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ROCKET PROPULSION ESTABLISHMENT
(WESTCOTT)

R.P.E. TECHNICAL NOTE No. 220

THE DEVELOPMENT OF THE LINNET SOLID PROPELLENT ROCKET MOTOR

by

N. J. Morris and E. H. Mathews

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SUMMARY

The 7.25-inch diameter motor developed for use in the Red Top air-to-air missile employs a charge of colloidal propellent, as necessitated by the somewhat wide temperature limits demanded by the specification. The performance requirements have been met satisfactorily within the rather limited development time-scale available by the use of a charge composited from three extrusions of different conduit area. The reasons underlying the decision to use such a 'stepped-conduit' charge are given, the testing of all components is described, and the results of static and projection firing trials are tabulated and discussed.

The igniter of this motor incorporates an effective form of attenuator to give protection against radio frequency hazards to the firing circuit.

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1 INTRODUCTION

The Linnet I and Linnet IIA rocket motors were intended to meet the requirements specified for an internally stowed rocket motor for the Red Top air-to-air missile. The specification demanded the following performance from the motor at the temperatures stated:

Total impulse	not less than 16,700 lb-seconds at 15°C
Burning time	1.7 seconds at 50°C to 2.7 seconds at -40°C
Minimum thrust*	5000 lb at -40°C
Maximum thrust	8000 lb at 50°C
All-up weight of motor, (excluding tail pipe)	107 lb

The arrangement of the missile required the motor body to be placed in the centre section to minimise the shift of the centre of gravity of the missile during boosted flight, the exhaust gases being ducted axially through the rear section by means of a tail-pipe. The internal dimensions of the missile sections therefore determined the maximum motor body and tail-pipe dimensions. In addition, the specification contained two novel requirements. The tail-pipe was to be permanently secured within the rear section of the missile where it would support certain items of equipment; the centre and rear sections of the missile were to be joined after alignment by an external locking ring (hence a simple push-fit joint between motor and tail-pipe was essential). The second requirement, not made until issue 3 of the specification, called for an attenuator to be fitted to the motor igniter as protection against accidental firing of the igniter fuze by currents induced by external R/F radiation; the insertion loss for the attenuator was to exceed 30 dB between frequencies of 0.5 to 10,000 Mc/s.

As operation over the conditioning temperature range -40 to 50°C was required, and because the reliability of case-bonded propellents at the lower extreme was uncertain[1] the motor design for Linnet was based on a loose inhibited charge of extruded colloidal propellent; satisfactory behaviour of such charges at -40°C had been demonstrated in the successful development of the Magpie II motor[2] for the Firestreak air-to-air missile.

During development of the first version of the new motor, designated Linnet I, a charge cracked during a firing at -40°C, causing failure; since motors were urgently required for the missile flight test programme, the low temperature limit was raised to -25°C. No trouble was experienced in motors fired at this temperature, but a small number fired at 50°C showed excessively high levels of pressure and thrust. Linnet I, therefore, had to be confined to missile research and development flight trials with a restriction limiting firings to the conditioning temperature range -25 to 35°C.

*Amended in issue 3 of the specification to 5500 lb.

The second version, designated Linnet IIA, was a development of Linnet I, incorporating charge improvements designed to ensure safe operation over the full temperature range -40 to 50°C, and certain modifications to the hardware which had been requested by the user. Linnet IIA has been cleared for firing from manned aircraft and meets the detailed requirements of the missile specification, except that at -40°C a proportion of motors gave thrusts and burning times which were marginally outside the prescribed limits.

Preparations for production of Linnet IIA are in progress at R.O.F. Bishopton and Ordnance Board trials covering rough usage, climatic storage, and temperature cycling are now being arranged.

2 CHARGE DEVELOPMENT

2.1 Design CD80, propellent VU

The original requirements were for a total impulse of not less than 16,700 lb-seconds at 15°C with a burning time of 1.7 to 2.7 seconds. The user, however, expressed preference for a burning time rather greater than the mean of these limits at 15°C, so the specification was altered (issue 4) to ask for burning times over the required temperature range of not less than 1.9 or more 2.7 seconds. A burning time of 2.3 seconds at 15°C was therefore selected in designing the charge.

An overall specific impulse (total impulse/total motor weight) of more than 150 lb-sec/lb had been demanded, compared with the value of 124 for the earlier Magpie II motor using propellent PU. It was clear that a composition with a specific impulse greater than that of PU (195 lb-sec/lb*) was required, and hence propellent VU (see Appendix I), having a specific impulse of at least 214 lb-sec/lb* was selected for the first design studies.

Using standard design procedure, the following values were derived:

Charge weight, M	= 78 lb
Length, L	= 34.9 inches
Diameter, d	= 7.33 inches
Thickness of web, w	= 1.80 inches
Cross sectional area of propellent, A_s	= 37.9 sq inches
Cross sectional area of conduit, A	= 4.30 sq inches .

A mean operating pressure of 1300 lb/sq in. at 15°C was considered (Appendix I) to be near the optimum, preventing unduly low pressures at -40°C and yet not exceeding the motor body tube design maximum of 1600 lb/sq in. at 50°C. A nozzle throat area of approximately 3.6 sq in. was found to be required to produce this mean pressure at 15°C giving a value for the ratio, λ ≠, of less than 1.20. Little was known of the degree of erosive burning which would result from operation of a

*Measured uncorrected values

≠ $\lambda = \dfrac{\text{Conduit cross-sectional area, A}}{\text{Nozzle throat cross-sectional area } A_t}$

charge in propellent VU at a value of λ as low as 1.2, and in the absence of such knowledge, it was decided to limit the initial peak pressure by arbitrarily reducing the initial burning surface area.

The design adopted (CD80, Fig.1) was based on the calculated values of web thickness and conduit area for a charge of 7.33 inches outside diameter having a four-point star-centre conduit. The variation of perimeter with depth of web burned off (Fig.1) for this design is markedly progressive, with an initial burning surface area almost 40 per cent below the final area; it was assumed that erosive burning of the propellent would increase the pressure level in the early stages of burning, thereby producing a level pressure/time curve.

2.2 Manufacture of CD80 charges

S/ROF Bishopton was asked to extrude charges to design CD80 in propellent VU and rapidly succeeded in producing extrusions with conduits of good dimensional accuracy. All extrusions were examined by X-ray techniques to the standards detailed in Appendix II. Extrusions less than 34.9 inches long were composited to make up 34.9-inch charges containing not more than one joint. The end faces of extrusions used in composited charges were machined square to the longitudinal axis of the charge[3] and were found to preserve their flatness for several weeks after the end-facing operation. The inhibitory coating of ethyl cellulose was applied to the external cylindrical surface by the stress relief method[4].

2.3 Firing trials of CD80 charges

The ballistic assessment of CD80 charges was carried out in thick-walled 'heavy duty' motors having almost exactly the same internal dimensions as the light-weight tube being developed for the Linnet motor.

Typical thrust/time and pressure/time curves, with performance figures, are given in Fig.2. The pressure/time curve accurately reflects the progressive burning character of the charge design, with initial pressure and thrust levels some 35 per cent below the peak levels at the burning time t_b; the expected increase in initial pressure due to erosive burning was not, therefore, realised. It was concluded that, at pressures below 1000 lb/sq in. the degree of erosive burning of propellent VU was negligible, even at a conduit-to-throat area ratio as low as 1.2.

The performance of motors using this charge compared poorly with the specification requirements, in that a thrust of 8000 lb, a maximum not to be exceeded, was reached even at 15°C; furthermore, the thrust level during the first 1.5 seconds of burning did not reach the amended minimum requirement of 5500 lb, even at 15°C. It was clear that at 50°C the maximum thrust would exceed the 8000 lb limit, whereas at -40°C the minimum thrust recorded would be well below the stipulated 5500 lb.

Since this charge design was obviously incapable of meeting the specified performance at temperature extremes, a new charge was designed and existing CD80 extrusions were used only for nozzle and tailpipe development firings.

2.4 Design CD86, propellent VU

Charge design CD86 was prepared, therefore, with the intention of increasing the initial burning surface area while maintaining the ratio, λ, constant at approximately 1.2. Fig.3 shows the six-point star centre conduit of CD86 and it is seen that although the conduit area has been reduced by less than 1 per cent the perimeter has been increased to a figure some 15 per cent greater than that of CD80. The variation of perimeter with depth of web burned is correspondingly less progressive than for design CD80. The effect of erosive burning at the higher initial operating pressures produced by charges to design CD86 as compared with those produced by charges to design CD80 could not be assessed, but the results obtained from firings of CD80 charges suggested that design CD86 offered a reasonable prospect of meeting the thrust requirements.

Closer study of interchangeability requirements for motor tube and missile body assembly had shown that a reduction in mean tube and charge diameters was essential, hence CD86 charges were designed to a mean diameter of 7.29 inches as against 7.33 inches for CD80 charges.

2.5 Manufacture of CD86 charges

2.5.1 Conduit geometry

The original CD86 design (Issue A) called for a nominal root radius at the base of the conduit star points of 0.050 inch. Early extrusions from ROF Bishopton had extremely sharp corners at the root of the star points and despite continued efforts by S/ROF this defect persisted in several batches of propellent charges. Though such charges proved useful in the ballistic evaluation of design CD86 and the later "stepped-conduit" design, the lack of significant root radii eventually led to a motor failure during static firing trials at RPE. On this occasion a motor conditioned to -40°C burst on ignition and the resulting fire destroyed all traces of the charge. Shortly before firing, however, a loud crack, which was presumed to have emanated from the motor, had been heard over the intercommunication link between the firing bay and the control room. A similar motor was therefore conditioned to -40°C, fitted with thrust head and tail-pipe in the firing bay and allowed to rest on the rig; after about 30 minutes a loud crack was heard from the round and immediate inspection revealed a split in the propellent web along the whole length of the charge (Fig.4).

It was concluded that the effect of warm air admitted to the motor during the fitting of the tail-pipe and thrust head had resulted in temperature gradients across the propellent web, and that the induced stresses had been sufficient to split the charge radially from its weakest point, the sharp corner of the star-shaped perforation. This conclusion was confirmed when it was found that charges cracked in much the same way after sealed motors had been subjected to only one cycle between temperature extremes of -40 and 50°C.

The need* for a generous radius at this point was therefore underlined and issue B of design CD86 called for a nominal radius of 0.10 inch at the

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*The same trouble was experienced in some of the earliest (1941) star-centre rocket charges ever extruded and the remedy was the same.

star point roots. Though some charges occasionally have root radii slightly below the desired minimum of 0.10 inch, it has been shown in laboratory tests by D/ERDE[5] that the present extrusions from the die and pin at ROF Bishopton possess greatly improved resistance to cracking. Temperature cycling trials conducted at RPE confirmed this result as Linnet charges have successfully withstood twelve cycles between -40 and 50°C.

The laboratory tests at ERDE on early Linnet extrusions showed that charge splitting was not entirely due to inadequate root radii; the impact strength of the propellent in batches BX1225, 1358, 1344 and 1343 was well below the value of 0.04 ft-lb which should have been attained by propellent VU. Later extrusions had satisfactory impact strengths. The reasons for such variations in impact strength are being investigatedø; instructions on this aspect and for a minimum root radius of 0.10 inch are to be included in the Linnet charge manufacturing specifications and drawings.

Apart from the inadequate root radii, the conduit geometry of the initial extrusions conformed to the requirements of design CD86; increase of the root radius to 0.10 inch, however, reduced the conduit area and perimeter slightly below design requirements. The following table illustrates the variations in these dimensions of extrusions taken at random from the batches shown:

Propellent batch number	Cross sectional area of conduit, A, sq inches	Perimeter of conduit, P, inches	
Nominal values	4.32	18.52	
BX 1208[x]	4.01[x]	18.56[x]	
BX 1225[x]	4.29[x]	18.70[x]	
BX 1274[x]	4.50[x]	19.00[x]	
BX 1358	4.20	17.90	
BX 1367	3.75	17.90	
BX 1391	4.27	18.00	
BX 1401	4.10	17.70	
BX 1433	4.28	18.22	
BX 1466	4.175	End A	End B
		18.20	18.20
"	4.32	18.25	18.28
"	4.30	18.00	-
"	-	17.62	18.13
"	-	17.62	17.92
"	-	18.00	18.15
"	-	18.19	18.25
"	-	18.19	18.30

[x]First extrusions with root radius less than nominal 0.05 inch.

ø By the Panel on the Control of Quality of Rocket Propellent Charges.

The variations within the last batch should be noted; so far there is no prospect that charges can be extruded to closer limits of accuracy than those tabulated without incurring unacceptably high wastage of "re-work" propellent material at the factory. Despite such variations, however, the performance of Linnet IIA motors is generally satisfactory over the whole operating temperature range. The detail dimensions of extrusions are now being closely examined to determine acceptable inspection limits. It is hoped that such dimensional limits will be broad enough to maintain a reasonable level of acceptance for extrusions.

2.5.2 Quality of extrusions

All extrusions were subjected to visual and X-ray examination at ROF Bishopton against the standards detailed in Appendix II. The general quality of charges reaching RPE was excellent, with the single exception of those from propellent lot BX 1225 which were found to contain flaws of a most unusual type. These were discovered by the violent burst, about 0.1 second after ignition, of a motor containing a charge from this batch. Fortunately several large fragments of propellent were recovered, which gave evidence that the extrusion contained zones of porous or badly consolidated propellent; it was deduced that the charge had split due to very high pressure generated in at least one of these porous zones (Fig.5). The remaining extrusions of this batch were found to contain porous zones near the base of four of the six star points, and in some charges the porosity emerged at the surface of the conduit. The defect was ascribed by S/ROF Bishopton and D/ERDE to low extrusion pressures (about 2800 lb/sq in) following the application of Teflon coating to the die; an extrusion pressure not less than 3600 lb/sq in. is now prescribed, and no further trouble of this nature has been experienced.

The inability of X-ray and ultrasonic inspection techniques to detect zones of porosity remains a disquieting feature. The flaws described can only be detected visually if they emerge at the surface, and there is, therefore, no adequate check on the internal mass of each extrusion.

2.6 Firing trials of CD86 charges

Extrusions from propellent batch BX 1208 were made up into charges 34.9 inches long and fired in "heavy duty" motors, ignition being effected by 40 grams of composition SR371C contained in a millboard "pill box" cemented to the head-end face of the charge. The motors were fired at ambient temperature (~ 10°C) giving pressure/time curves shown in Fig.6. The high pressures in the early stages of burning were considered to be characteristic of erosive burning; the initial peak pressures from these two rounds of 1770 and 1750 lb/sq in. respectively were very close to the factored "limit value" (see Section 4) of 1800 lb/sq in. for the motor tube, and it therefore was probable that the peak pressures reached after conditioning to 50°C would be excessive. For confirmation, two motors were fired at 50°C; one burst almost instantaneously at 2600 lb/sq in. whilst the other gave an initial peak pressure of 2138 lb/sq in. (Fig.7), i.e. above the design 0.1% proof stress capability of the lightweight motor tube.

It was clear from these firings that the degree of erosive burning of propellent VU was excessive at 50°C and pressures of 1300 lb/sq in. with a value of λ of less than 1.2. The time available for motor clearance was limited, and because of the time required for charge re-design and manufacture of new dies and pins for extrusion, an attempt was made to reduce initial peak pressures by modifying existing CD86 extrusions.

2.7 'Stepped conduit' charges

The initial peak pressure was reduced by local increase of the conduit cross sectional area at the nozzle end of the charge, together with a simultaneous reduction of the initial burning surface area. The increase in the value of λ ensured reduced gas velocity over the propellent surface at this end, and a corresponding reduction in the peak pressure arising from erosive burning.

The charge conduit area was increased by machining away the tips of the splines at the nozzle end; the axial extent of machining was fixed arbitrarily at one quarter of the overall length extending from the nozzle end face. To determine the diametral extent of machining, charges were prepared in which the star tips were removed down to diameters of 2.0, 2.5 or 3.0 inches. These were fired at temperatures of either -40, 15 or 50°C with the results shown in Fig.8; it is seen that, as expected, the initial peak pressure is reduced by increasing λ, though at the expense of charge weight. The charge produced by machining the conduit to a bore of 2.5 inches was considered to be nearly the best that could be secured by this modification, as the initial peak pressure of 1450 lb/sq in. at 50°C was within the design maximum for the tube (of 1600 lb/sq in.), while the sacrifice of propellent was little more than 1.0 lb; extrusions so modified were given the designation CD93 (Fig.9).

The weight of the modified charge did not now reach the minimum of 76 lb needed for a total impulse of 16,700 lb-seconds. It was therefore decided to replace at least a part of the 'lost' propellent, by modifying the head-end portion of the charge. By design CD92 (Fig.10) an increase of ~ 3 per cent in loading density over CD86 is secured, and a 10-inches length of this extrusion formed the head-end of the 'stepped conduit' Linnet I charge assembly which then had a nominal weight of 76.5 lb; a spare, imperfect, extrusion pin for charge CD86 was modified for rapid manufacture of the CD92 pin. The 'stepped conduit' Linnet I charge (Fig.11) was prepared by cementing together[6] appropriate lengths of extrusions CD86, CD92 and CD93.

2.7.1 Firing trials of Linnet I charge

Typical thrust/time and pressure/time curves for motors fired at -25[ø], 15 and 50°C are shown in Fig.12 and 13. The performance of Linnet I was generally satisfactory over this range of temperature with initial pressures never exceeding 1550 lb/sq in.; the 'stepped-conduit' charge was therefore most effective in eliminating dangerously high initial pressures while still providing a total impulse above the specified minimum.

[ø] The lower temperature limit of only -25°C was imposed following failure of a round due to charge cracking at -40°C, see paragraph 2.5.1.

Such firings proved Linnet I suitable for use in Red Top missiles during development trials with manned aircraft, but also showed that further development would be necessary to provide a motor for Service use capable of meeting all the specified requirements. For example, even at -25°C Linnet I rarely reached the specified minimum thrust of 5500 lb for the first 1.5 seconds of burning; it was clear, therefore, that at -40°C the thrust would fall well below this minimum value, and this was confirmed by further firings. Thus, while Linnet I motors were being supplied for experimental firings from aircraft, the charge design was critically examined with a view to increasing the thrust over the first 1.5 seconds of burning.

2.7.2 Development of Linnet IIA charge

The actions taken to produce a charge capable of providing a minimum thrust of 5500 lb at -40°C were influenced by the pressing need to comply with an exacting time schedule for motor and missile development. Given more time, it is possible that a less complex design than the existing 'stepped conduit' charge might have been perfected. Because of the uncertainties surrounding any completely new charge design, however, and the time which would be taken in design and manufacture of satisfactory extrusions, it was decided to modify the existing Linnet I charge design.

Extra initial burning surface area for increased thrust was obtained by greatly reducing the extent of inhibitory coating on the head-end face and by machining undercuts at each composited joint between charge sections (Fig.11); in this way some 8 per cent of extra burning surface was made available. Charges of this 'stepped and slotted conduit' type were fired at -40, 15 and 50°C; the first firings at -40°C showed that the minimum thrust of 5500 lb could just be achieved, while at 50°C the peak thrust level was only slightly in excess of the 8000 lb specified. As more rounds were fired during clearance trials, however, it was seen that a small proportion of motors failed to produce an initial thrust of 5500 lb, with action times marginally exceeding the 3.2 seconds demanded; typical pressure/time and thrust/time curves are shown in Fig.14 and 15. The submission to D/GW(Tech) detailing the performance of Linnet IIA commented on these marginal variations from the Design Specification; nevertheless production of Linnet IIA for Missile Evaluation Trials was ordered and the minor deviations in performance referred to have been accepted by the user.

To ensure correct fit in the tube at all temperatures between -40 and 50°C and in all conditions of tube tolerance, each Linnet IIA charge is machined on the cylindrical surfaces from somewhat oversize extrusions. With the additional machining of the bore of the rear extrusion and the machining of slots the preparation of charge assemblies is more complex than that of previous extruded charges of similar size. It is, however, relatively simple to machine extruded colloidal propellent, and, in this instance at least, the technique has enabled the charge to be matched to the severe limitations in space and the exacting performance demands over a wide temperature range.

3 IGNITION

3.1 Ignition of Linnet I

For early firings of Linnet I motors, ignition was effected by 40 grams of composition SR371C initiated by a single fuze, electric, F53. The composition was contained in either a millboard carton or a metal housing fitted with a thin alloy burster foil. This simple ignition system worked effectively between -40 and 50°C and met the specified requirement regarding ignition delay.

3.2 Igniter for Linnet IIA

The detail design of an igniter for Linnet IIA presented many problems, owing to the need to produce an igniter robust enough for Service use that would fit in the very small space available at the head-end of the motor. A further demand on available space was made by the need to fit an attenuator to give protection against possible firing currents induced by pick up of R/F energy in the fuze circuit. For convenience, details in the final form of the igniter assembly are described under separate headings below; the assembly is shown in Fig.16.

3.2.1 Canister for pyrotechnic composition

In some early designs of igniter, the composition was in direct contact with each insulated sealed terminal carrying the firing current to the fuze. In at least one instance, a significant reduction in insulation resistance between the motor body and the terminal was caused by moisture in the composition. A canister to separate the composition physically and electrically from the terminals was therefore provided.

3.2.2 Sealing of canister

Experience has shown that any form of cement used to seal igniter canisters may give rise to desensitization of the composition or of the fuze by solvent from the cement. The Linnet IIA igniter therefore makes use of soft rubber washers to effect seals beneath "turned over" metal joints after the filling operation. The fuze F53 is held in a rubber grommet which fits in the base of the canister and each lead from the fuze is brought out through holes in the grommet; the leads are a sufficiently tight fit in the grommet to ensure complete sealing.

Experience with the earlier Magpie motor had shown that the thin alloy burster foil used to close the canister tended to distend under the low ambient pressure at high altitudes, due to expansion of air sealed in the canister at ground level. As a result of this distension the loose pyrotechnic filling occasionally fell away from the fuze; on at least one occasion, this fault led to the misfire of a Magpie motor in an airborne Blue Jay missile[7]. In Linnet IIA therefore the fuze was fitted with a thin-walled, closed sleeve of nitrocellulose filled with a small quantity of SR371C composition to ensure efficient 'take-over' from the fuze.

3.2.3 Sealed terminals

The miniature spark plug type terminals used for many years to connect the fuze leads through the head-end pressure plate to an external plug or socket have proved to be a continual source of trouble due to variations in manufacture∅. The terminals in the pressure plate of the Linnet IIA igniter consist of a simple conducting pin centralised in a hole in the pressure plate by a pressure moulding of phenol-formaldehyde resin which acts as an insulant. This arrangement successfully provides pressure-tight insulated conductors in a location with restricted space without the screw threads and O-seals needed for small spark plug devices.

3.2.4 Radio frequency attenuator

Issue 3 of the missile specification called for an attenuator to be fitted to the igniter as protection against accidental firing by currents induced from external R/F radiation. A development contract placed on Elliott Bros. Ltd. specified an insertion loss of not less than 30 dB between 0.5 Mc/s and 10,000 Mc/s, and stated that the impedance or resistance at 400 c/s should not be greater than 0.66 ohm. The insulation resistances between lines and between a line and the igniter body were required to be not less than 8 Megohms and 4 Megohms respectively. The design and development of this attenuator, which is 'potted' directly into the external face of the igniter/pressure plate assembly is described in reports covering work under contract by Elliott Bros. Ltd.[8,9]. These documents describe tests, under various environmental conditions, which show the attenuator to be completely effective in meeting requirements for signal attenuation, impedance and insulation resistance.

3.2.5 Installation

The igniter assembly is a push fit into the head-end boss of the motor tube, and is retained by a screwed locking ring. The locking ring itself is retained on the igniter by a spring circlip, so that the assembly can be withdrawn by simply unscrewing the locking ring. This form of installation permits angular location of the igniter assembly, thus enabling the socket in the side of the attenuator to be positioned exactly opposite the fixed firing lead within the missile body.

The motor is sealed by an O-ring seal located on the igniter assembly, or by a similar seal fitted to the polythene plug which is used during transport or storage of the motor.

4 MOTOR TUBE

4.1 Design

The tube was designed to comply with the safety requirments laid down in G.W. Design Memorandum A.V.P.32, which specifies various factors of safety for

∅ Little control could be exercised over firms producing these items in their own experimental laboratories, and each firm showed declining interest in view of the small quantities required.

rocket motors intended to be fired from manned aircraft. This document states that where the limit value of the internal pressure of the motor, i.e. the maximum to be expected under the most adverse environmental conditions, is based "on accurate measurements of pressure during several firings of the actual motor under the appropriate conditions", reduced factors on proof strength and ultimate tensile strength of $1\frac{1}{8}$ and $1\frac{1}{3}$ respectively may be used.

The charge was designed to operate at a pressure not exceeding 1600 lb/sq in. To obtain an estimate of the tube wall thickness required, an approximate tube bore of 7.6 inches was derived from the missile body drawing. Steel to specification SAE4130 was chosen for the tube material, since this was available at Bristol Aerojet Ltd., Banwell, in a range of sheet sizes and thickness, and offered 0.1 per cent proof strength of 67 ton/sq in. and ultimate tensile strength of 80 ton/sq in. after heat treatment. The thickness derived from the usual simple hoop stress equation, using the above factors, was estimated to be 0.0425 inch based on proof strength and 0.0423 inch on the ultimate tensile strength; sheet steel of 0.048 inch minimum thickness (18 swg) was selected since it offered the closest match to the calculated figures.

In its final form the Linnet IIA motor tube is strong enough to withstand internal pressures of 2000 and 2400 lb/sq in., as corresponding to the 0.1 per cent proof strength and ultimate tensile strength respectively; those figures comfortably exceed the factored limit pressures of 1800 and 2130 lb/sq in. Each tube is pressure tested hydraulically to 1700 lb/sq in., i.e. above the expected maximum pressure for the tube but well below the 0.1 per cent proof stress limit.

4.2 Manufacture

The tubes were manufactured by wrapping and welding. The tube for Linnet I was comparatively simple in design (Fig.17a) but suffered from some shortcomings in production. For example, since space limitations within the missile near the head-end of the motor allowed the head-end boss a minimum projection from the tube, the welded circumferential joint between them presented many difficulties in manufacture and inspection. This area proved to be a source of weakness, for on pressure testing to destruction failure always occurred at the weld. It was also found that the drawings allowed tolerances in production tubes to accumulate to an extent which affected interchangeability between motor and missile.

In the Linnet IIA tube (Fig.17b) the head-end boss was incorporated in the head-end forging and dimensional variations were reduced by drawings demanding closer tolerances, and by inspection which included gauging for fit between charge and tube, and between tube and missile body. An accurately controlled bearing surface was provided at the head-end for precise location of the motor in the missile body.

4.3 Firing trials

The only thermal insulation in early Linnet I tubes was provided by a preformed layer of Durestos bonded into the head-end closure of the tube. During clearance trials of Linnet I, a motor burst through overheating of the parallel portion of the tube near the head-end. The overheating was quite localised and arose through heat transfer from gases passing between charge and tube during pressurization of the annular space; Fig.18 shows the scorched area extending only six inches down the tube. The trouble was overcome by lining the tube for six inches from the head-end with sheet rubber of 0.025 inch thickness, bonded to the tube surface with Pliobond 20 adhesive. Fig.18 also shows an insulated tube after firing; thermocouple measurements recorded a temperature rise of less than 100°C at the end of firing and no further troubles from overheating have been experienced.

To prevent interference between the charge and the rubber liner, and the consequent threat of head-end obturation of the motor, the diameter of the charge is reduced at the head-end by 0.06 inch over a length of six inches. The improved stress coating technique[3] is effective in applying the inhibitory sleeve to the charge despite this local reduction in diameter.

In other respects, tubes for Linnet I and Linnet IIA have been satisfactory.

5 NOZZLE END-PLATE

The venturi nozzle end-plate assembly (Fig.19) consists of a screwed end-plate made from steel to specification DTD5122, lined in the convergent section with pressure-moulded Durestos to specification BS771 type HR and fitted with a throat insert of molybdenum. The final choice between carbon and molybdenum, after trials of various materials, was made in favour of molybdenum on the evidence of significant erosion of inserts made from the relatively low density carbons then available.

In all previous motors which used propellent PU (calorimetric value 840 cal/gm) a simple mild steel nozzle throat and end-plate assembly had proved adequate; propellent VU (calorimetric value 1080 cal/gm), however, is hot enough to burn through a mild steel end-plate in 2.5 seconds. An insulating layer (varying from 0.15 to 0.30 inch thick) of Durestos was therefore applied to the convergent portion of the end-plate, and this gave complete protection.

To provide a satisfactory electrical 'earthing' area at the rear of the motor assembly, the external surface of the end-plate is nickel plated on its maximum diameter; the remaining surface is protected by paint.

6 TAILPIPE

The tailpipe was designed, in conformity with user requirements, not only as a duct for the exhaust gases but also as a structural member of the missile rear section. Assembly of the missile in Service had to be effected by rapid connection of the fore, centre and rear sections, and much care was devoted to the design of all components to secure complete interchangeable assembly. As the centre section containing the motor body was to be joined to the rear section by a simple clamping ring, the joint between motor and tailpipe was designed as a push fit between the two components, sealed by O-rings fitted to the nozzle end-plate.

In its final form the tailpipe consists of a tube of Mintex (asbestos impregnated with phenolic resin) reinforced by an external wrapping of glass tape impregnated with epoxy resin. A mild steel adaptor for the joint is scarfed into the tailpipe (Fig.20). This illustration shows a pipe which has been sectioned axially after firing of the motor to illustrate the resistance to erosion of the material; the loss of wall thickness is approximately 0.1 inch. The tail pipe, which has proved reliable, supports the missile equipment under all conditions of flight loading, and its external surface temperature remains low.

7 TRIALS

7.1 Reliability trials - Linnet I

A total of 62 Linnet I motors was fired at temperatures of -25°C, 20°C or 50°C to demonstrate the reliability of the design and compare its performance against the specification requirements. Of these, 42 motors were fired statically at RPE, with results listed in Table I, and 20 were fired in projection test vehicles at RAE Larkhill, with results listed in Table II.

The firings showed that the performance generally met that required by the user for development trials after the acceptance of the revised low temperature limit of -25°C. The failure of round 7LWE 113 due to overheating of the tube and the remedy adopted have already been discussed in Section 4.3. The telemetry records of motors projected showed behaviour similar to that of motors fired statically, in spite of axial accelerations up to 30 g.

7.2 Reliability trials - Linnet II

A total of fourteen Linnet IIA motors was fired statically at RPE at temperatures of -40°C, 15°C or 50°C, and a further four motors were projected after conditioning to either -40°C or 50°C. All functioned normally, with results listed in Table III. The marginal discrepancies from the specified limits have been accepted by the missile contractor, as noted in para.2.7.2.

7.3 Temperature cycling

Six Linnet I motors were subjected to temperature cycling between -25 and 50°C, the cycle consisting of 18 hours storage in each temperature, with an intermediate period of exposure to air temperature for six hours. All withstood twelve of these cycles without deterioration of the charge, and fired satisfactorily (Table I).

Six Linnet IIA motors withstood similar cycling between -40 and 50°C with equally satisfactory results as shown in Table III. Two further motors were subjected to a special programme of conditioning to show that Linnet IIA could provide a minimum thrust of 5500 lb after "soaking" to -26°C, followed by three hours storage at -48°C; this programme was intended to simulate the effect of low speed, high altitude flight by an aircraft carrying Red Top after arctic take-off conditions. Each motor operated satisfactorily with performances within the specified limits (Table III).

7.4 Vibration trials

As the first extrusions in propellent VU cracked at low temperatures, it was considered desirable, despite the success of the temperature cycling trials, to simulate the severest possible conditions of under-wing stowage for Linnet I.

Six motors were therefore conditioned to extreme temperatures, and subjected to a three hour period of vibration before firing. Each round was conditioned to 45°C for 24 hours, and then transferred to a temperature of -65°C for one hour before horizontal vibration lasting for three hours, this treatment being the closest simulation to under-wing conditions for a missile carried by an aircraft which had taken off in tropical conditions and cruised at 40,000 ft for up to three hours. A full specification of trial conditions (with the results of the test) is given in a report issued by the missile contractor[10]. It had been intended to vibrate each motor continuously over a frequency range of 15 to 300 c/s which would be swept automatically, but the equipment was found incapable of supplying enough power to maintain the required velocity of ±3.08 inches/second at frequencies over 140 c/s; above this frequency, power sufficient only to maintain a constant acceleration of ±6 g was supplied.

The motors and charges were undamaged by this treatment, and were fired statically at temperatures of -25, 20 or 50°C. The ballistic results included in Table I show that performance was normal, with the exception of one round, previously referred to in section 4.3.

7.5 Summary of results

The trials have shown the Linnet motor to be reliable over a wide range of conditions. Linnet IIA has been shown to perform safely at temperatures between -40 and 50°C or after temperature cycling between these extremes, with only marginal deviation from the specified limits of thrust, burning time and total impulse. The improved extrusions possessing star root radii of nominal 0.10 inch can withstand the variations of temperature encountered during operational usage when subjected to vibration of a wide range of frequency and acceleration.

Further trials to demonstrate the serviceability of the motor after simulated tropical storage and rough usage have been arranged in conjunction with the Ordnance Board.

8 ASSEMBLY OF MOTOR IN MISSILE

The centre section of the missile is to be supplied to the Services complete with rocket motor. The motor is secured by a simple circlip and thrust ring system (Fig.21) and is centralised by three bearing pads at the forward end and by a split Durestos ring at the rear end-plate. To confirm the adequacy of this arrangement, six motors were fired statically at RPE after mounting in the missile centre section, the thrust acting through the missile structure. The satisfactory results of these firings are included in Table III.

To minimise transport of components, motors are to be mounted in their centre sections at the Ordnance Factory where they are filled with charges. The packaging of Linnet IIA, contained within the missile centre section, and of the igniter, will be reported separately.

9 CONCLUSIONS

The Linnet IIA rocket motor (Fig.22) has been developed for use from manned aircraft over a conditioning temperature range of -40 to 50°C against detail requirements contained in GW(Air) Systems Specification AAGW 1/59.

The performance requirements, together with a comparatively short development time-scale, have led to the use of a charge of relatively complex design, involving the use of machined sections of propellent of differing conduit cross section. The motor fitted with this charge meets almost every aspect of the design specification, with but marginal discrepancies of thrust and burning time after conditioning to -40°C. The development of a less complex charge from a single extrusion of propellent would probably show advantages in ease of production and possibly in reliability but the difficulties to be faced in developing such a charge to meet the wide performance specification have been clearly demonstrated.

A compact form of radio frequency radiation attenuator has been successfully fitted to the igniter assembly and shown to be effective over a wide range.

REFERENCES

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2	Morris, K.	Development of the Magpie motor for use in the Firestreak air-to-air missile Unpublished work at R.P.E.
3	White, E.C.	The facing of cordite charges using an inserted tooth milling cutter R.A.E. Tech. Memo. No. RPD102 April 1956
4	Cooke, W.L.	Inhibition of burning of colloidal propellents; stress relief process; and improved method of applying the inhibitory sleeves to cordite charges R.P.E. Tech. Note No. 205 August 1961
5	Vernon, J.H.C.	Report to Panel on the control of quality of rocket propellent charges WAE/5/12, 28th July 1961. E.R.D.E. Waltham Abbey
6	Errington, K.D. Hardaker, P.N.B.	A general appreciation of the construction and operation of the experimental solid propellent rocket motor filling factory at the Rocket Propulsion Department, Westcott R.A.E. Tech. Note No. RPD82 May 1953
7	Crook, J.H. Harrison, E.G.	Ignition of solid propellent rocket motors for guided weapons R.A.E. Tech. Memo. No. RPD119 January 1957

REFERENCES (CONTD)

No.	Author	Title, etc
8	-	Final progress report No. B77 Elliott Bros. (Radar Division) March 1961
9	Capewell, W.K. Lawrence, E.D.	An investigation into the pass band performance of the Linnet motor R/F hazard attenuator Elliott Bros. (Radar Division) March 1961
10	Freeman, A.S.	Vibration testing on Linnet motors at Westcott De Havilland Aircraft Co Ltd. Tech. Note No. GW378, Environmental Test Report No. 14 January 1961

ATTACHED:

Appendices I and II
Tables I to III
Drgs No. RP 3357 - 3374
Detachable Abstract Cards

ADVANCE DISTRIBUTION:

Ministry of Aviation

C/GWL	D/A Arm	
C/ROF	D/AI	
DC/A(RD)	D/ I Arm	
DG/GW	AD/GW(P&W)	
DG/AW	AD/MXRD	
DG/RAF	ERDE	3
DG/AGS	RAE Farnborough	6
D/NA	RAE Aberporth	
D/GW(Air)	GW(G & C)	24
D/GW(N)	TIL 1b	130
D/GW(X)		

APPENDIX I

COMPOSITION AND BALLISTIC PROPERTIES OF PROPELLENT VU

Composition	Parts by weight
Nitroglycerine	42.2
Nitrocellulose	53.0
Dibutylphthalate	2.8
2-nitro diphenylamine	2.0
Wax	0.075
Lead stannate	3.0

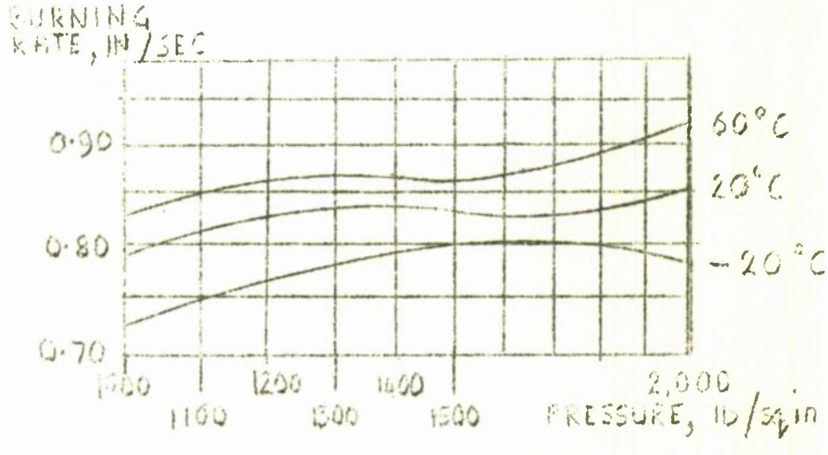
Calorimetric value (water liquid) 1080 cal/gm

Flame temperature 2870°K

Composition of exhaust

Proportions of main products,	by volume, per cent
H_2O	26.0
CO_2	15.0
CO	36.4
H_2	9.0
N_2	13.0

Typical variations of burning rate with pressure (as determined by the strand burner method at -20, 20 and 60°C)



APPENDIX II

ACCEPTANCE STANDARDS FOR EXTRUSIONS (CD86, CD92, CD93) IN PROPELLENT VU

1 Visual and X-ray Examination

(a) Foreign matter and ungelatinised paste not exceeding $\frac{1}{4}$ in. in maximum dimensions will be ignored.

(b) Air inclusions not exceeding 1/10 in. in maximum dimensions will be ignored, unless they exceed 12 per foot length.

(c) Air inclusions or flaws not exceeding $\frac{1}{4}$ in. in maximum dimension should not lead to rejection, providing they are more than 2 in. apart. A maximum of three such flaws per foot is allowable.

(d) Acceptable longitudinal flaws must be less than 1 in. in length and 1/10 in. in diameter. They may be slightly inclined to the axis to a maximum overall amount not exceeding $\frac{1}{4}$ in. Such flaws should be not less than 15 in. apart, and should be at least 2 in. distant from flaws described under (c).

(e) Flaws described under (c) and (d) must be at least 3 inches from the end of the charge or section.

(f) Discolouration will not be grounds for rejection.

(g) External surface roughness must not exceed 1/16 in. in depth measured from a straight edge placed longitudinally against the surface of the charge at the point under investigation.

(h) The internal conduit of the charge shall be smooth and must conform to the shape and dimensions produced by the approved die.

(i) Production from a new or modified die must be approved by R.A.E. Westcott.

TABLE I

Linnet I - Static firing results

Round Serial No.	Propellent weight, lb	Conditioning temperature, °C	Peak pressure, lb/sq in.	Peak thrust, lb	Burning time, t_b, sec	Action time, t_a, sec	Total impulse, lb-sec/lb	Ignition delay*, sec	Remarks
7LWE 91	76.75	-25	1373	No record	2.60	2.94	No record	~0.05	
7LWE 92	76.75	-25	1374	No record	2.56	2.92	No record	~0.06	
7LWE 93	77.25	-25	1398	No record	2.56	2.95	No record	~0.05	
7LWE 96	76.75	-25	1394	7540	2.52	2.90	16700	0.04	
7LWE 98	76.75	-25	1411	7720	2.50	2.90	16800	0.06	
7LWE 99	76.75	-25	1383	7620	2.54	2.92	16700	0.07	
7LWE 100	76.50	-25	1413	7760	2.52	2.92	16700	0.06	
7LWE 102	76.50	-25	1444	8100	2.54	2.95	17500	0.05	
7LWE 97	76.50	-25	1299	6820	2.62	3.05	16300	0.06	
7LWE 101	77.00	-25	1352	7370	2.60	2.95	16700	0.05	
7LWE 65	76.25	20	1459	8000	2.40	2.75	16900	0.05	
7LWE 83	76.25	20	1398	7880	2.34	2.80	16900	0.04	
7LWE 86	76.75	20	1494	7840	2.40	2.83	16800	0.05	
7LWE 87	76.50	20	1436	7830	2.40	2.85	16700	0.06	
7LWE 85	76.75	20	1467	8030	2.38	2.85	17000	0.05	
7LWE 88	76.75	20	1475	8150	2.40	2.85	16900	0.07	
7LWE 89	76.75	20	1399	7650	2.46	2.86	16950	0.06	
7LWE 84	76.75	20	1462	7730	2.42	2.82	16600	0.05	
7LWE 94	76.75	20	1428	No record	2.38	2.80	No record	0.06	
7LWE 95	76.75	20	1454	7800	2.38	2.83	16750	0.06	
7LWE 64	76.50	50	1471	8190	2.36	2.70	17050	0.04	
7LWE 66	76.50	50	1529	8260	2.34	2.70	17100	0.04	
7LWE 105	76.75	50	1587	8440	2.34	2.75	17000	0.04	
7LWE 110	76.75	50	1434	7940	2.36	2.78	17300	0.04	
7LWE 108	77.00	50	1432	7870	2.40	2.77	17400	0.04	
7LWE 107	77.00	50	1480	7870	2.44	2.82	17200	0.05	
7LWE 106	76.75	50	1575	8370	2.36	2.76	17200	0.05	
7LWE 103	76.75	50	1603	8780	2.32	2.76	16700	0.04	
7LWE 104	76.50	50	1555	8440	2.40	2.73	17000	0.05	
7LWE 111	77.00	50	1446	7980	2.38	2.84	17300	0.04	
The charges of the following rounds were subjected to temperature cycling between -25 and 50°C; see para. 7.3.									
7LWE 129	76.75	-25	1403	7840	2.68	3.05	16800	0.05	
7LWE 139	76.5	-25	1342	7280	2.62	3.05	16400	0.06	
7LWE 144	76.75	-25	1336	7070	2.60	3.05	16400	0.06	
7LWE 138	76.75	50	1483	7990	2.30	2.75	16700	0.04	
7LWE 140	76.75	50	1523	8130	2.34	2.70	17000	0.05	
7LWE 145	76.50	50	1431	7660	2.37	2.77	16800	0.05	
The following rounds had undergone storage at 45°C for 24 hours, at -65°C for one hour, followed by horizontal vibration for 3 hours; they were then brought to the temperatures stated and fired; see para. 7.4.									
7LWE 132	77.00	-25	1331	7200	2.64	3.08	16800	0.06	
7LWE 133	77.00	-25	1293	7000	2.68	3.08	16400	0.06	
7LWE 114	76.50	20	1450	8100	2.40	2.90	17100	0.05	
7LWE 116	76.50	20	1394	7580	2.44	2.92	16900	0.05	
7LWE 115	77.00	50	1430	No record	2.40	2.75	No record	0.05	
7LWE 113	76.25	50	1500 at 1.96 sec	8200 at 1.96 sec	Burst at 1.96 sec			0.04	

* From application of firing current to thrust reaching 4000 lb.

TABLE II

Linnet I - Projection firing results

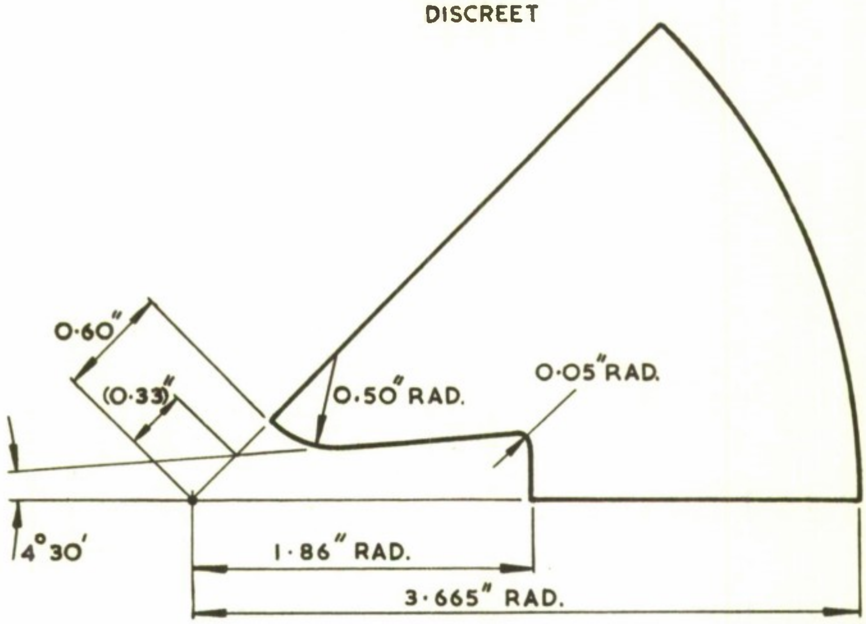
Round Serial No.	Propellent weight, lb	Conditioning temperature, °C	Peak pressure, lb/sq in.	Burning time, t_b, seconds	Action time, t_a, seconds	Ignition delay, second	Remarks
7LWE 59	76.25	50	1550	2.35	2.74	0.035	
7LWE 61	76.25	50	1472	2.37	2.74	0.03	
7LWE 62	76.25	50	1478	2.24	2.70	0.02	
7LWE 63	76.25	50	1497	2.37	2.74	-	
7LWE 60	76.50	50	1566	2.34	2.78	0.03	
7LWE 58	76.50	50	1587	2.25	2.78	0.03	
7LWE 71	77.00	50	1528	2.33	2.75	0.03	
7LWE 70	76.25	50	1420	2.26	2.72	0.03	
7LWE 81	76.25	50	1460	2.17	2.70	0.03	
7LWE 82	76.80	50	1477	2.17	2.69		
7LWE 72	76.25	-25	1357	2.66	3.09	0.02	
7LWE 75	76.50	-25	1344	2.67	3.10	0.03	
7LWE 73	76.75	-25	1305	2.67	3.11	0.04	
7LWE 76	76.50	-25	1285	2.68	3.10	0.03	
7LWE 74	76.75	-25	No record				Telemetry failure
7LWE 78	77.00	-25	1285	2.58	3.15	0.04	
7LWE 69	76.25	-25	1258	2.60	3.11	0.03	
7LWE 77	76.50	-25	1298	2.57	3.08	0.035	
7LWE 79	76.50	-25	1315	2.62	3.06	0.04	
7LWE 80	76.75	-25	1363	2.61	3.05	0.04	

TABLE III

Linnet II Series A - Projection and static firing results for regularity and after temperature cycling

Round Serial No.	Propellent weight, lb	Conditioning temperature, °C	Peak pressure, lb/sq in.	Peak thrust, lb	Burning time, t_b, seconds	Action time, t_a, seconds	Total impulse, lb-seconds	Ignition delay*, second	Remarks
Requirement	-	At any temperature from -40 to 50°C	-	8350	2.70 to 1.90	3.20	16700 at 15°C	0.075 ± 0.025	per AAGW 1/59 issue 4
7LWE 227	76.0	-40	Not recorded	6720	2.70	3.19	16400	0.07	) Motors fired within missile centre
7LWE 228	76.5	-40	Not recorded	6450	2.72	3.15	16500	0.085	) section, igniter R70 A1713
7LWE 234	76.5	-40	1206	6500	2.73	3.32	16300	0.085	) Charges temperature cycled. See
7LWE 235	76.0	-40	1180	6260	2.73	3.19	16100	0.075	) para. 7.3.
7LWE 236	76.75	-40	1222	6680	2.67	3.17	16750	0.07	
7LWE 237	76.75	-40	1179	6480	2.78	3.25	16750	0.07	
7LWE 241	76.0	-26, followed by 3 hours at -48	1230	6560	2.60	3.06	16400	0.07	) Motors specially conditioned. See
7LWE 242	76.0		1284	6860	2.62	3.09	16300	0.09	) para. 7.3.
7LWE 212	76.0	15	1450	7900	2.39	2.78	16750	0.05	
7LWE 226	76.25	15	1490	8000	2.27	2.85	16700	0.065	) Motors fired within missile centre
7LWE 229	76.0	15	1480	8000	2.33	2.80	16500	0.05	) section, igniter R70 A1713
7LWE 232	76.0	15	1364	7390	2.31	2.81	16500	0.05	) Charges temperature cycled. See
7LWE 233	76.25	15	1367	7260	2.40	2.88	16400	0.05	) para. 7.3.
7LWE 240	76.5	15	1430	7690	2.33	2.83	16650	0.07	
7LWE 217	76.0	50	1570	8050	2.30	2.69	16850	0.02	
7LWE 218	75.75	50	1556	7860	2.30	2.75	17000	0.04	
7LWE 230	76.25	50	1527	7920	2.31	2.69	17000	0.05	) Motors fired within missile centre
7LWE 231	76.5	50	1559	7790	2.32	2.69	16800	0.05	) section, igniter R70 A1713.
7LWE 238	76.75	50	1411	7820	2.37	2.76	17100	0.05	) Charges temperature cycled. See
7LWE 239	76.5	50	1464	7470	2.38	2.77	16750	0.05	) para. 7.3.

* From application of firing current to thrust reaching 4000 lb.



WEB BURNED OFF, INCHES	P, INCHES	A, SQ. INCHES	As, SQ. INCHES
0	14·30	4·36	37·84
0·2	15·4	7·3	34·9
0·4	16·6	10·5	31·7
0·6	17·5	14·0	28·2
0·8	18·5	17·6	24·6
1·0	19·3	21·4	20·8
1·2	20·2	25·3	16·9
1·4	21·0	29·4	12·8
1·6	22·0	33·7	8·5
1·8	23·0	38·2	4·0
1·805	23·1	38·4	3·8

FINAL SLIVER AREA:- 10%

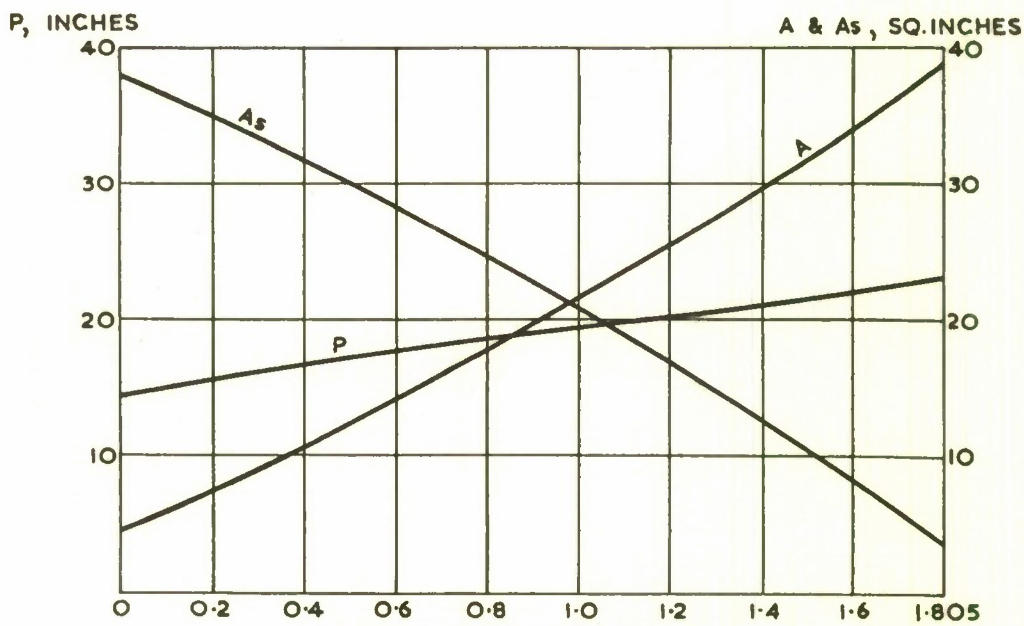
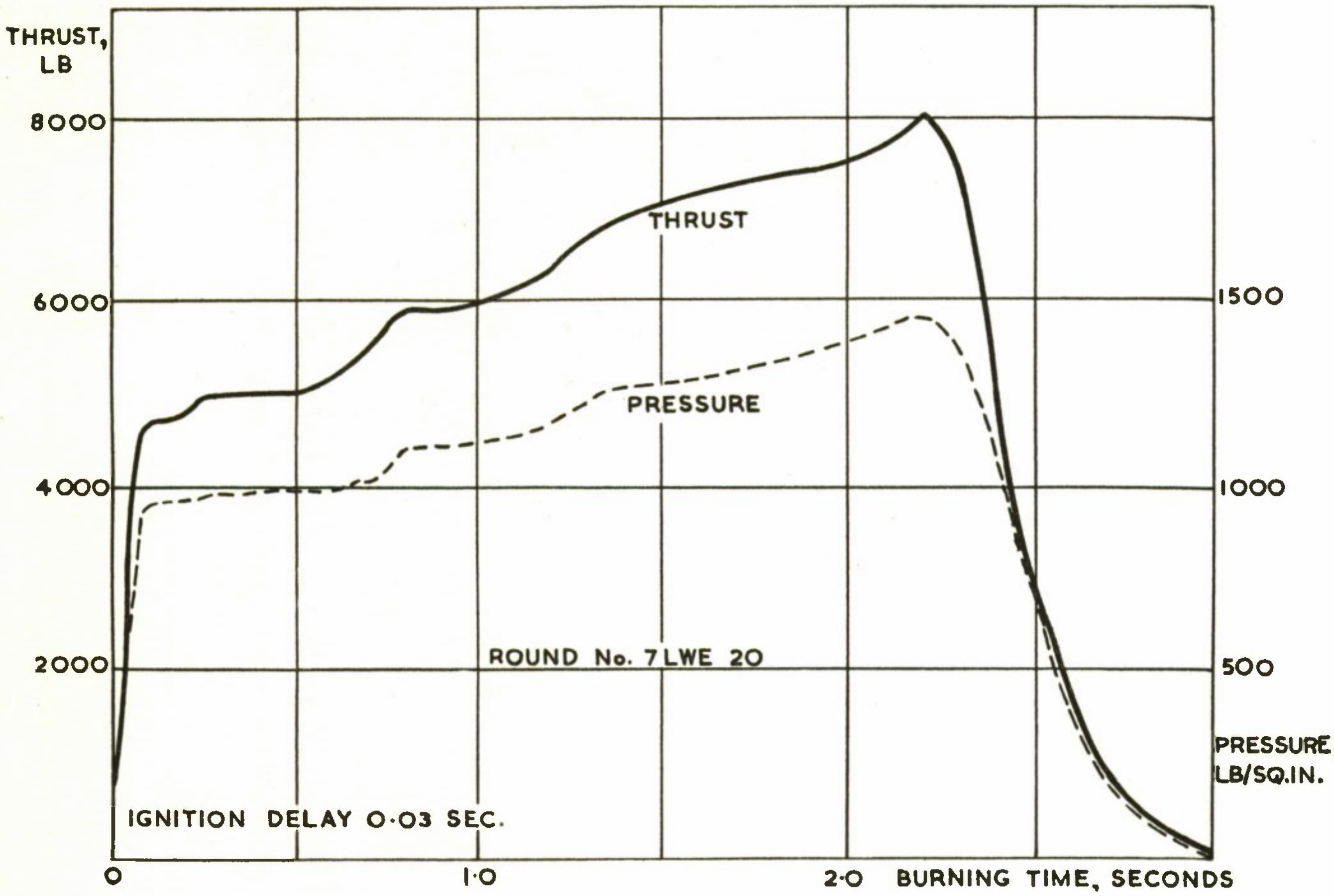


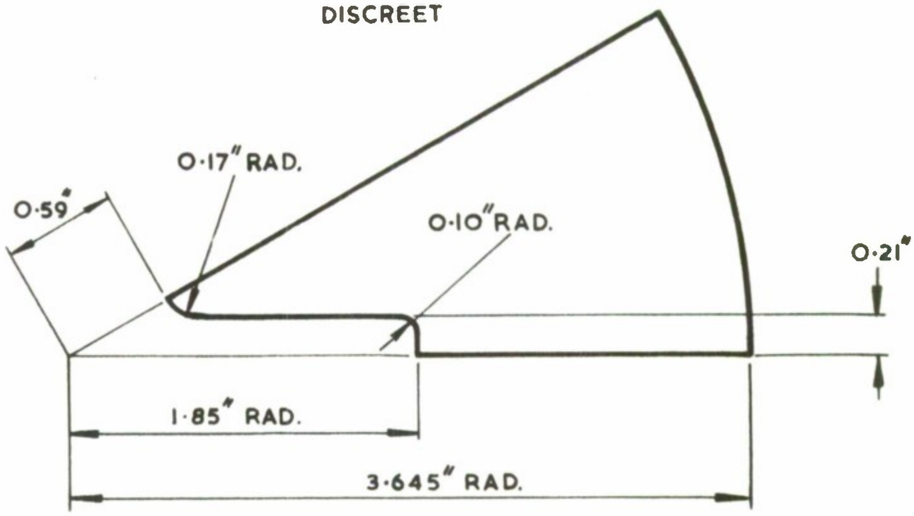
FIG. 1 CHARGE DESIGN CD 80



ROUND SERIAL No.	7 LWE 20
DATE FIRED	23.2.60
PROPELLENT TYPE	VU
PROPELLENT WEIGHT	75·75 LB
CHARGE LENGTH	24·95 INCHES
IGNITER	40 GRM SR 371C
NOZZLE THROAT DIA.	2·15 INCHES
BLAST PIPE EXIT DIA.	
TOTAL IMPULSE	16100 LB-SECONDS
MAXIMUM THRUST	8000 LB
MAXIMUM PRESSURE	1490 LB/SQ.INCH
BURNING TIME t_b	2·28 SECONDS
ACTION TIME t_a	2·75 SECONDS

MOTOR AND PERFORMANCE DETAILS

FIG. 2 VARIATION OF PRESSURE AND THRUST WITH BURNING TIME FOR CHARGE CD 80 AT 15°C



WEB BURNED OFF, INCHES	P, INCHES	A, SQ. INCHES	As, SQ. INCHES
0	18·52	4·32	37·42
0·2	19·53	8·12	33·62
0·4	19·15	11·99	29·75
0·6	18·76	15·78	25·95
0·8	18·37	19·49	22·25
1·0	18·69	23·20	18·54
1·2	19·55	27·02	14·72
1·4	20·63	31·04	10·70
1·6	21·77	35·28	6·46
1·785	22·85	39·41	2·33

FINAL SLIVER AREA = 6·2 %

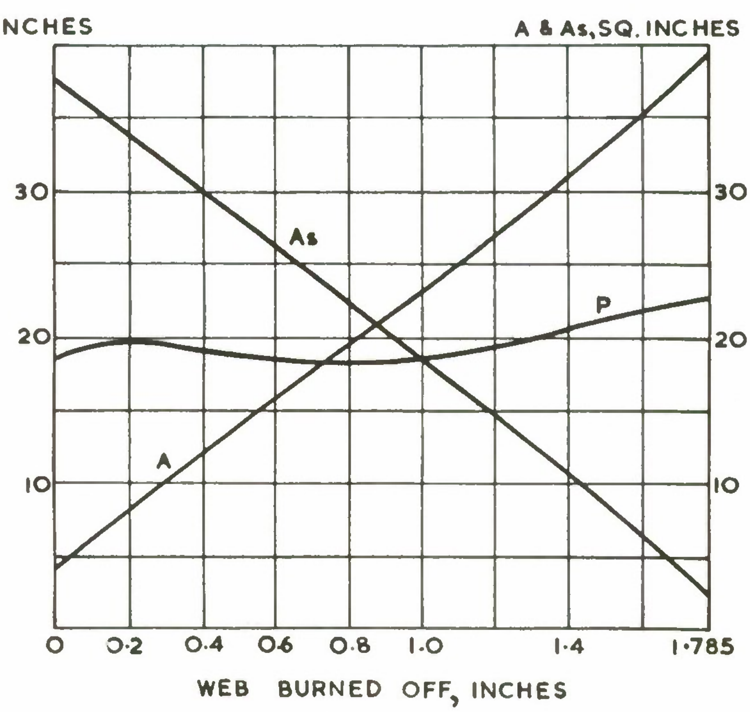


FIG. 3 CHARGE DESIGN CD 86

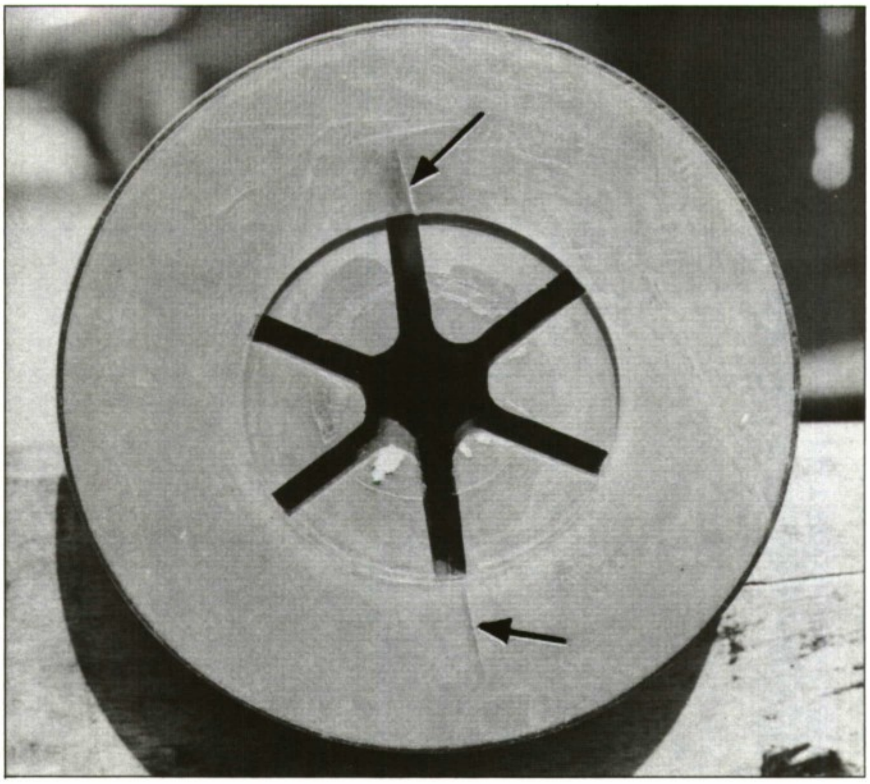


FIG.4 C D 86 CHARGE WITH RADIAL CRACKS ORIGINATING FROM ROOTS OF STAR POINTS

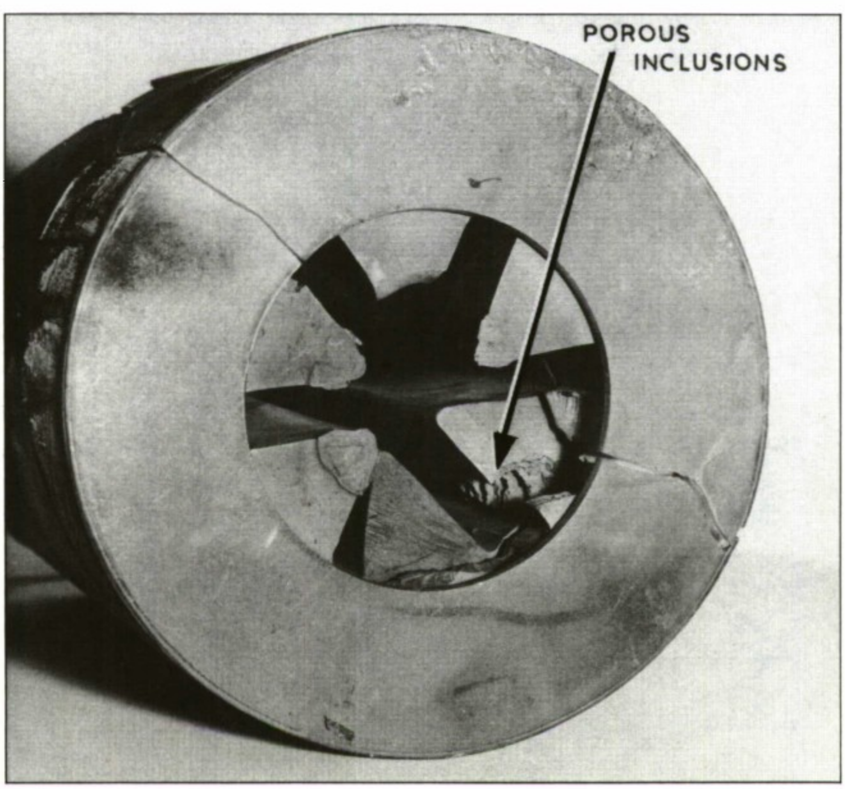


FIG.5 CD86 CHARGE SHOWING CRACKS AND POROUS INCLUSIONS

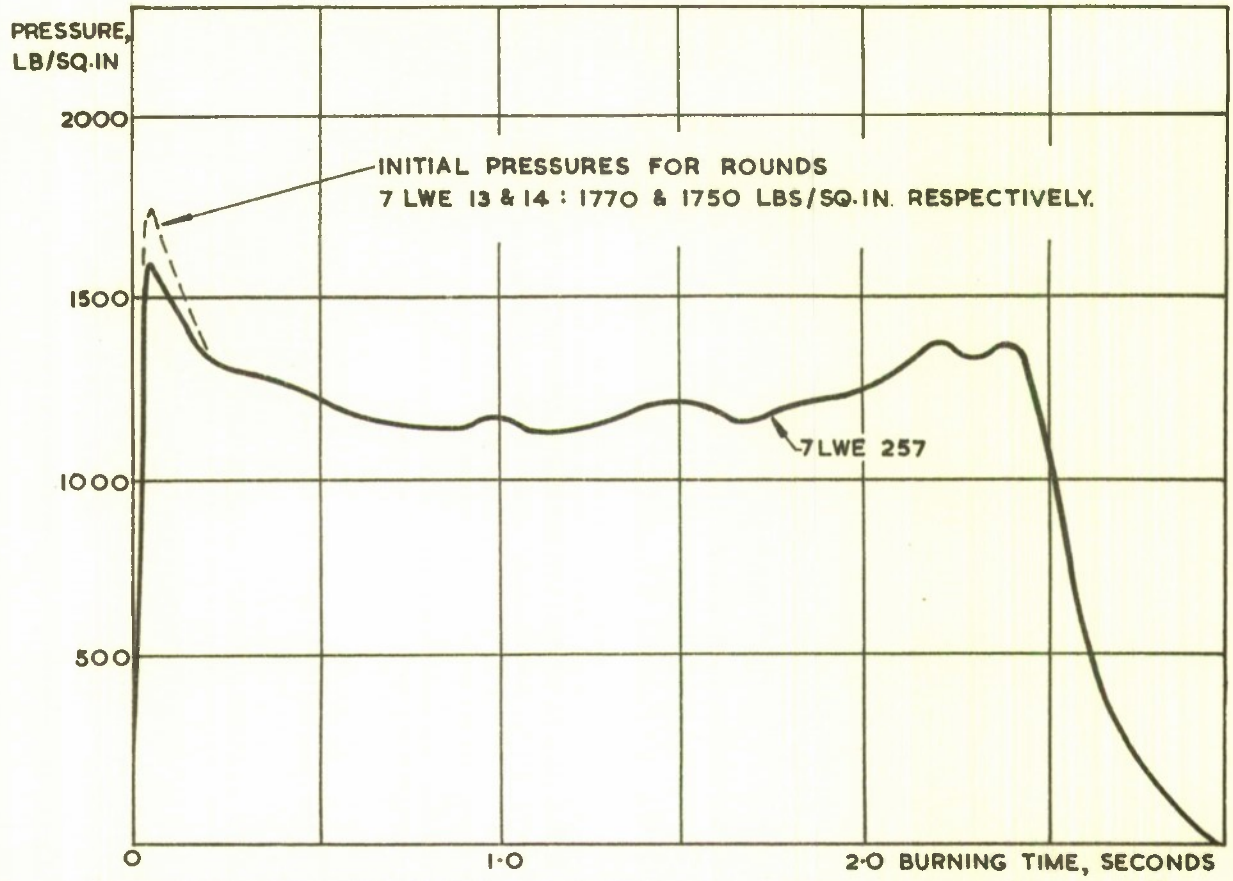


FIG.6 VARIATION OF PRESSURE WITH TIME OF BURNING FOR CHARGE CD86 FIRED AT ~ 10°C

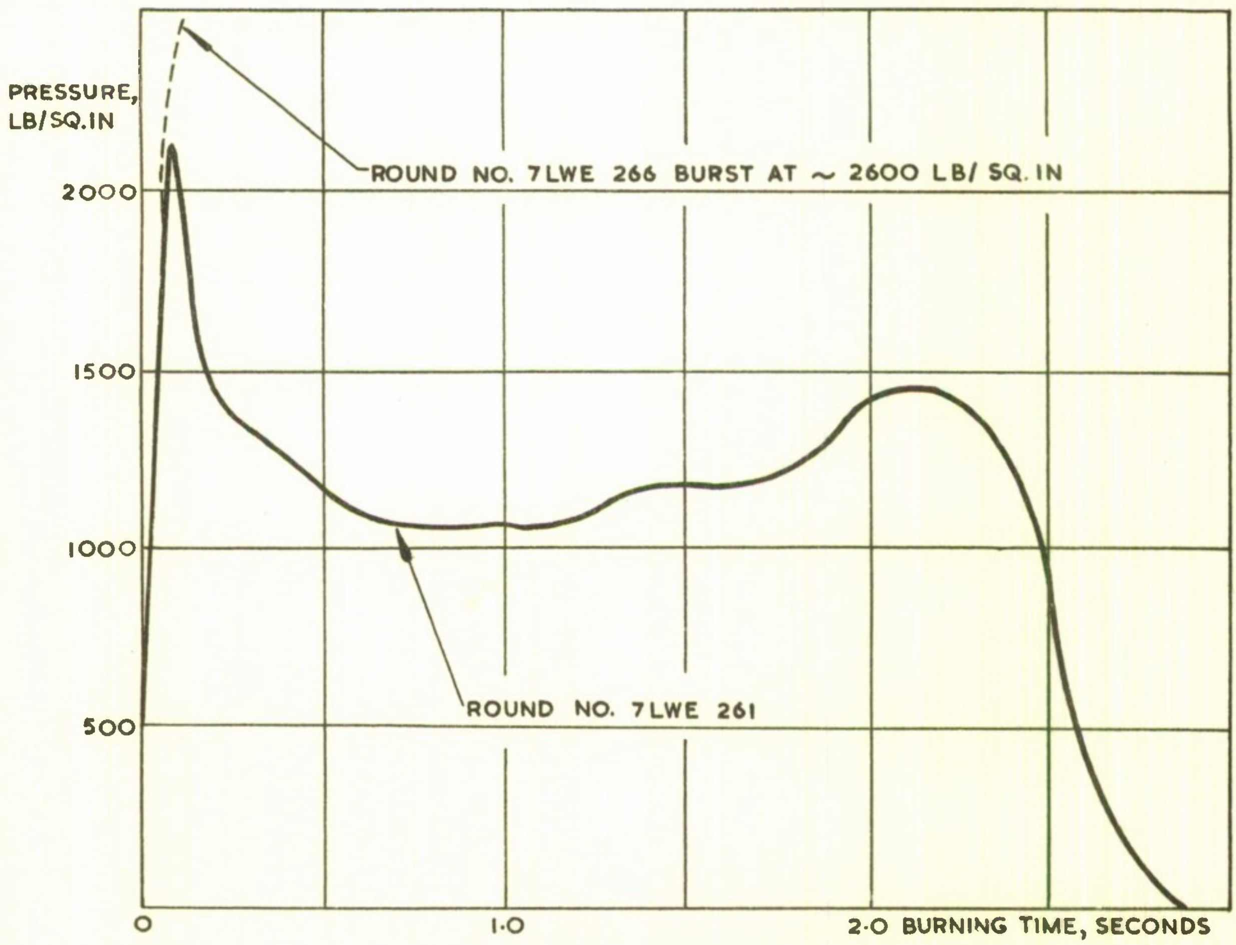


FIG.7 VARIATION OF PRESSURE WITH TIME OF BURNING FOR CHARGE CD86 FIRED AT 50°C

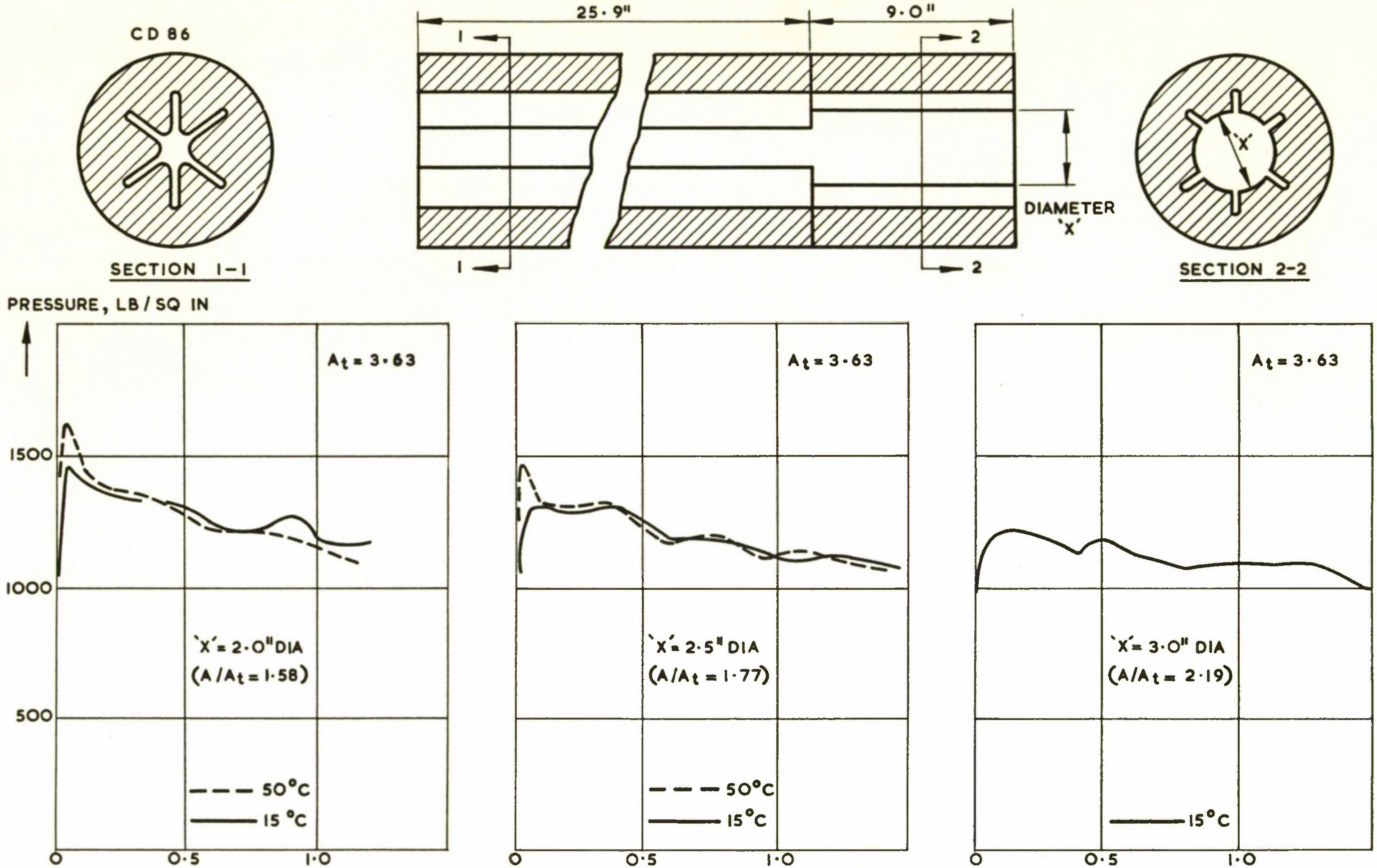
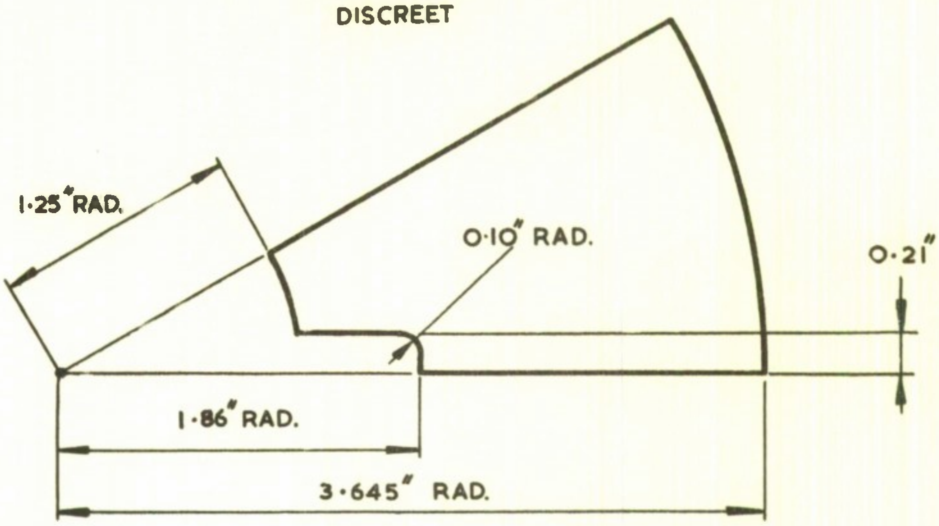


FIG. 8 VARIATION OF PRESSURE WITH TIME OF BURNING OF STEPPED CHARGES SHOWING EFFECT OF DIFFERENT LOCAL INTERNAL DIAMETERS OF STAR POINTS



WEB BURNED OFF, INCHES	P, INCHES	A, SQ. INCHES	As, SQ.INCHES
0	14.82	6.43	35.31
0.2	15.49	9.46	32.28
0.4	16.30	12.64	29.10
0.6	17.20	15.99	25.75
0.8	18.17	19.53	22.21
1.0	18.69	23.21	18.53
1.2	19.57	27.04	14.70
1.4	20.63	31.06	10.68
1.6	21.77	35.30	6.44
1.785	22.85	39.43	2.31

SLIVER AREA = 6 %

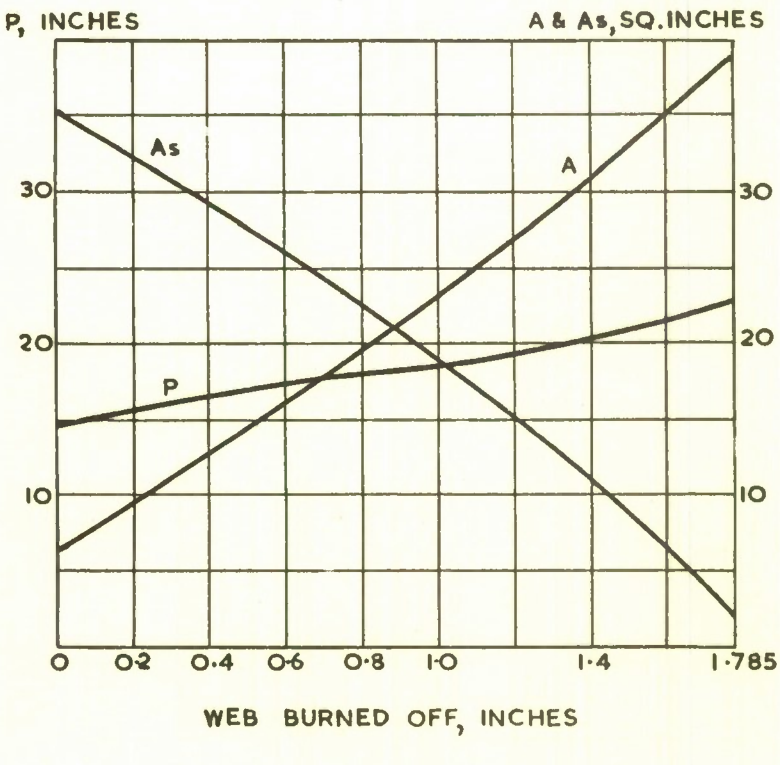
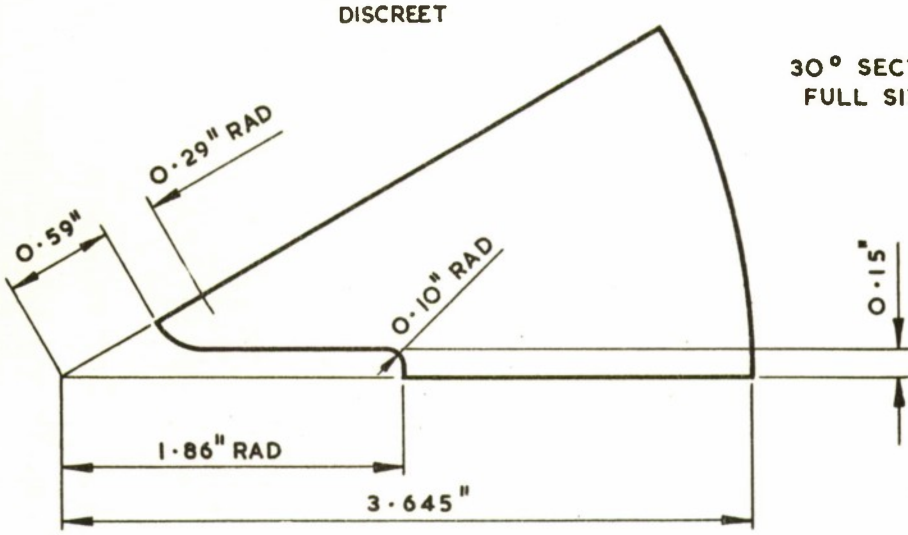


FIG. 9. CHARGE DESIGN CD 93

30° SECTOR
FULL SIZE



WEB BURNED OFF, INCHES	P, INCHES	A, SQ. INCHES	As, SQ. INCHES
0	18·10	3·43	38·31
0·2	19·35	7·17	34·57
0·4	19·70	11·08	30·66
0·6	19·31	14·98	26·76
0·8	18·92	18·80	22·94
1·0	18·91	22·59	19·15
1·2	19·67	26·44	15·30
1·4	20·67	30·48	11·26
1·6	21·77	34·72	7·02
1·785	22·84	38·87	2·87

SLIVER AREA = 7·5%

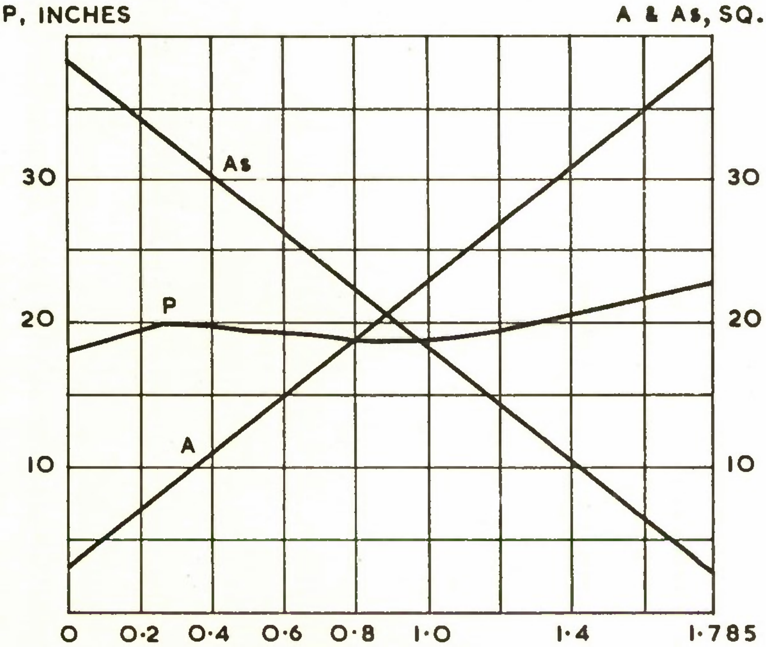


FIG. 10 CHARGE DESIGN CD92

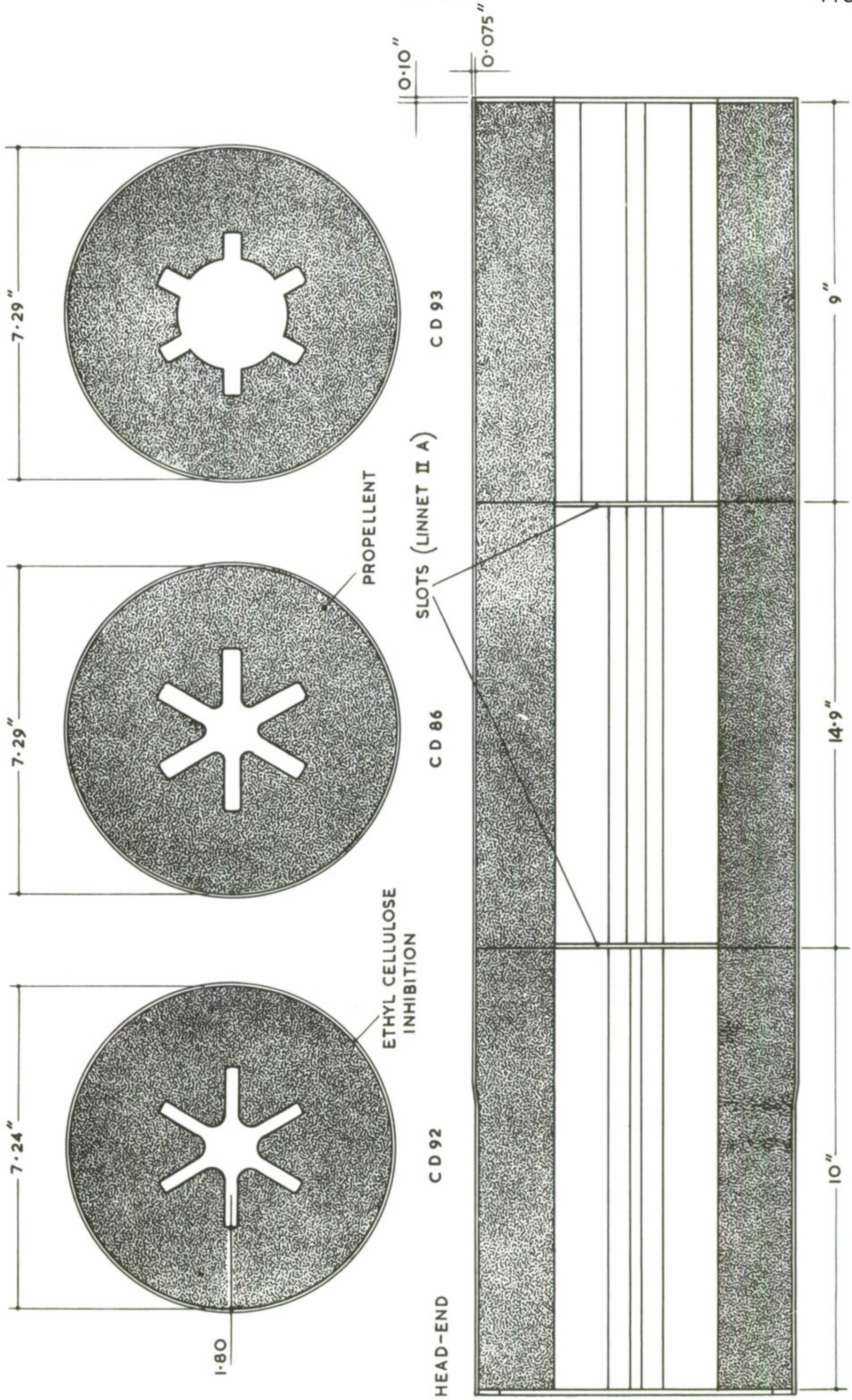


FIG. 11 LINNET CHARGE ASSEMBLY

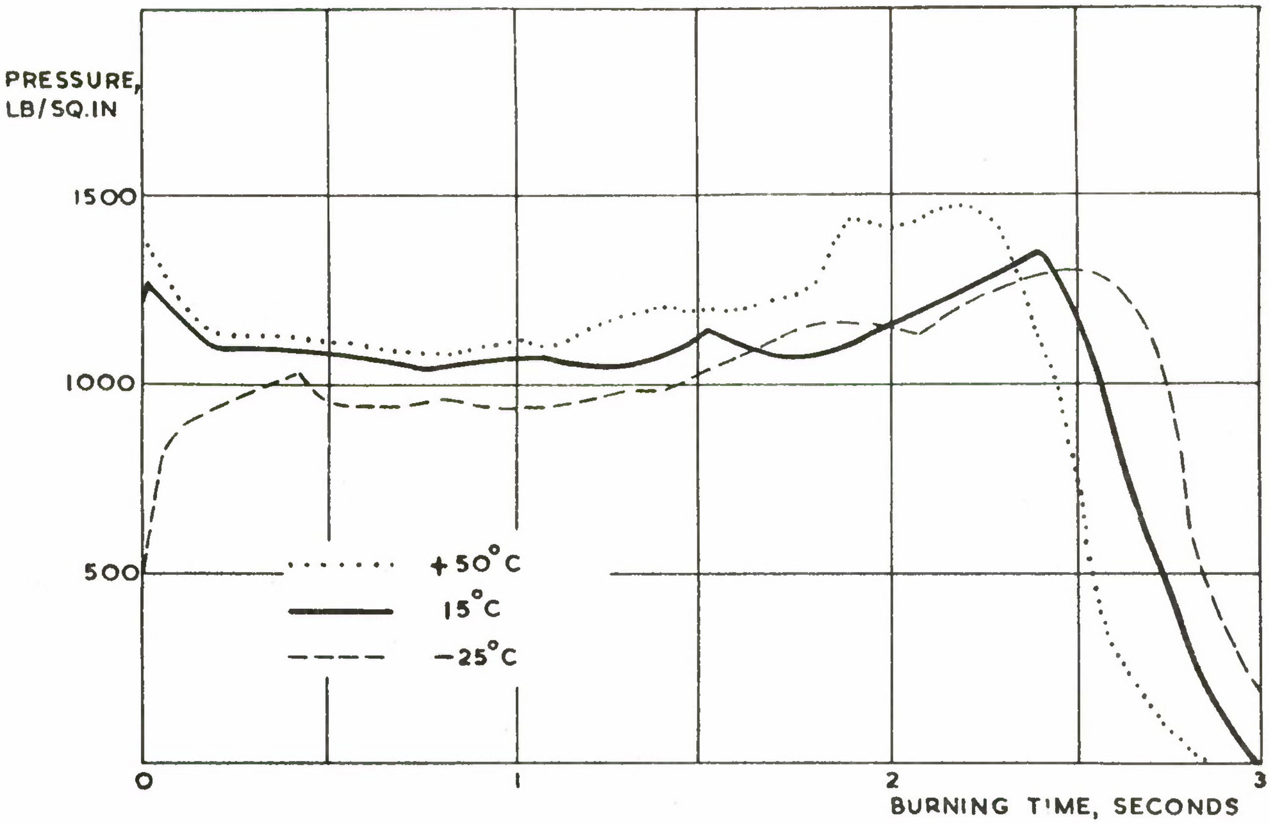


FIG. 12 TYPICAL VARIATION OF PRESSURE WITH TIME OF BURNING FOR LINNET I MOTORS FIRED AT − 25, 15 AND 50°C

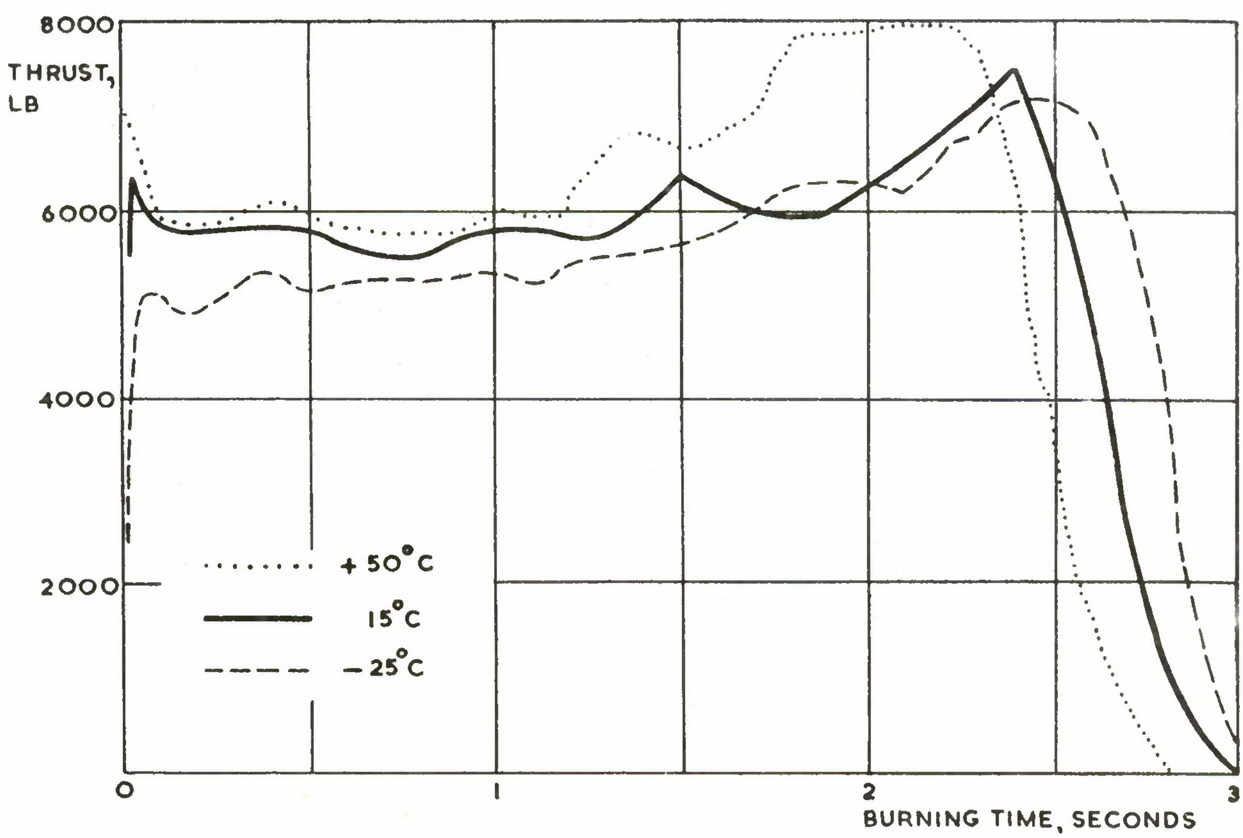


FIG.13 TYPICAL VARIATION OF THRUST WITH TIME OF BURNING FOR LINNET I MOTORS FIRED AT − 25, 15 AND 50°C

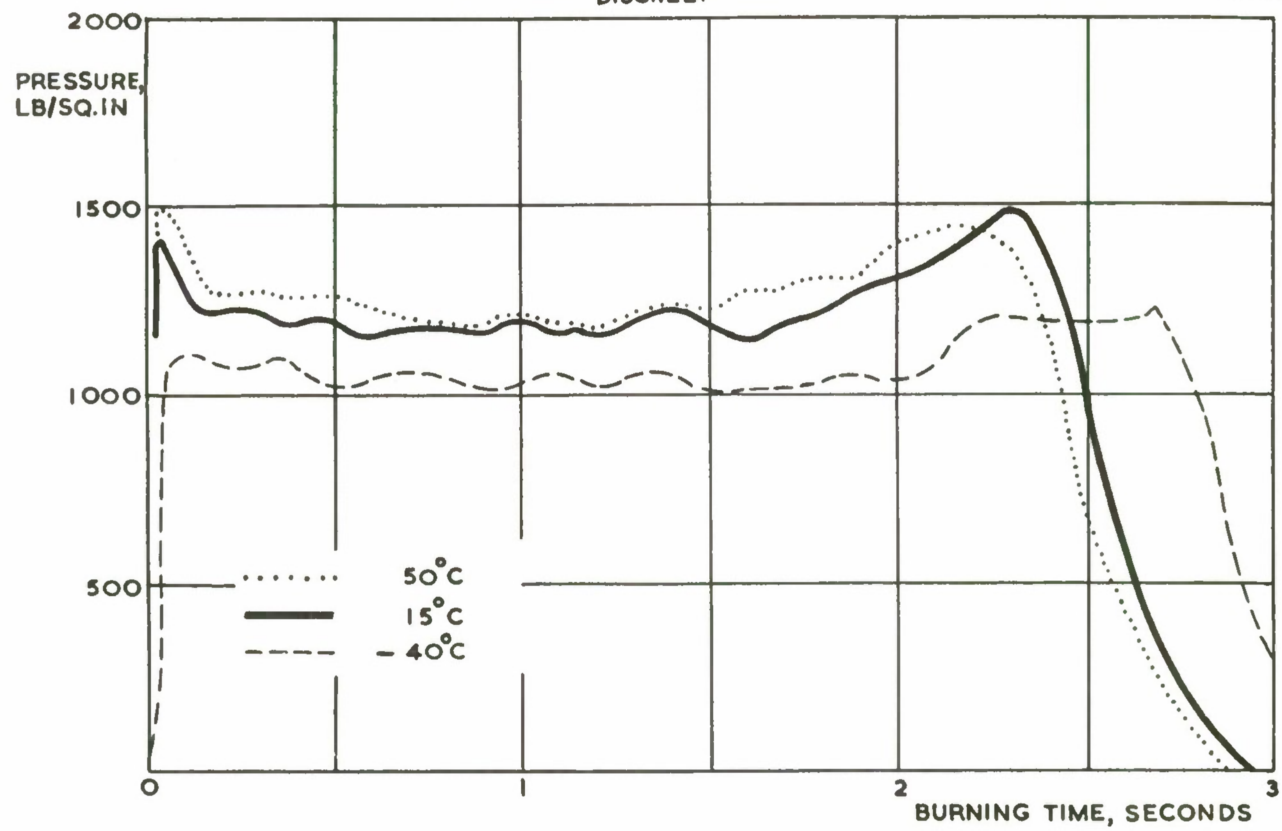


FIG.14 TYPICAL VARIATION OF PRESSURE WITH TIME OF BURNING FOR LINNET IIA MOTORS FIRED AT −40, 15 AND 50°C

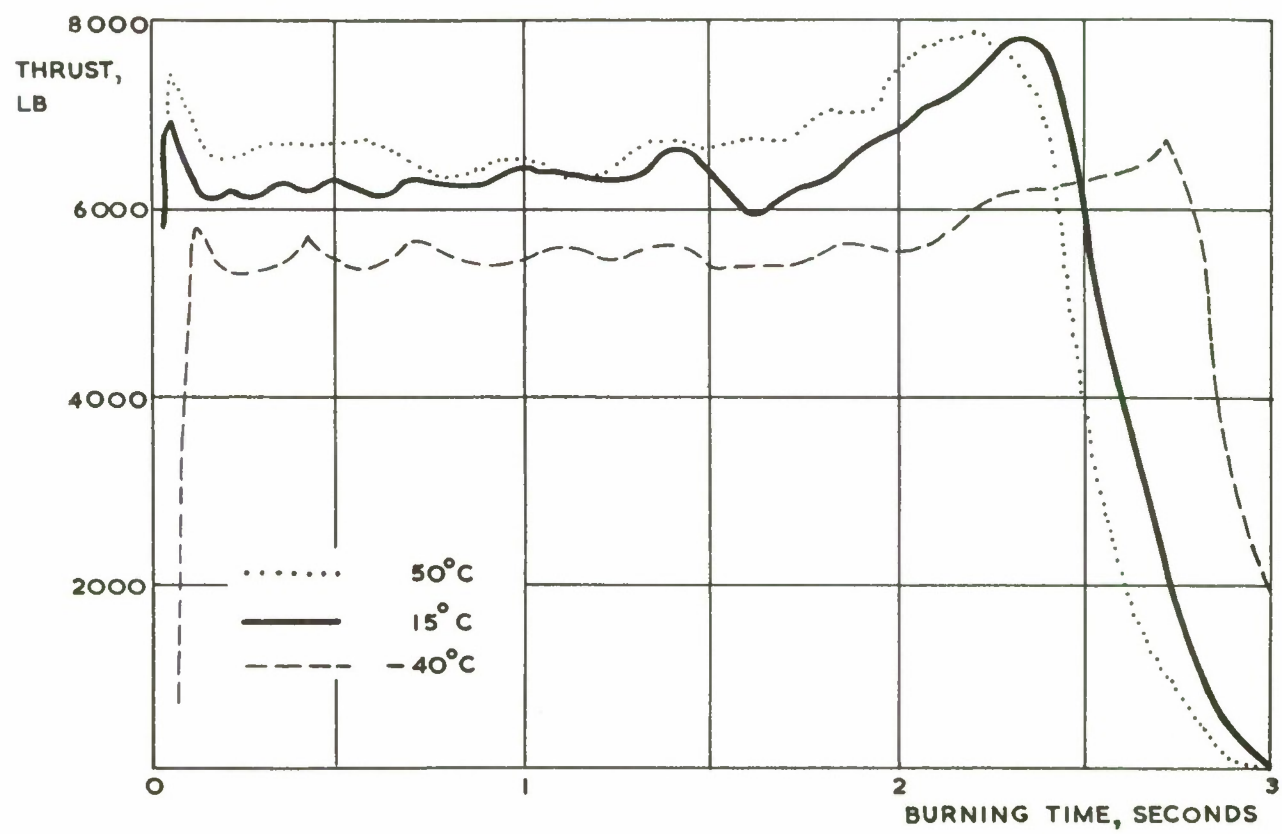


FIG. 15 TYPICAL VARIATION OF THRUST WITH TIME OF BURNING FOR LINNET IIA MOTORS FIRED AT −40, 15 AND 50°C

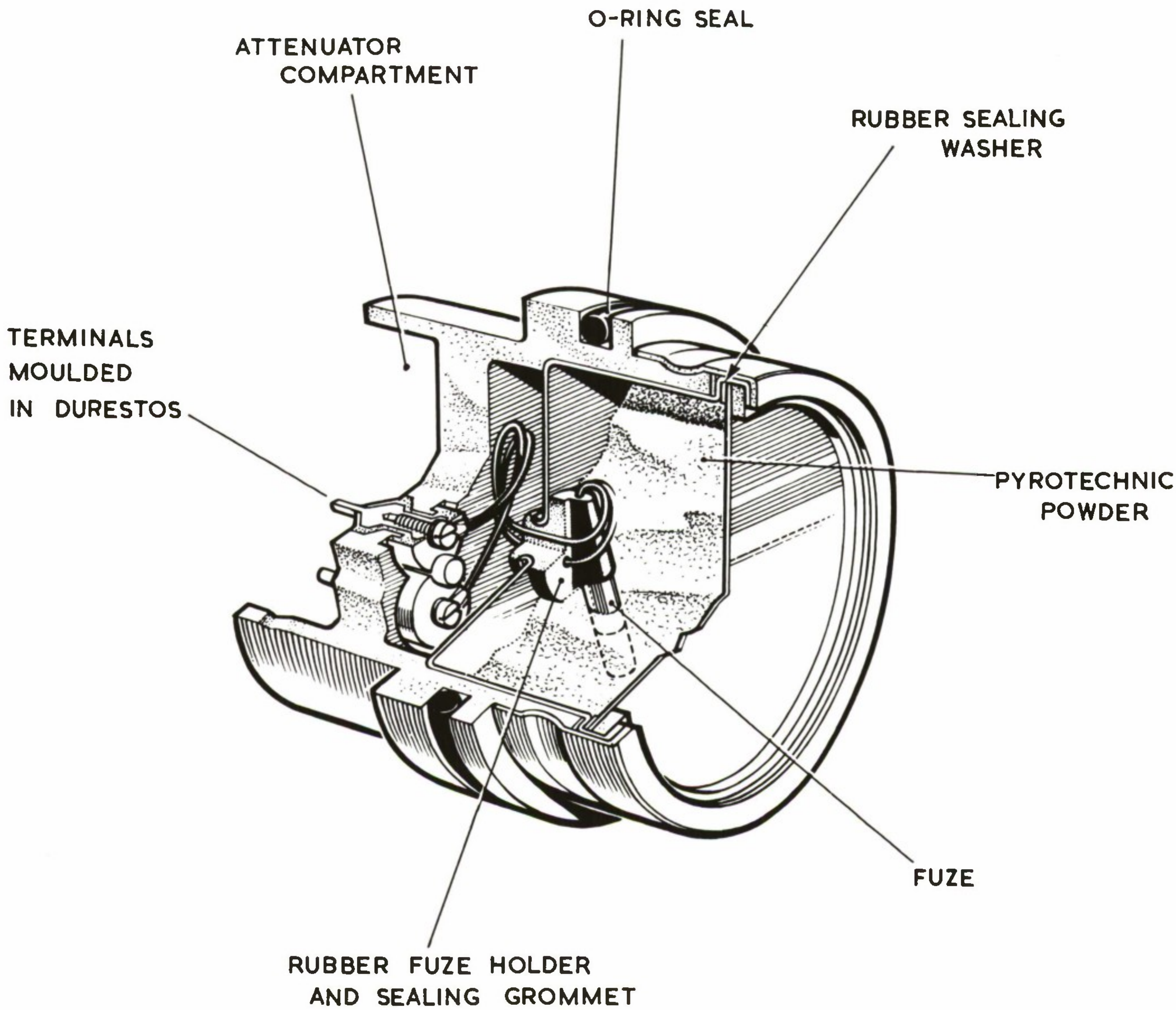


FIG. 16 LINNET II A IGNITER

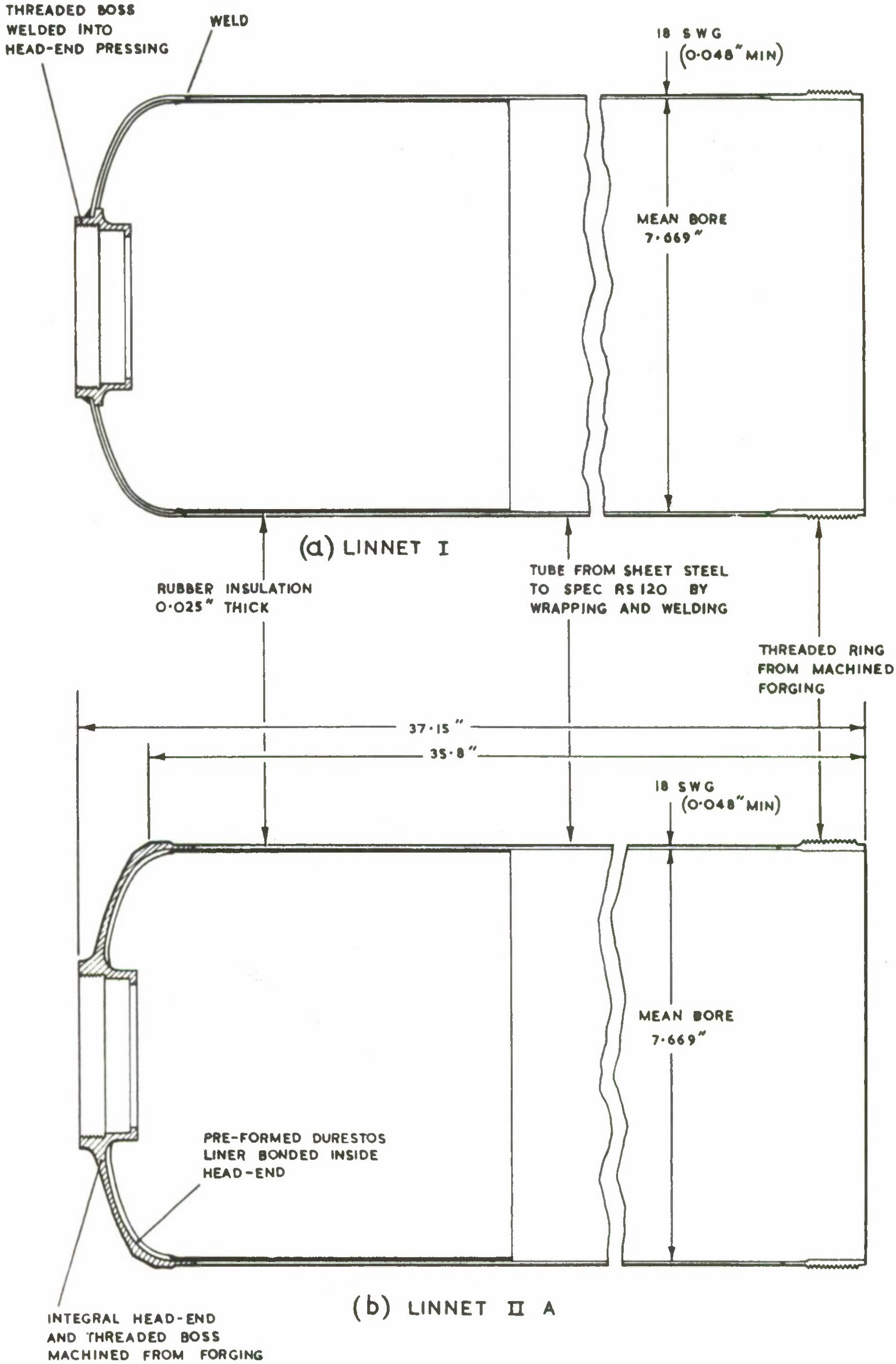
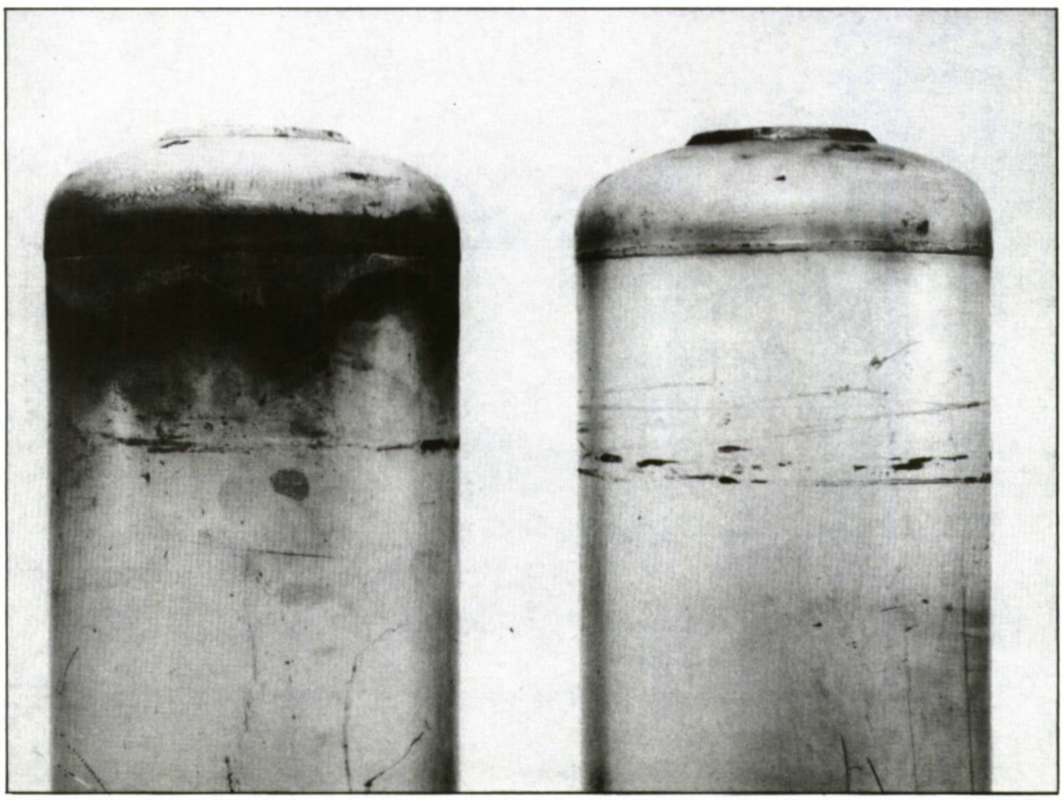


FIG. 17 LINNET MOTOR TUBE



(a) UNLINED TUBE

(b) TUBE LINED WITH 0·025 INCH THICK RUBBER SHEET EXTENDING 6 INCHES FROM HEAD END

FIG.18 LINNET MOTOR TUBES AFTER FIRING SHOWING EFFECT OF LINING AT HEAD-END

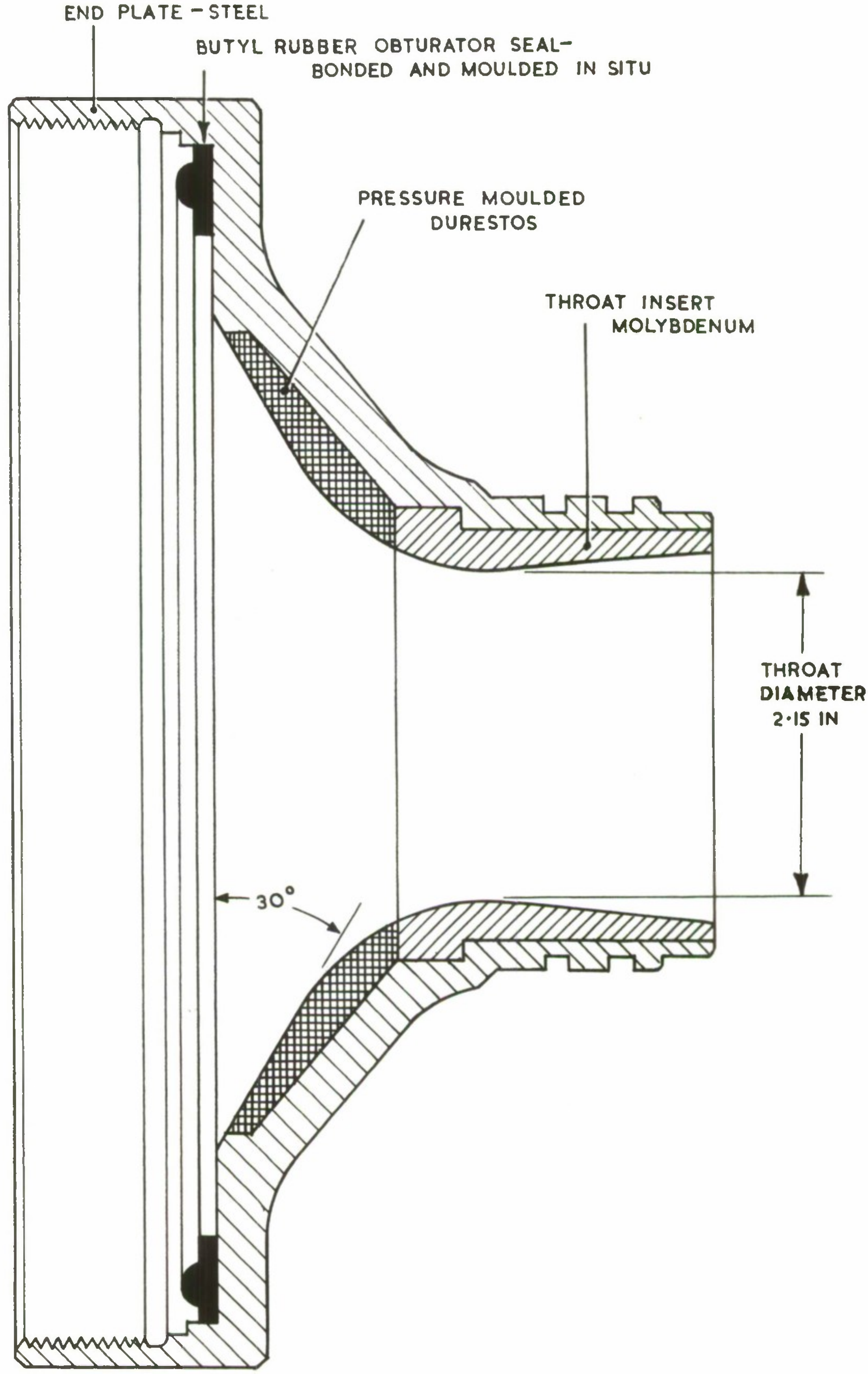


FIG. 19 NOZZLE END-PLATE ASSEMBLY

A STEEL ADAPTOR
B MINTEX LINING
C GLASS TAPE/EPOXY RESIN REINFORCEMENT

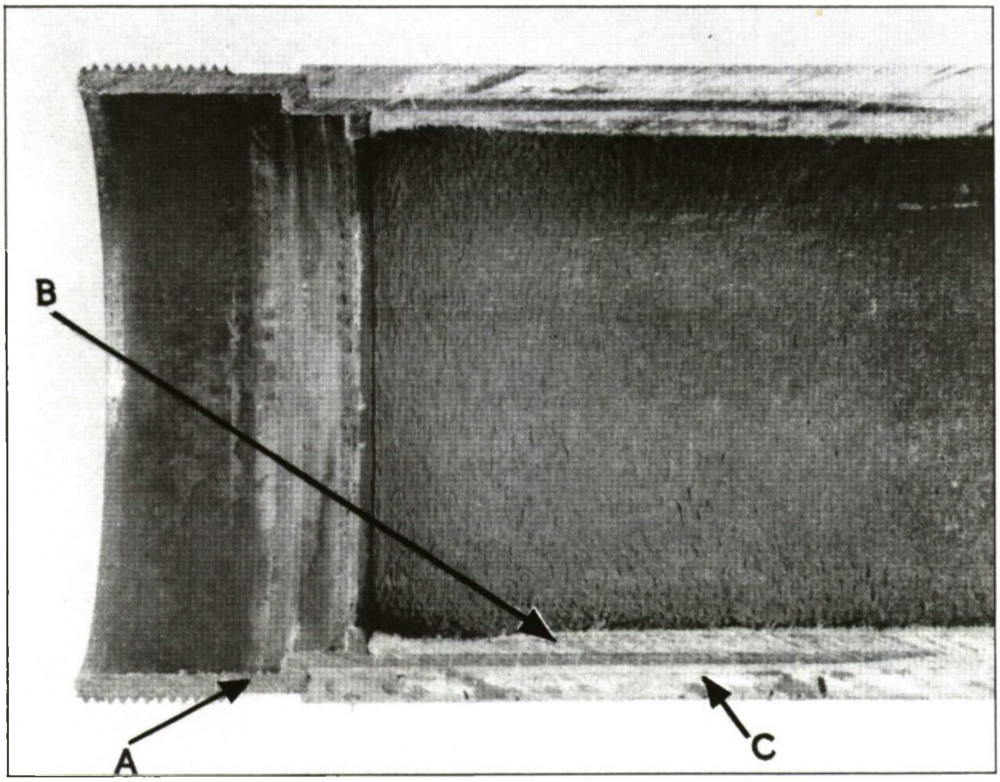


FIG. 20 TAILPIPE SECTIONED AXIALLY AFTER FIRING

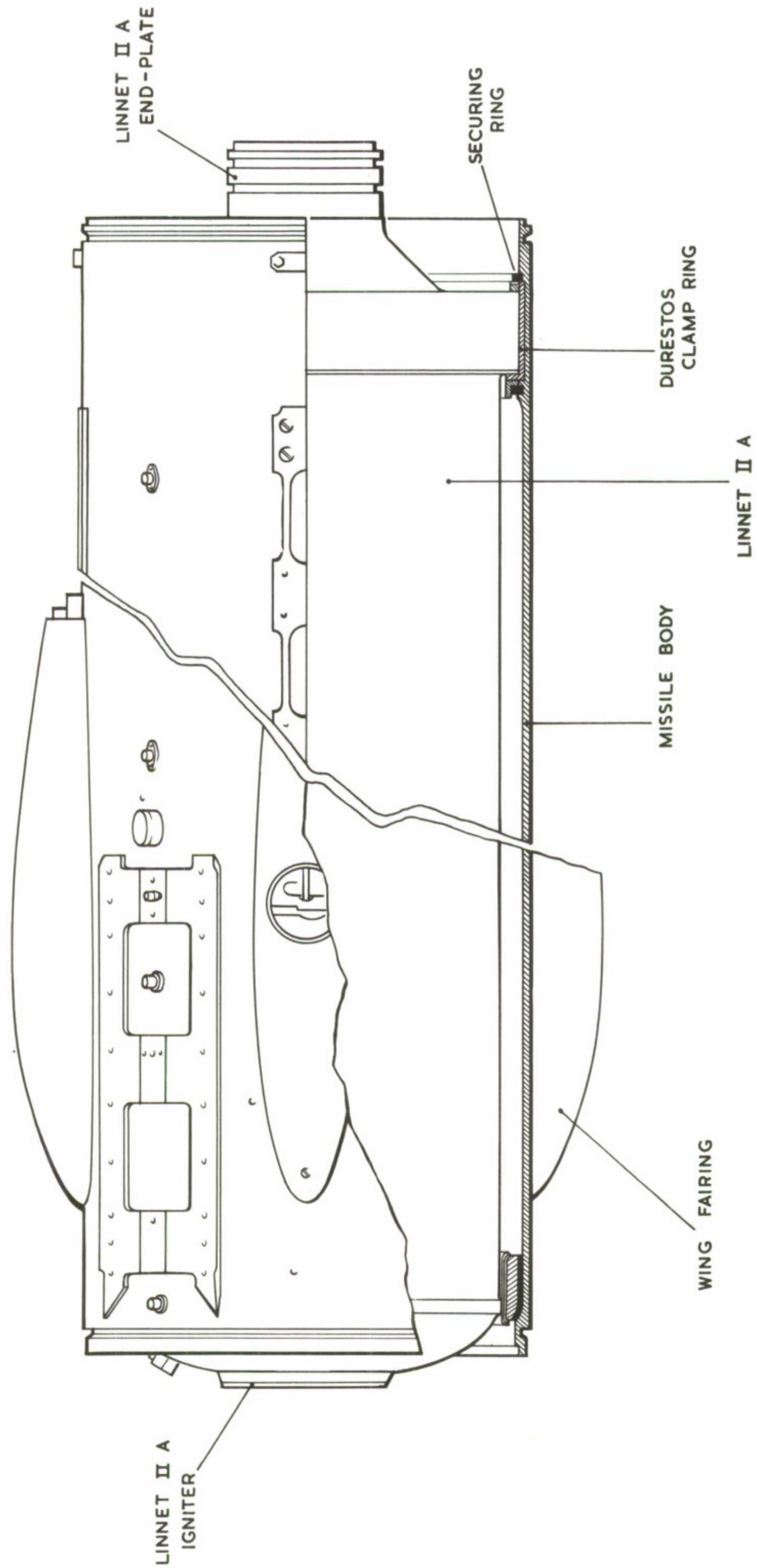
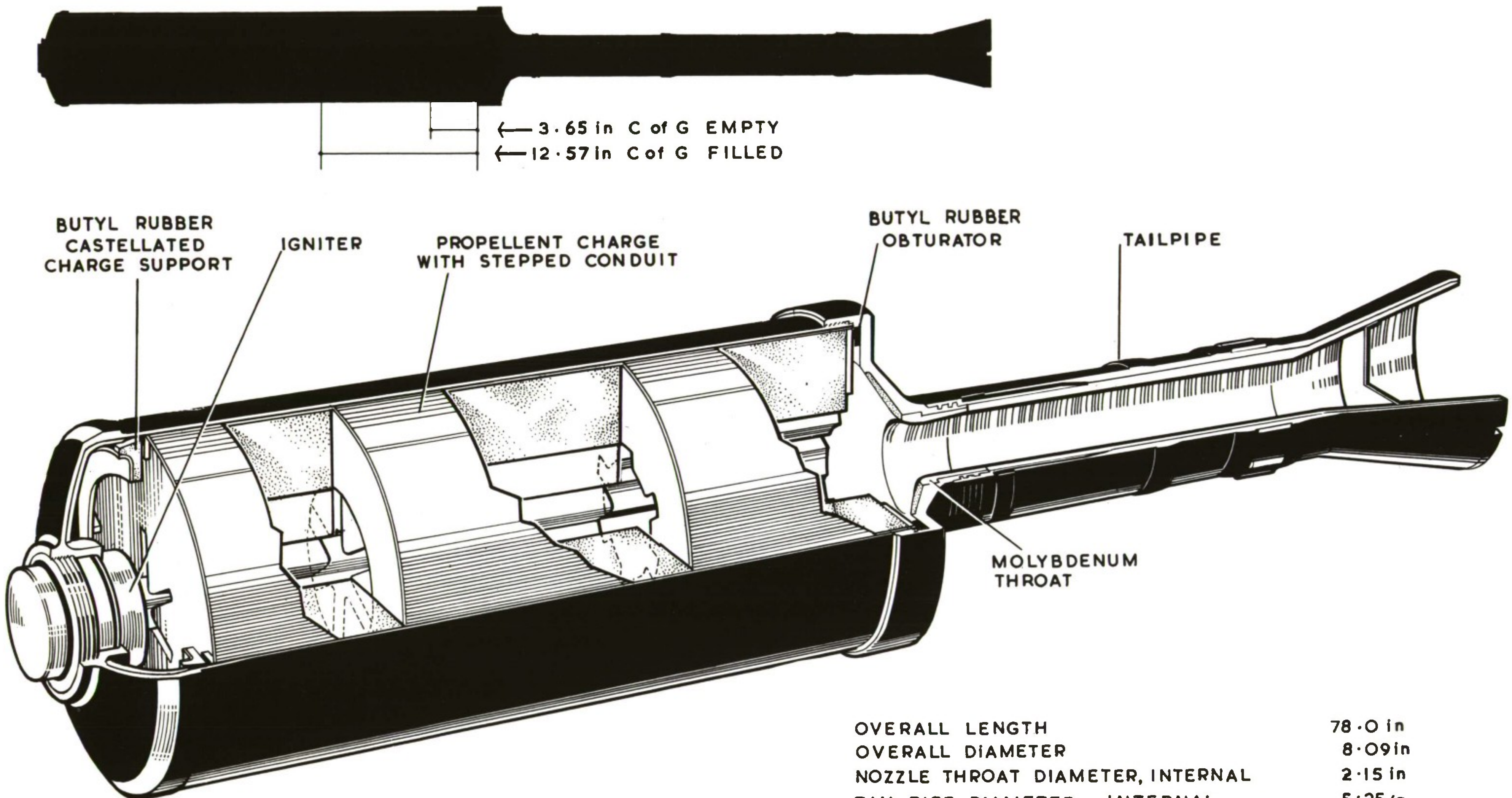


FIG. 21 ASSEMBLY OF LINNET II A IN MISSILE CENTRE SECTION



OVERALL LENGTH	78·0 in
OVERALL DIAMETER	8·09 in
NOZZLE THROAT DIAMETER, INTERNAL	2·15 in
TAIL PIPE DIAMETER . INTERNAL	5·25 in

FIG. 22 LINNET II A MOTOR

Information Centre
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22060-6218
Tel: 01980-613753
Fax 01980-613970

Defense Technical Information Center (DTIC)
8725 John J. Kingman Road, Suit 0944
Fort Belvoir, VA 22060-6218
U.S.A.

AD#: AD 349208

Date of Search: 11 December 2008

Record Summary: DSIR 23/31710
Title: Development of Linnet solid propellant rocket motor (RPE TN 220)
Availability Open Document, Open Description, Normal Closure before FOI Act: 30 years
Former reference (Department) ARC 25873
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