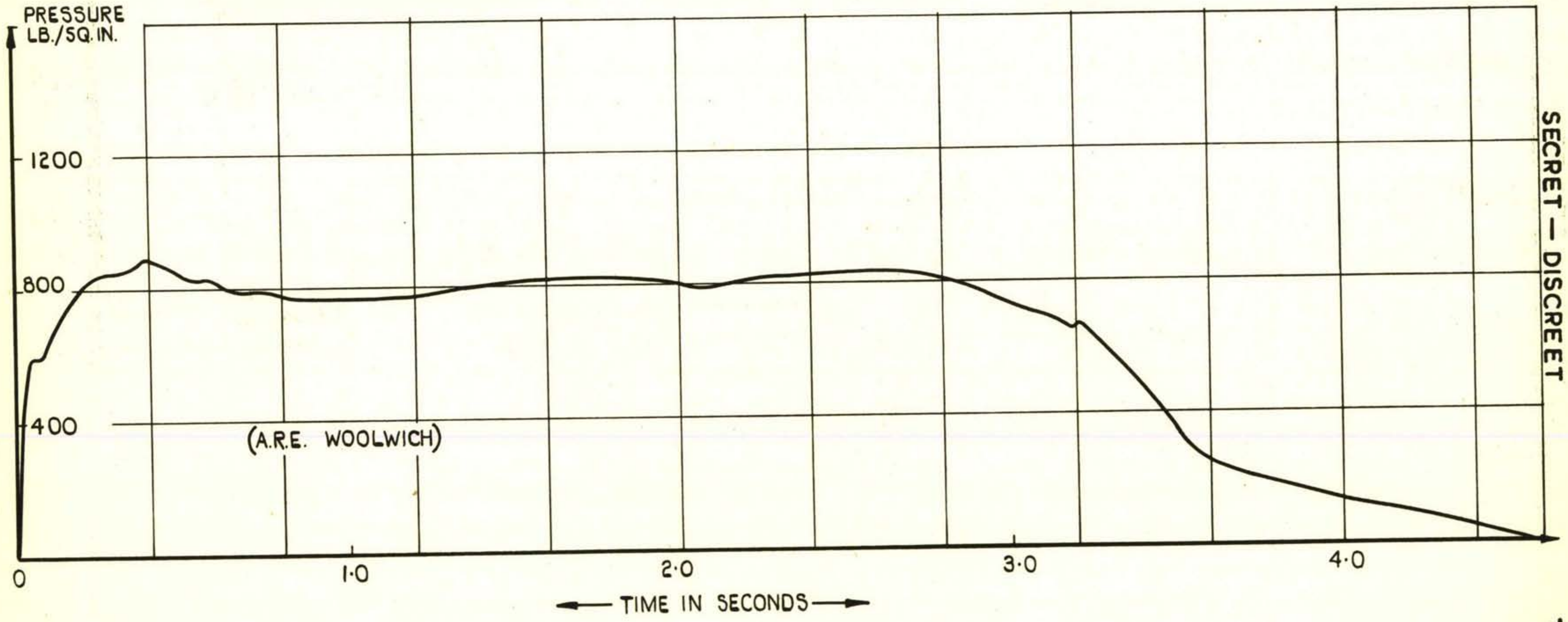


FIG.16 PRESSURE / TIME CURVE — ANNULUS FILLED WITH ETHYLENE GLYCOL AND FITTED WITH RESERVOIR AT FORWARD END, FIRING AT − 5° F

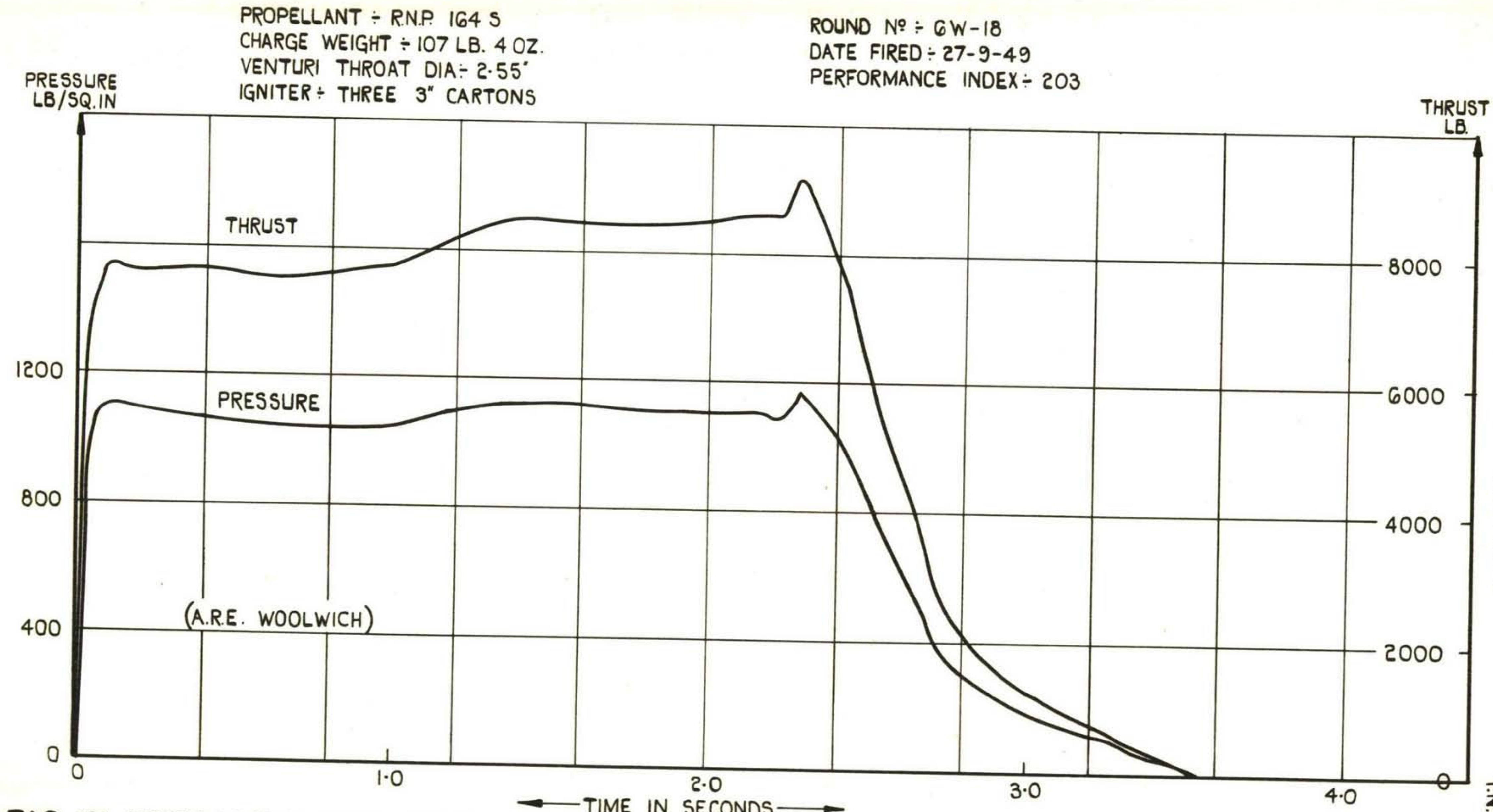


FIG. 17 PRESSURE AND THRUST / TIME CURVES — ANNULUS FILLED WITH ETHYLENE GLYCOL, FIRING AT AIR TEMPERATURE.

SECRET — DISCREET

PROPELLANT ÷ R.N.P. 164 S
CHARGE WEIGHT ÷ 106 LB. 10 OZ.
VENTURI THROAT DIA ÷ 2·55"
IGNITER ÷ THREE 3' CARTONS

ROUND Nº ÷ GW-19
DATE FIRED ÷ 27-9-49
PERFORMANCE INDEX ÷ 205

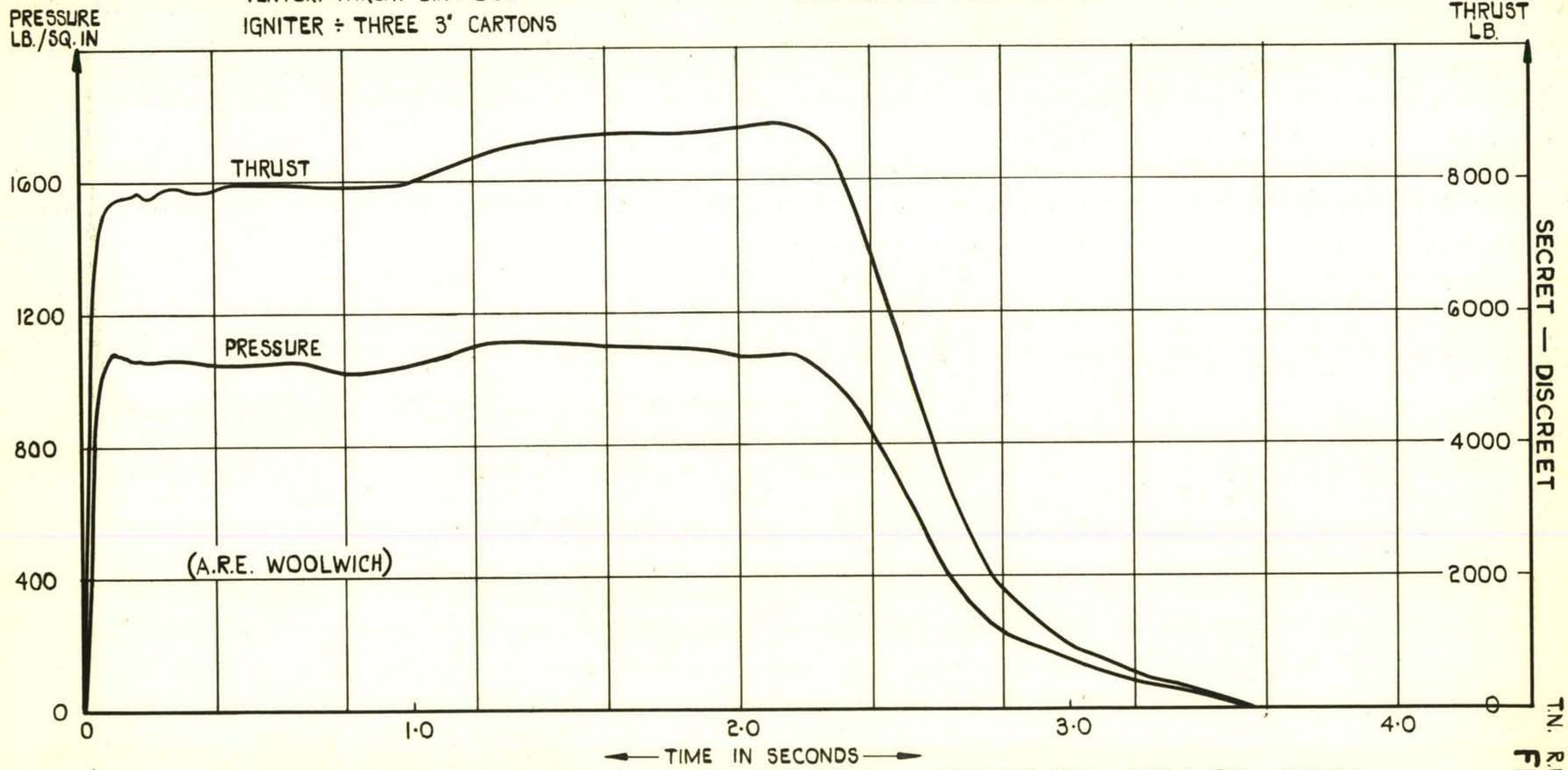


FIG. 18 PRESSURE AND THRUST / TIME CURVES — ANNULUS FILLED WITH ETHYLENE GLYCOL, FIRING AT AIR TEMPERATURE.

PROPELLANT ÷ R.N.P. 164 S
CHARGE WEIGHT ÷ 106 LB. 7 OZ
VENTURI THROAT DIA. ÷ 2·55"
IGNITER ÷ THREE 3" CARTONS

ROUND Nº ÷ GW-20
DATE FIRED ÷ 29-9-49
PERFORMANCE INDEX 205

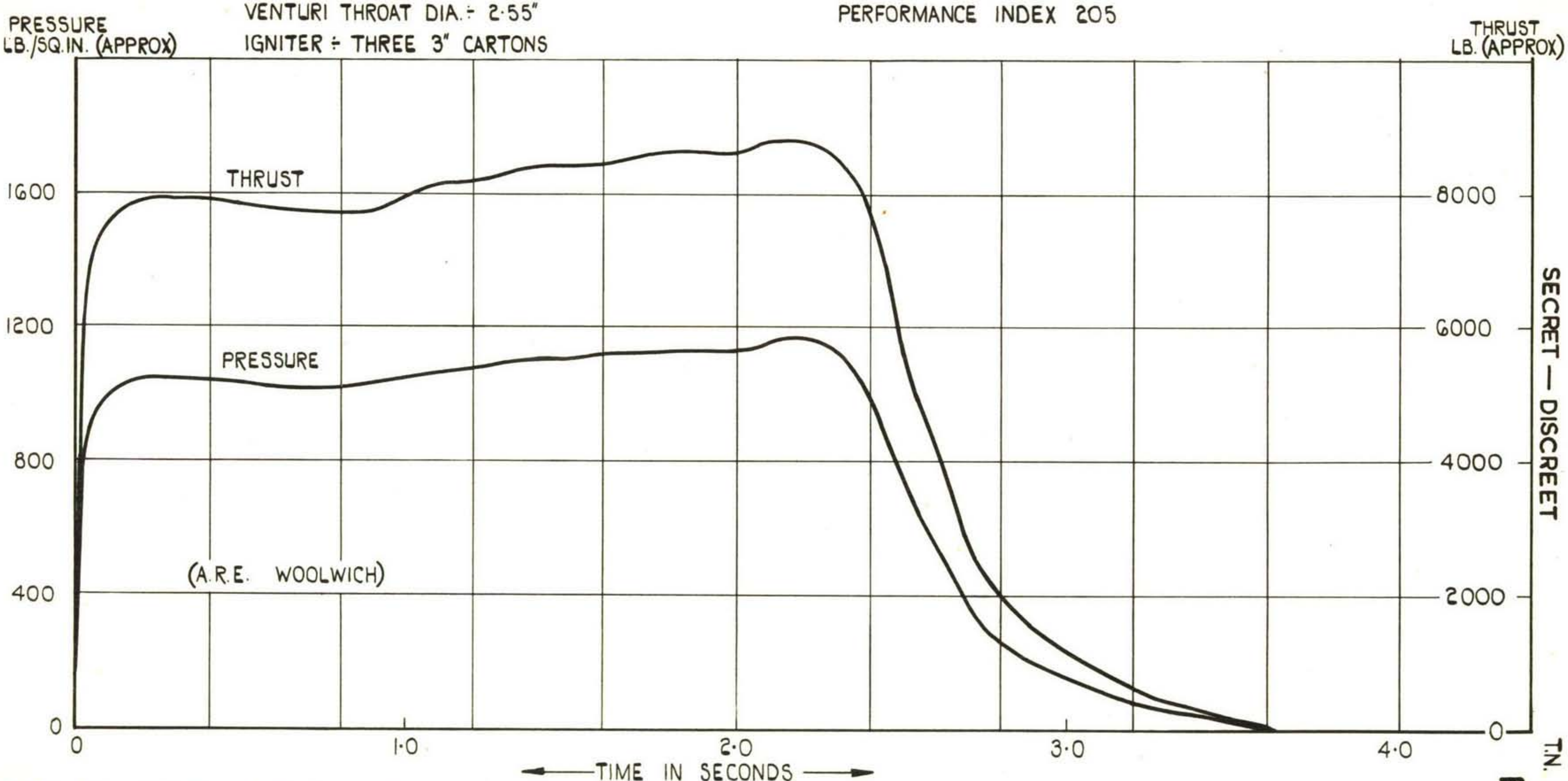


FIG. 19 PRESSURE AND THRUST / TIME CURVES — ANNULUS FILLED WITH ETHYLENE GLYCOL, FIRING AT AIR TEMPERATURE.

SECRET — DISCREET

FIG.20

PROPELLANT ÷ R.N.P. 164 S
CHARGE WEIGHT ÷ 104 LB. 10 OZ.
VENTURI THROAT DIA ÷ 2·55"
IGNITER ÷ THREE 3" CARTONS

ROUND № ÷ GW-21
DATE FIRED ÷ 29-9-49
PERFORMANCE INDEX ÷ 204

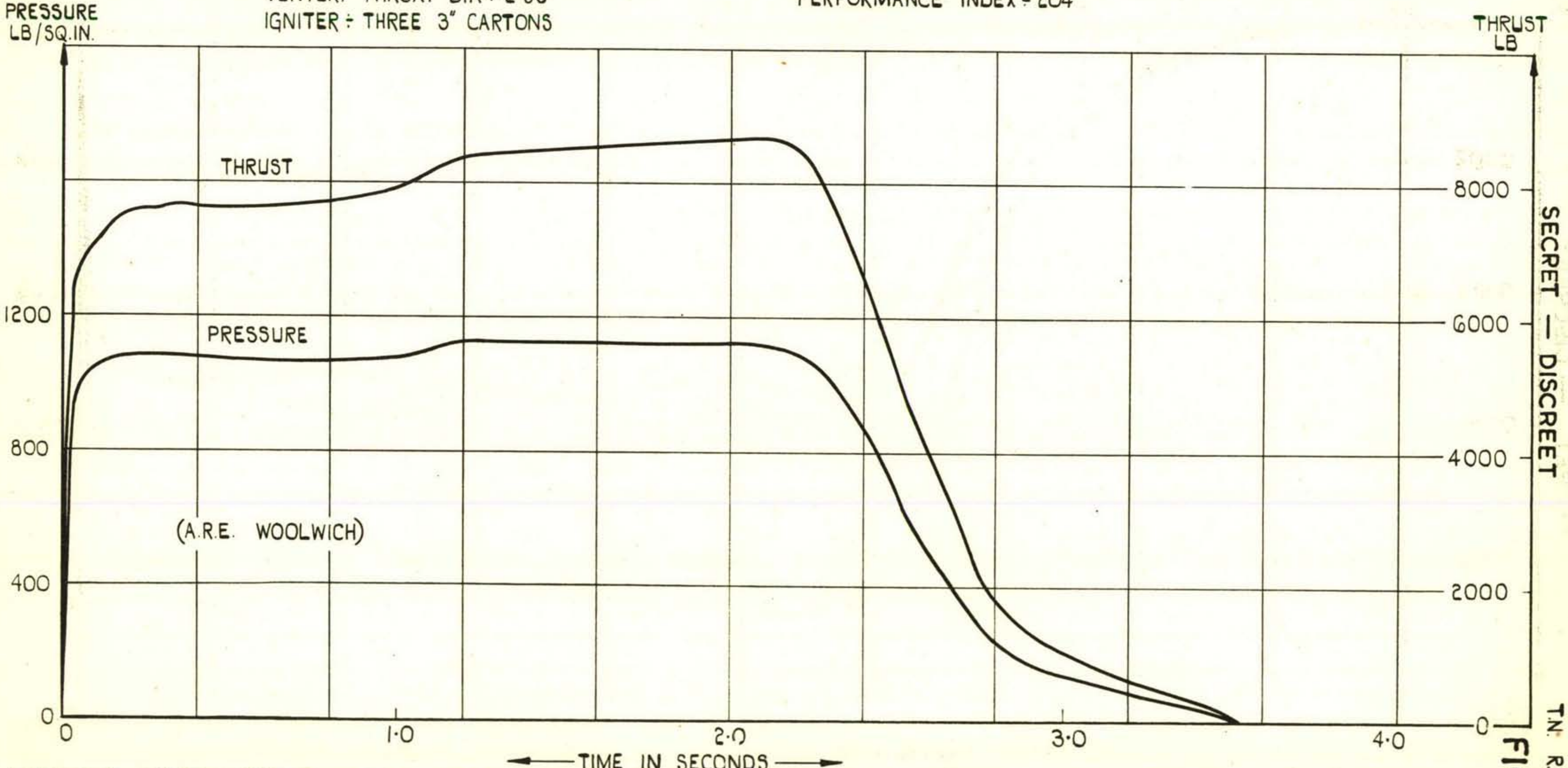


FIG.20 PRESSURE AND THRUST / TIME CURVES — ANNULUS FILLED WITH ETHYLENE GLYCOL, FIRING AT AIR TEMPERATURE.

PROPELLANT ÷ R.N.P. 164 S
CHARGE WEIGHT ÷ 107 LB. 8 OZ.
VENTURI THROAT DIA ÷ 2·55"
IGNITER ÷ THREE 3" CARTONS

ROUND Nº ÷ GW-22
DATE FIRED ÷ 10-10-49
PERFORMANCE INDEX ÷ 204

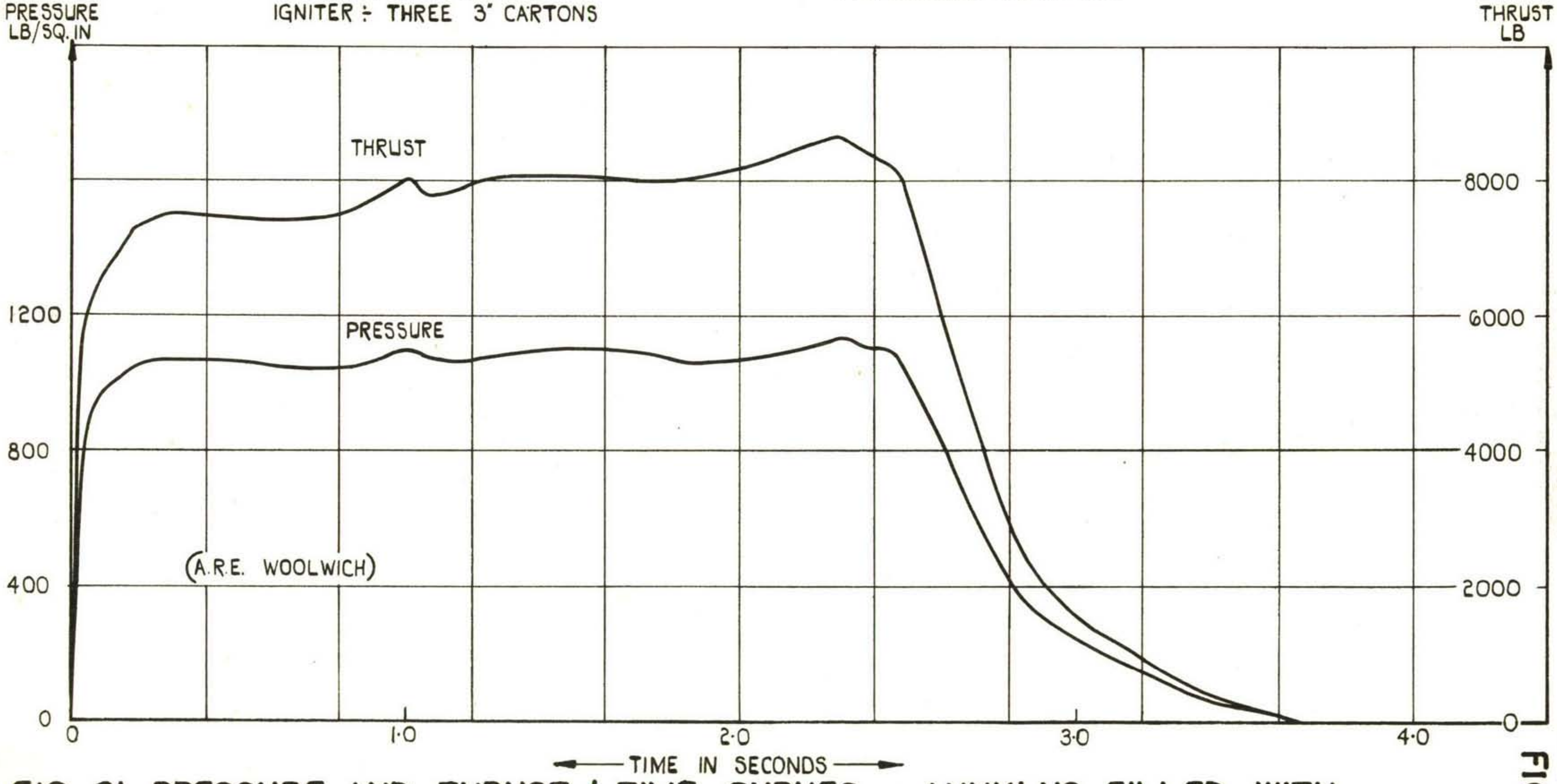


FIG. 21 PRESSURE AND THRUST / TIME CURVES — ANNULUS FILLED WITH ETHYLENE GLYCOL, FIRING AT AIR TEMPERATURE.

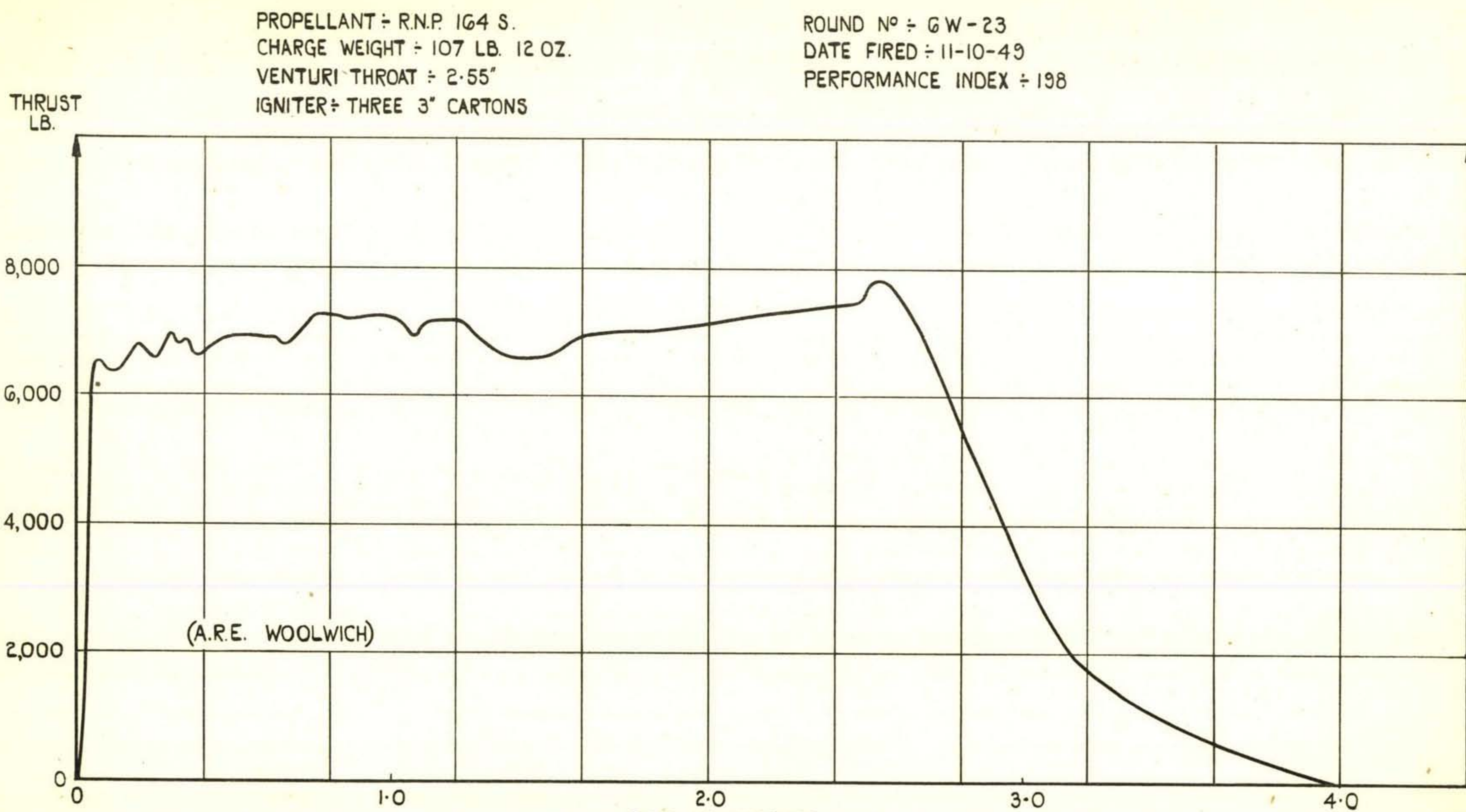


FIG. 22 THRUST / TIME CURVE — ANNULUS FILLED WITH ETHYLENE GLYCOL, FIRING AT 32° F

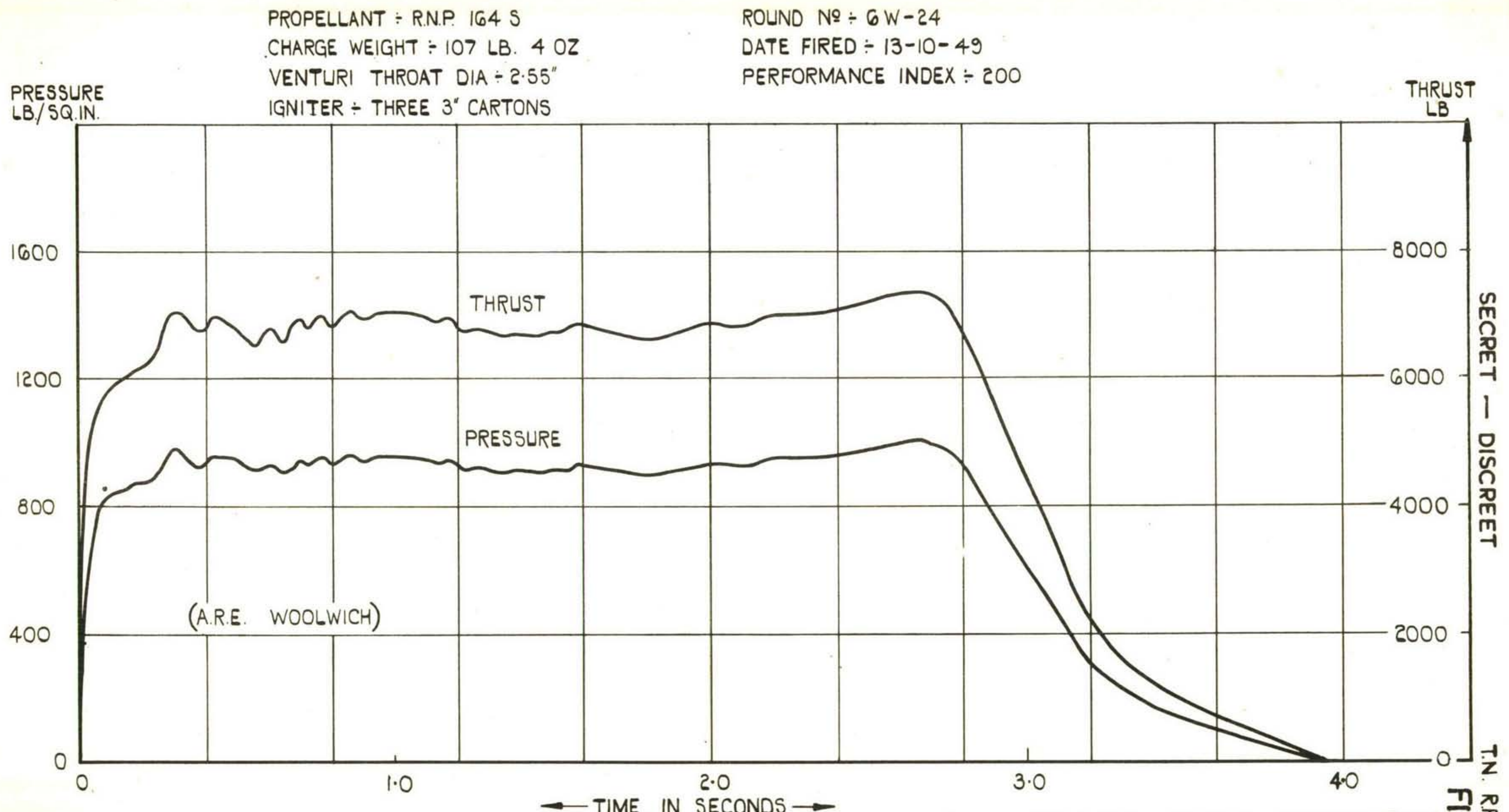


FIG. 23 PRESSURE AND THRUST / TIME CURVES — ANNULUS FILLED WITH ETHYLENE GLYCOL, FIRING AT 32° F.

PROPELLANT ÷ R.N.P. 164 S
CHARGE WEIGHT ÷ 108 LB. 3 OZ.
VENTURI THROAT DIA ÷ 2·55"
IGNITER ÷ THREE 3" CARTONS

ROUND Nº ÷ GW-25
DATE FIRED ÷ 13-10-49
PERFORMANCE INDEX ÷ 202

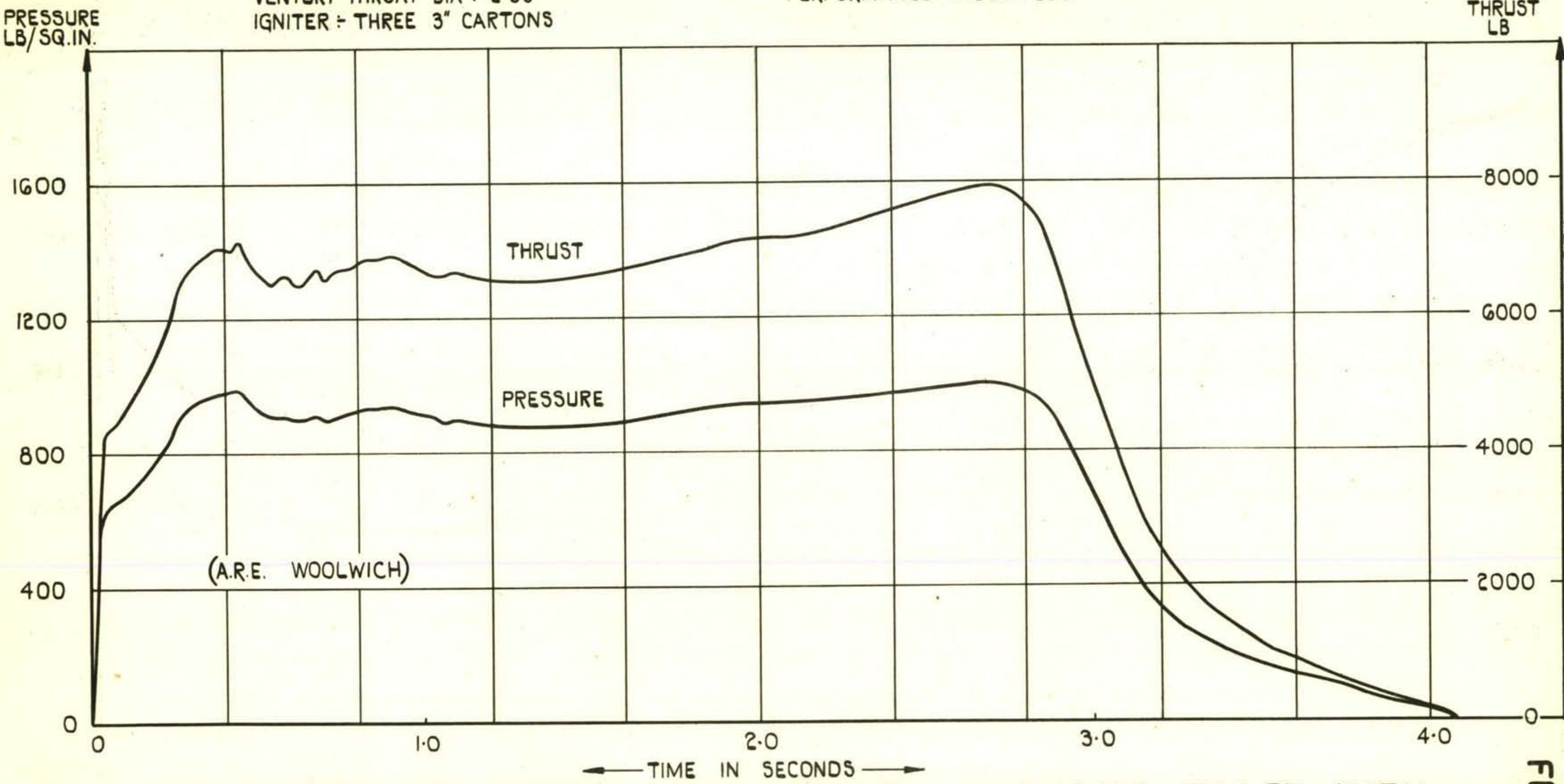


FIG. 24 PRESSURE AND THRUST / TIME CURVES — ANNULUS FILLED WITH ETHYLENE GLYCOL, FIRING AT 32° F

FIG.25

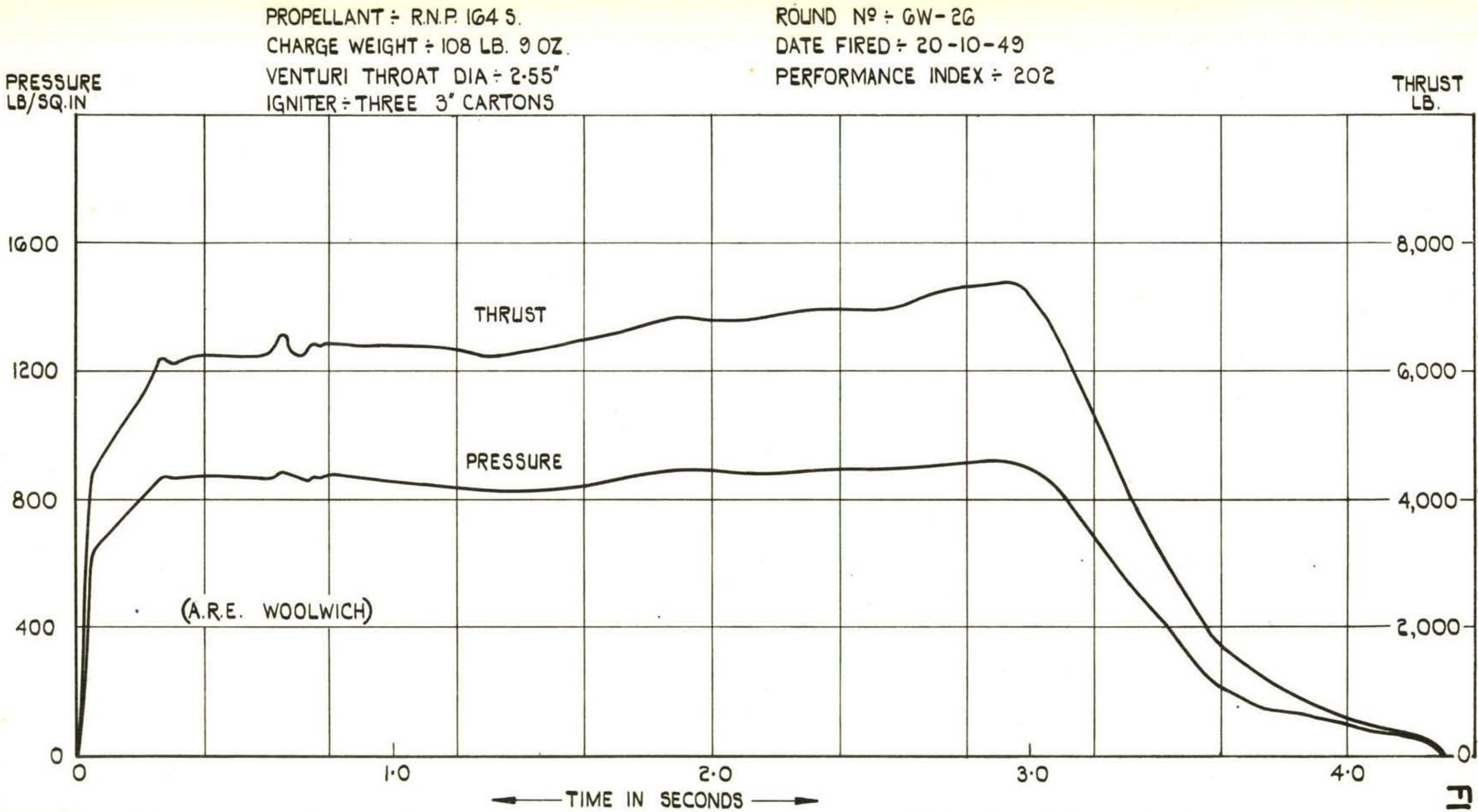


FIG. 25 PRESSURE AND THRUST / TIME CURVES — ANNULUS FILLED WITH ETHYLENE GLYCOL, FIRING AT 32° F

SECRET — DISCREET

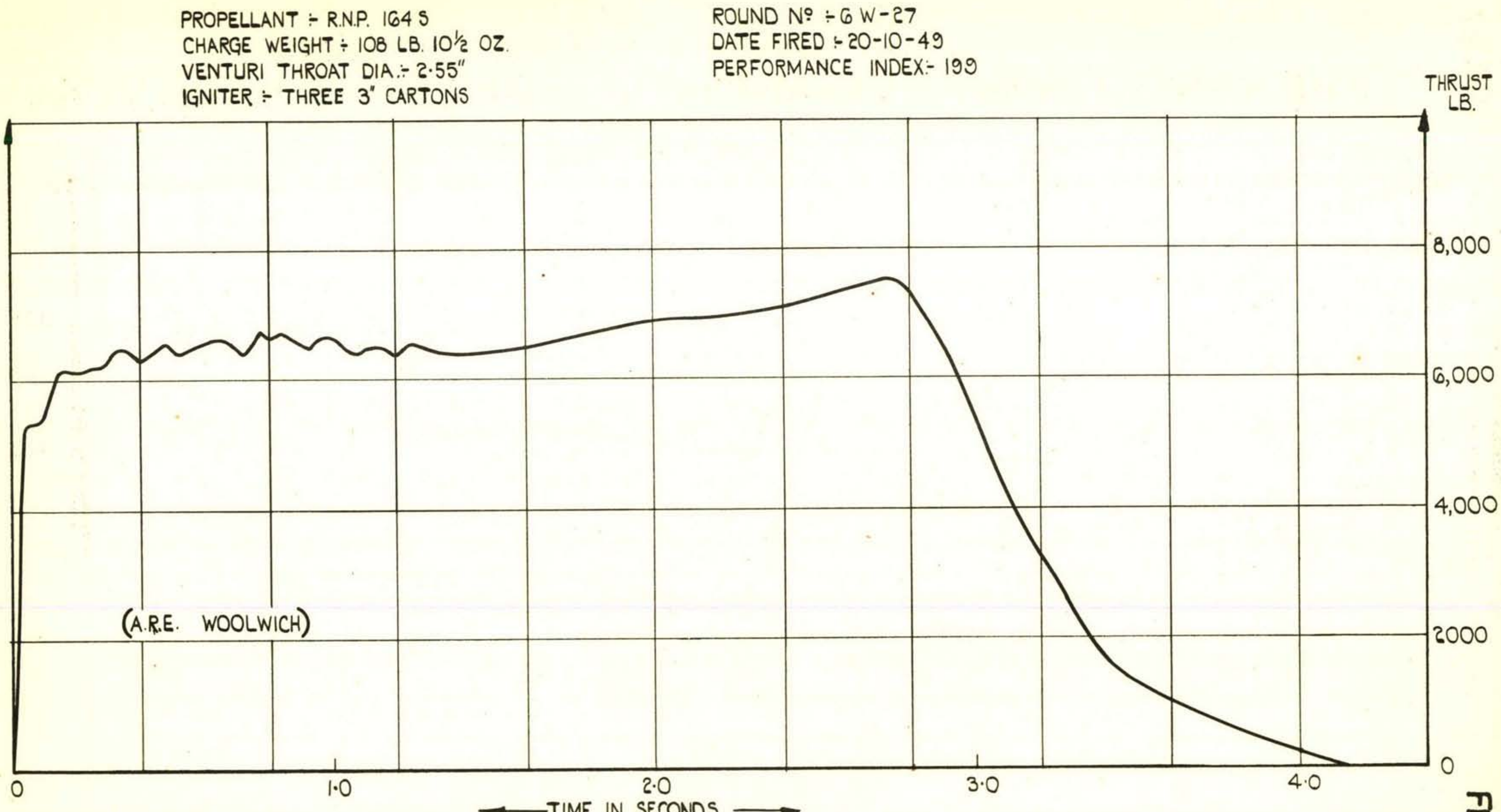


FIG. 26 THRUST / TIME CURVE — ANNULUS FILLED WITH ETHYLENE GLYCOL, FIRING AT 32° F.

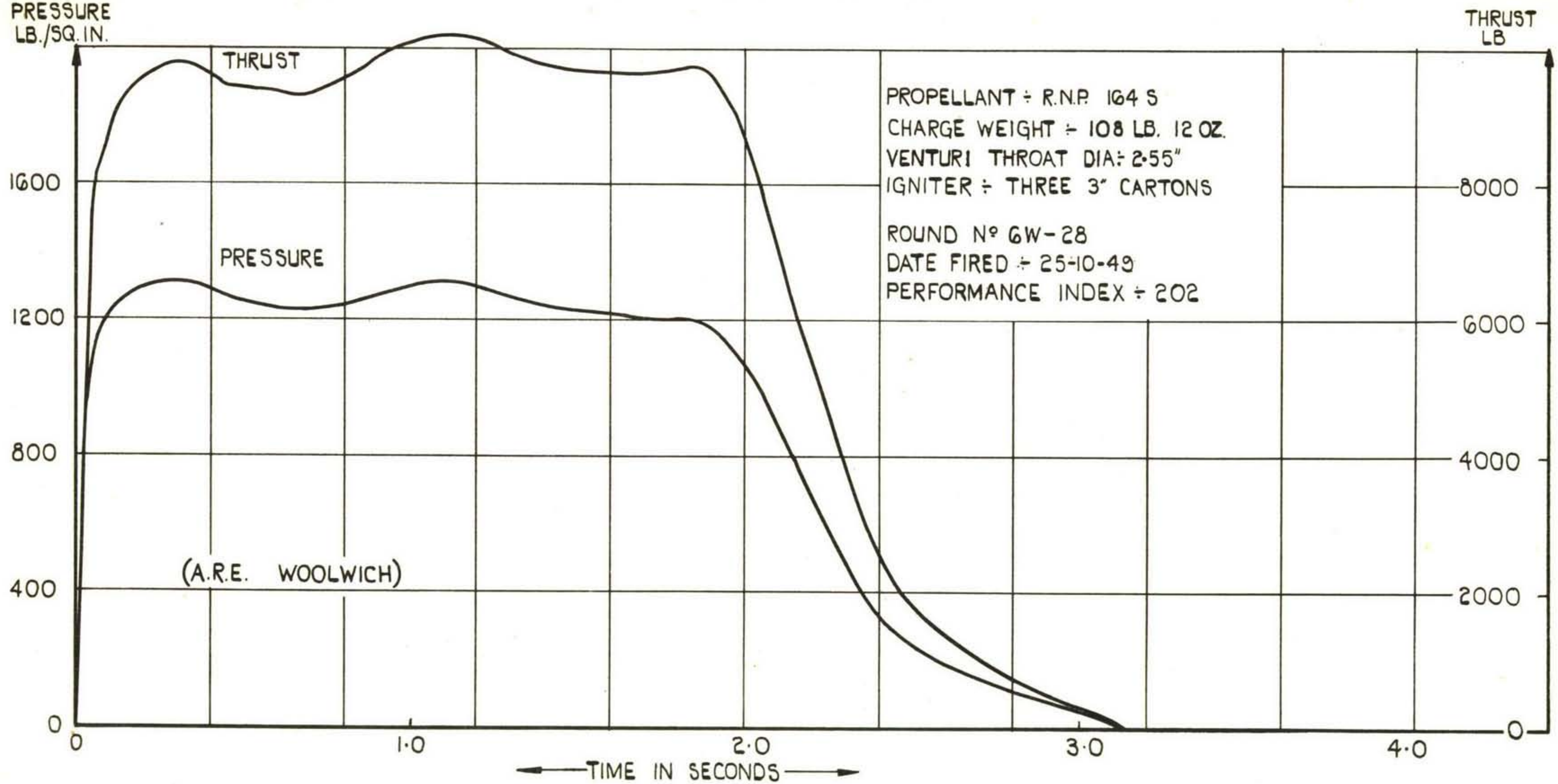


FIG. 27 PRESSURE AND THRUST / TIME CURVES — ANNULUS FILLED WITH ETHYLENE GLYCOL, FIRING AT 100° F

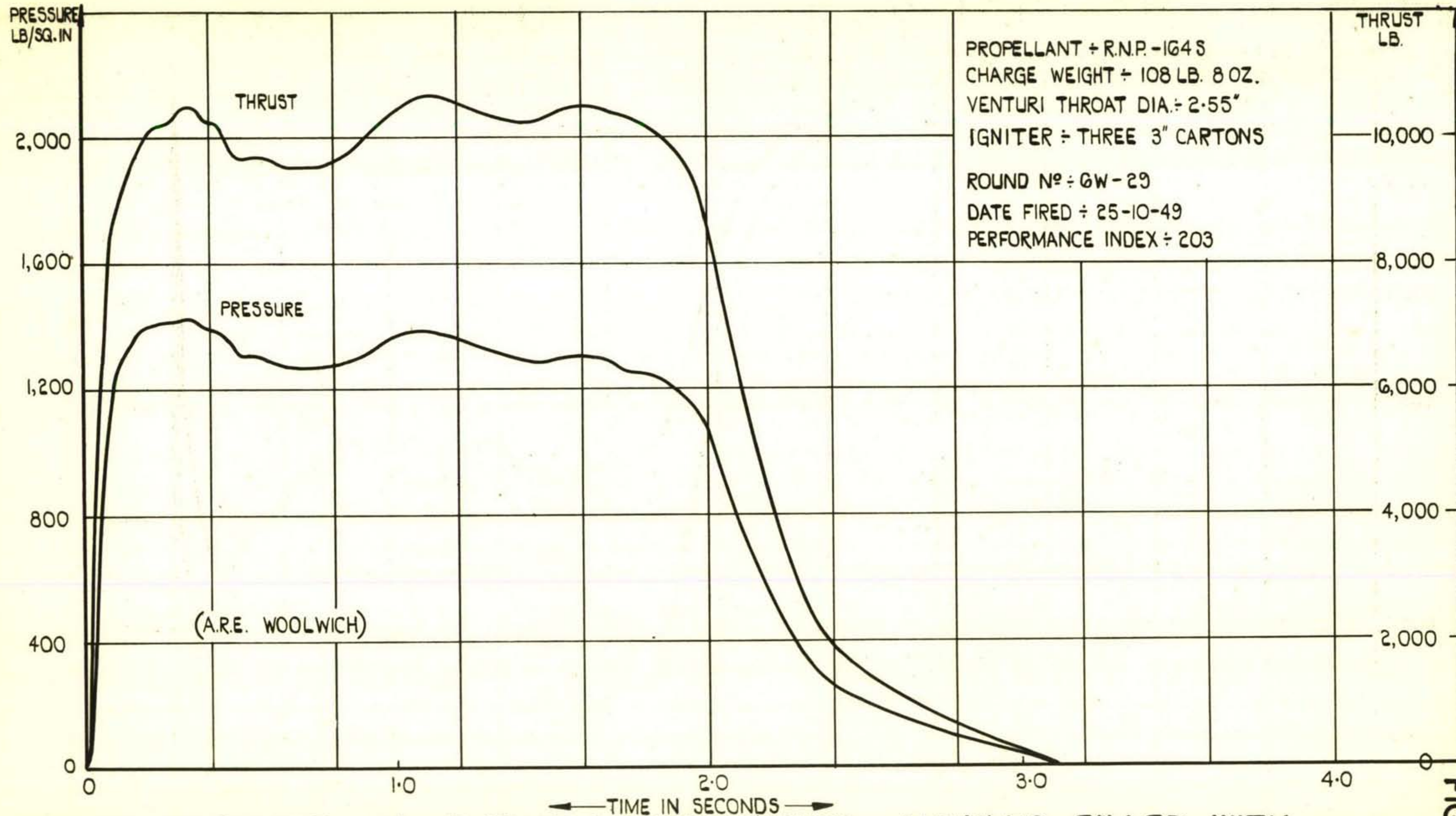


FIG. 28 PRESSURE AND THRUST / TIME CURVES — ANNULUS FILLED WITH ETHYLENE GLYCOL, FIRING AT 100° F

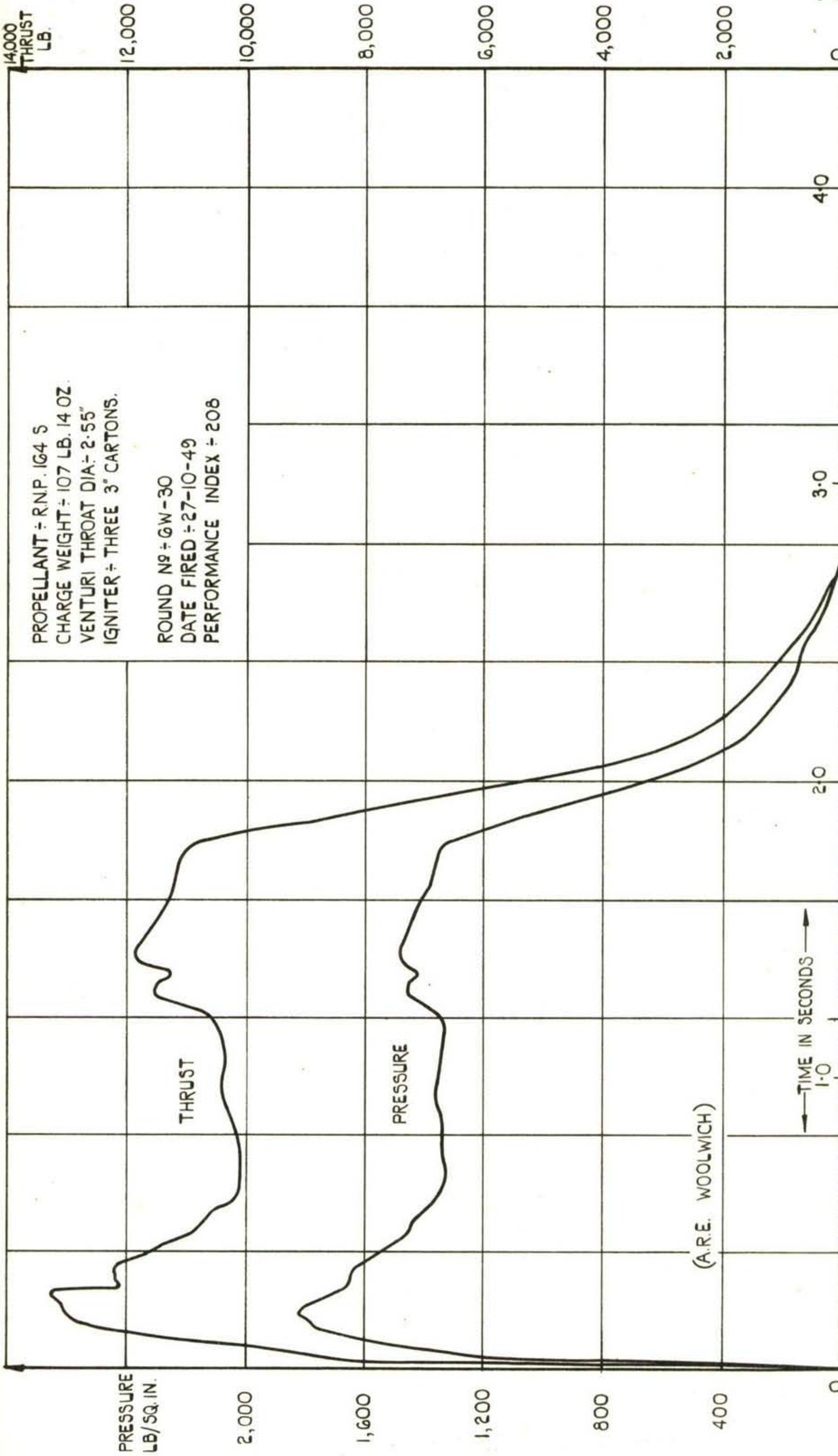


FIG. 29 PRESSURE AND THRUST / TIME CURVES – ANNULUS FILLED WITH ETHYLENE GLYCOL, FIRING AT 120° F

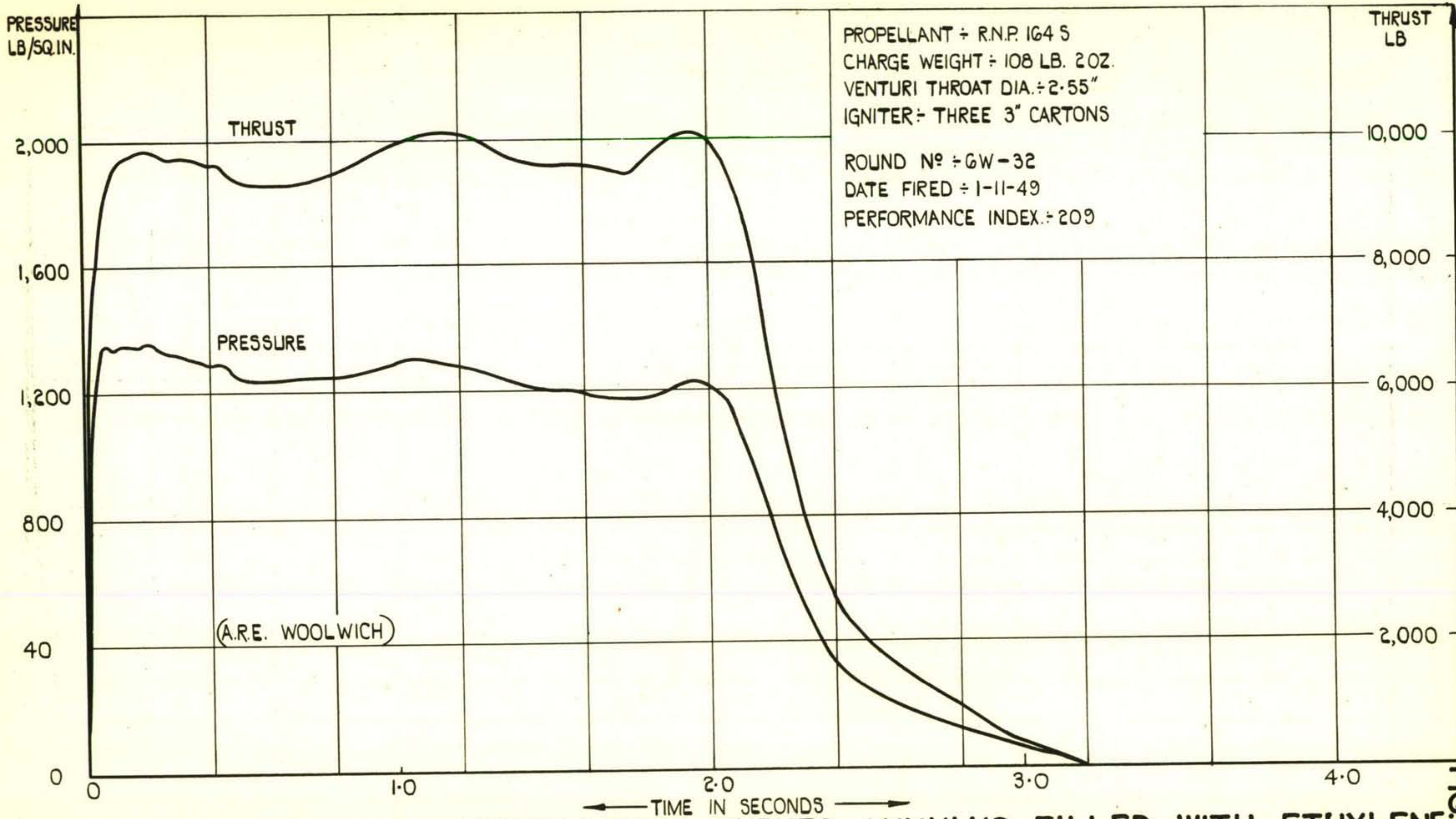


FIG. 30 PRESSURE AND THRUST / TIME CURVES ANNULUS FILLED WITH ETHYLENE GLYCOL, FIRING AT 100° F

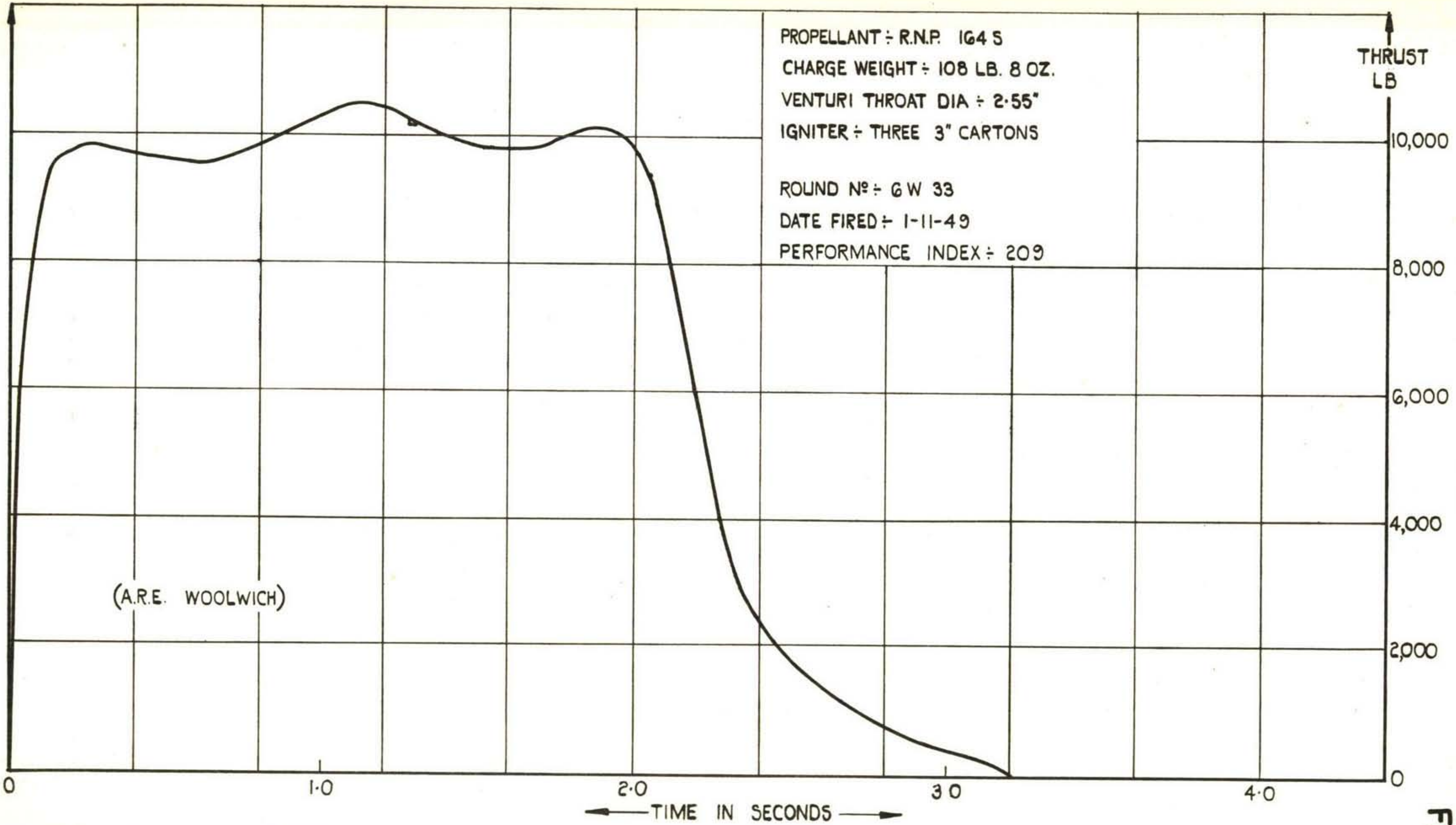


FIG. 31 THRUST / TIME CURVE — ANNULUS FILLED WITH ETHYLENE GLYCOL, FIRING AT 100° F

FIG. 32

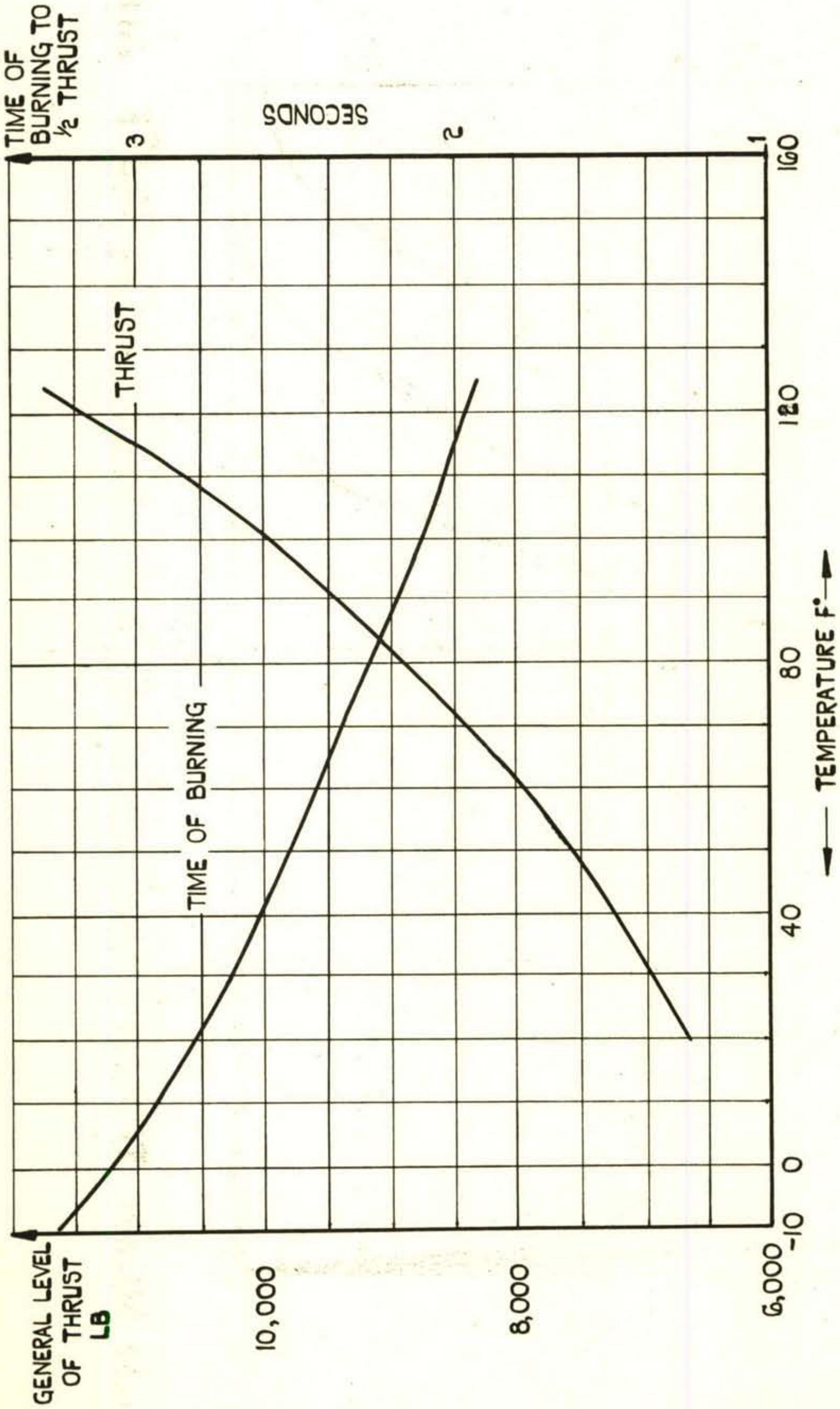


FIG. 32 VARIATION OF THRUST AND TIME OF BURNING WITH TEMPERATURE.

~~SECRET — DISCREET~~

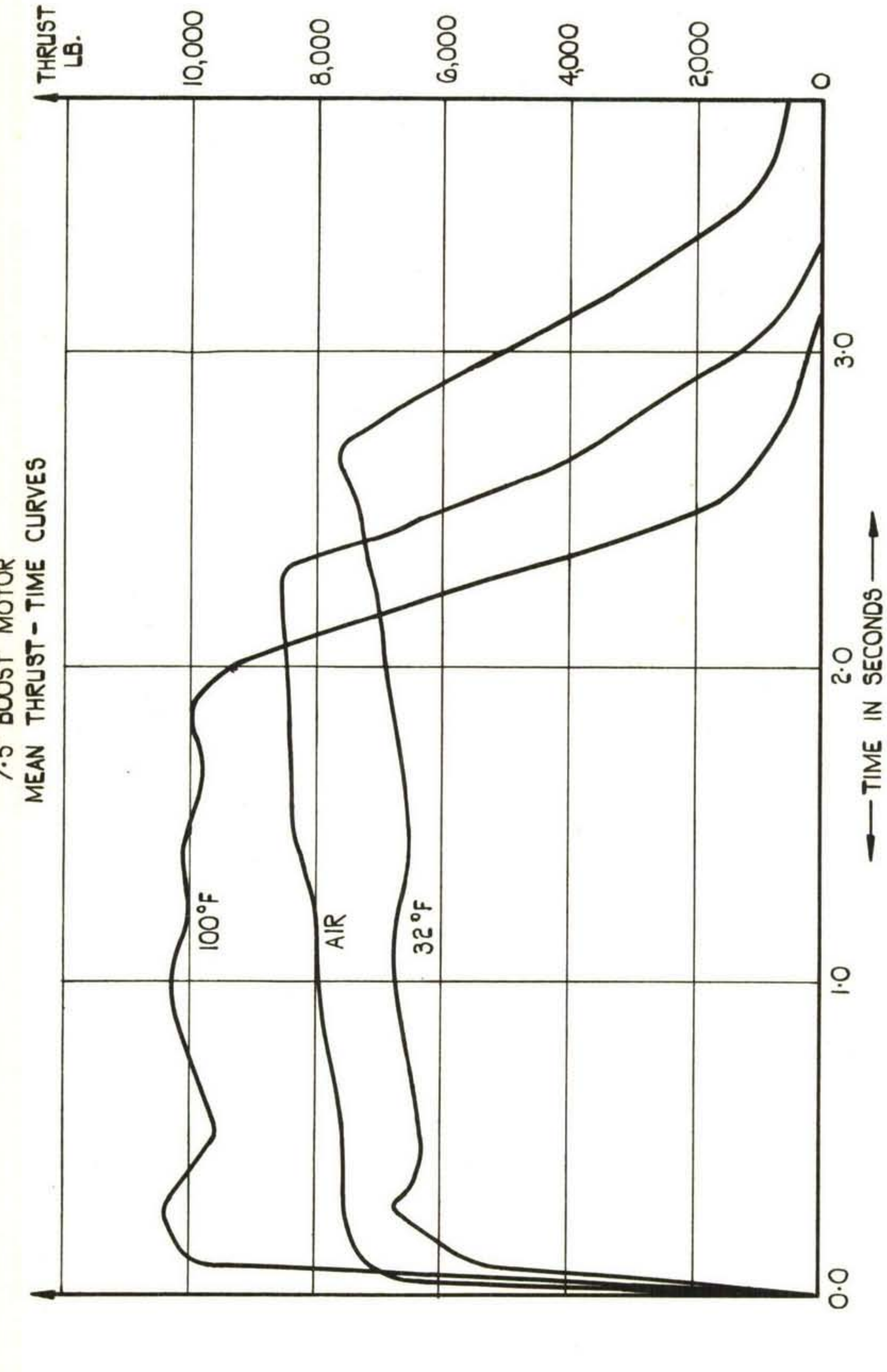


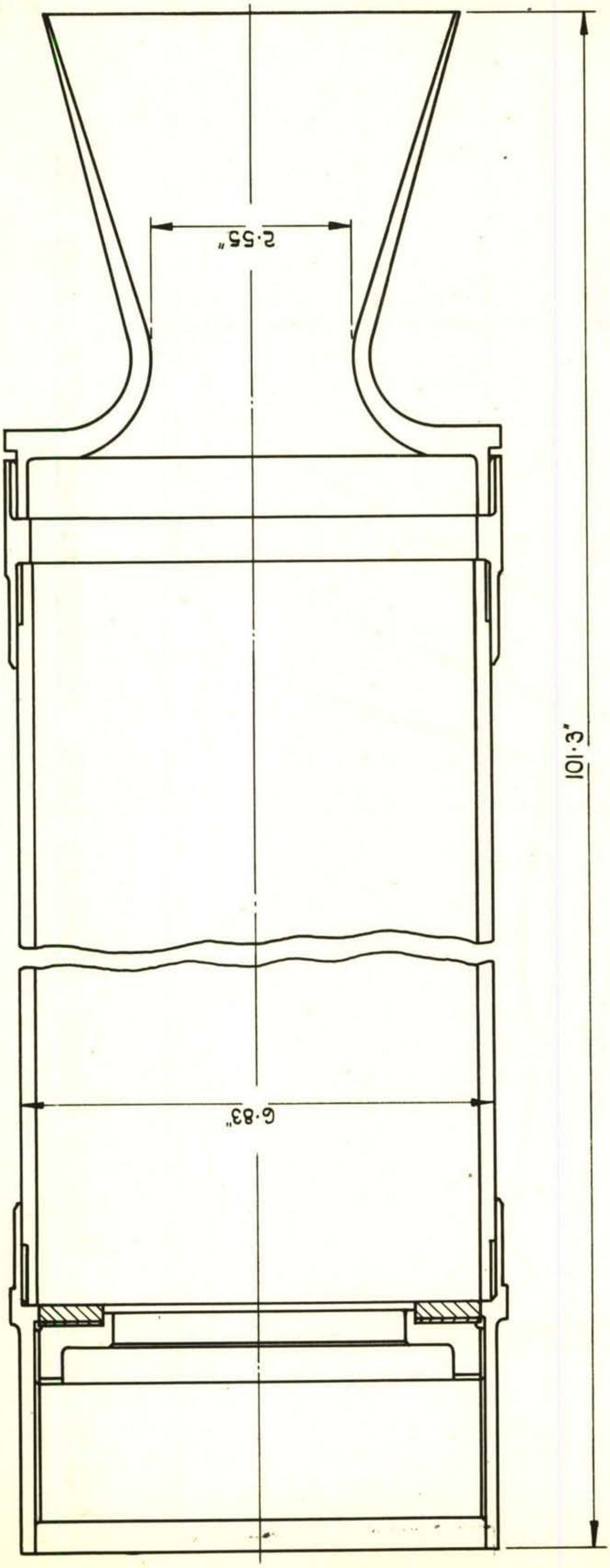
FIG. 33 MEAN THRUST / TIME CURVES (AIR TEMPERATURE, 32°F AND 100°F)

UNCLASSIFIED

SECRET — DISCREET

T.N. R.P.D. 67

FIG. 34



BASED ON DB(L) 4963/GF/98

SCALE ÷ HALF SIZE

FIG. 34 EMPTY ASSEMBLY

UNCLASSIFIED