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Procurement Executive
Ministry of Defence
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C O N T E N T S

MINISTRY OF DEFENCE

PROCUREMENT EXECUTIVE

ERDE/RPE ANNUAL REPORT 1974/75

INTRODUCTION

1 Useful progress has been made over the year in the integration of ERDE and RPE into a single management unit. Both establishments have a heavy work load and RPE in particular is under intensive pressures from project work. The management, detailed reporting and committee work arising from projects is putting such demands on staff time that the work itself is suffering and the sheer volume of paper work falling on Heads of Branches is leaving them insufficient time to carry out their proper supervisory functions.

2 An essential aim of this year's programme has therefore been to reduce the number of tasks assigned to RPE, either by termination or transfer of the work to ERDE. A sizeable number of less vital tasks have been identified and eliminated and these are detailed in the section on the Research Programme. Some cuts have also been made in the numbers of supporting staff not directly engaged on R & D. This has released a number of staff who can be redeployed on project work and has enabled us to make a small start in research in two areas - ignition and complete motor studies, which were previously almost totally neglected. Nevertheless the staffing level at RPE, both non-industrial and industrial remains critical and its ability to undertake any new project work must be limited.

3 In the coming year closer co-operation is planned in areas other than the direct R & D work. The general administrative procedures of the two sites will be brought into line and a common costing system implemented. RPE has already undertaken the production and printing of ERDE reports and the possibilities of closer integration and economies in supporting services such as information work, documentation, glass blowing etc will be explored. The acquisition of a new computer should allow us to transfer some of the administrative tasks on both sites to computerised operation.

4 Both Establishments continue to suffer from the shadow of rationalisation plans and this is affecting both staff morale and building plans. The situation is worse at ERDE where only essential maintenance is being done, whereas RPE has been able to make some at least of the essential improvements as a result of project needs. The long period of 3-day working affected both Establishments to a lesser extent than might have been expected. The co-operation given by all staff was exceptional so that at both sites it proved to be possible to maintain something like 80% of normal output. The effect on others has yet to work its way through and it may well prove that shortages of supplies from outside will have more effect ultimately on our time scales for project work than the immediate local effects of the 3-day week.

THE PAST YEAR

5 Many of the achievements of the past year are listed in the R & D Programme sections. A few of the more notable highlights are as follows.

6 RPE

a) Three more flight trials of a packaged liquid motor, this time with imposed lateral accelerations, have been wholly successful as have the

continuing storage and temperature cycling trials. Static firings of the large solid launcher motor for KH793 have also gone well and the project remains on schedule despite the heavy demands it has put on RPE.

b) An apparently successful solution has been found to the problems of dieseling in liquid monopropellants; this should much reduce the problem of application to GW systems.

c) The work on plume technology which is often regarded as esoteric and long range is already finding many practical applications in real systems. In the past year we have been asked to evaluate the plume characteristics of 11 different motors including some from foreign sources.

d) The Crake motor for Blowpipe, which was designed and developed at RPE has been wholly successful. It has been cleared over its operational temperature range and the design frozen for production.

7 ERDE

a) The increasing refusal of commercial firms to manufacture small specialised orders for components in plastics and rubbers has had to be countered by an increased willingness by ERDE to undertake quantity production. In the past year some 55 different items were made, largely by industrial labour, amounting to 50,000 components.

b) A variety of essentially smokeless inhibitors have been developed, which are applicable by either stress relief or for use as beakers. We are now in a position to recommend effective solutions to this problem and research work on it is being terminated.

c) The troubles encountered in casting RDX/TNT mixtures in shell have been studied and a major source of cracking has been identified and a method developed for its elimination. The origins of poor adhesion to the shell wall have also been established.

d) The ERDE process for asbestos grading is now installed and working at full scale in a Finnish Mining Company. They plan further extensions and substantial royalties should accrue to NRDC.

e) Plastic propellant has been improved in low temperature performance, possibly to a $-55^{o}C$ limit in a suitable design of case-bonded rocket charge, and an alternative binder system has been developed which shows promise of enabling plastic propellants to be formulated to withstand temperatures down to $-70^{o}C$. This will put us in a better position to make a choice, if such a choise be needed, between plastic and rubbery propellants for UK uses.

ASSUMPTIONS ON WHICH THE R AND D PROGRAMME IS BASED

8 ROCKET MOTORS AND PROPELLANTS

There is a need to maintain the present level of UK research and development expertise in both explosives and rocket propulsion technology (ie solid and packaged liquid propellants, rocket motors, gas generators and power cartridges) to assist the work of associated weapon design establishments (both intra and extramural), the Ordnance Board and the ROFs, to advise the Services on foreign purchases, and to support the UK space research programme.

9 There will be a continuing need for solid propellants to meet the diverse requirements of rocket motors for guided and unguided weapon and space applications, gas generators, power cartridges and guns.

10 There is a need to increase Service Life whilst at the same time reducing unit costs of rocket motors, gas generators and power cartridges.

11 In view of the well established thermochemical limitations on propulsive performance of the known and foreseeable solid propellants, increases in overall motor performance will be found mainly by reduction in hardware mass and/or charge designs giving a higher loading density, or operating at a higher pressure. However, improved internal ballistics, propellant mechanical properties, processing characteristics and safety are also needed.

12 There will be increased emphasis on low signature rocket motors for applications such as ATGW, SAM and USGW (first and second propulsion stages) in addition to requirements for clean propellant charges for gas generators and power cartridges. Such requirements will be met in the main by cast or extruded double base propellants.

13 The superior capabilities of operating temperature range and motor size of cast composite propellants will be needed for some future applications where smoke is not a disadvantage; in particular the potential of the HTPB system merits further study.

14 There will be a continuing need to maintain a design and production capability in plastic propellant to meet specific motor requirements for both space and defence application and to fulfil the considerable PDS obligation.

15 There is a need to maintain the research programme on packaged liquid propulsion systems (both mono and bi-propellant systems) to provide a longer term backing to Lance procurement, the KH793 programme and the possible future LRATGW and medium SAM. The potential of an air augmented monopropellant system in specialised applications merits further consideration.

16 There is a need to improve the performance of gun propellants and combustible cartridge cases; reductions in barrel wear, temperature co-efficients and smoke, are all desired for both tank and field guns.

17 EXPLOSIVES AND INITIATORY DEVICES

There will continue to be a need for a wide range of high explosives and initiatory devices to meet the diverse requirements of conventional munitions. Emphasis will continue to be placed on extending the Service Life of initiator systems; initiator compounds are required which are fully compatible with the other components of detonators and the weapon environment.

18 IS requirements will require improved techniques for both identification and detection of explosives and EOD.

19 MATERIALS

It is assumed that ERDE's role as non-metallic materials adviser to Land Service Establishments will continue, and that this will involve work on a variety of ad hoc problems, on the provision of data sheets on new plastics and rubbers to designers and the assessment of the behaviour of these materials on tropical exposure. ERDE is the main centre for the small intramural team on adhesives and the assumption behind the research programme in this area is that there is a real

need for metal to metal adhesives which will (a) be substantially more flexible than those now available, without loss of strength, and (b) be capable of cold curing without the use of corrosive hardeners. In composites it is assumed that lightweight high strength materials are needed for a variety of different applications such as rocket motor bodies, blast pipes, airborne equipment and armour.

THE RESEARCH PROGRAMME

20 INTRODUCTION

The forward research programme is set out in detail in Appendix F and is discussed below. A breakdown of the work items in even greater detail is provided by the separate Research Programmes of the two establishments and these can be made available on request. Some substantial changes have been made over the year. At RPE we have been forced to terminate all in house work on resistojets, on rheology for solid propellants, on basic combustion studies, Raman scatter and polyferrocene catalysts for propellants. There has also been a cut back in the staff deployed on radio interference in rocket plumes (although not on visible or IR work), and on nozzles. All work at RPE on hydrazine should be completed this year. ERDE has rounded off most of its programme on smoke from inhibitors and has transferred work on flame suppression to RPE where the testing can be more conveniently done. In return ERDE will undertake most of the rheological work, will take on more responsibilities for nozzle development, for the study of improved insulants, adhesives and inhibitors and for more complete motor studies. These changes have done something to help balance the load, and as indicated earlier, they have enabled us to make a small start to be made in work on ignition and on complete motor studies.

21 A major preoccupation of ERDE is the need or otherwise to maintain research on composite propellants and whether this should be on all types. One difficulty is the absence of strictly comparable data derived from trials of different compositions in the same motors, and some of the complete motor studies in the current programme are designed to fill this need. Plastic propellant remains a viable option for RS80 but unless it is adopted for this weapon we would propose to round off all new work on this propellant and to concentrate exclusively on HTPB as being the best of its kind. It is hoped that the latter can be brought to a stage when proven compositions would be available for use in development within the coming year. Rubbery propellants offer so many different advantages over double base types (significantly better performance, greater stability and resistance to temperature cycling, wider operational temperature range and less vulnerability to detonation by fragments) that it is difficult to contemplate their total abandonment despite the current UK Service concentration on double base propellants and the limitations of smoke.

22 There is a major need for a Manual which sets out in detail the existing state of the art of rocketry in all its aspects. Weapon designers still tend to ask for more than can be achieved without excessive effort or cost and are often insufficiently aware of past work to avoid pitfalls which tend to recur in cyclic fashion. It is proposed to make a start on the production of such a Manual this year, although internal staff pressures will require that much of it will have to be written by suitable retired staff under contracts.

FIELD 3A SOLID PROPELLANTS

23 Extruded Cordite

Much of the work on extruded cordite is concerned with the maintenance of expertise and of the quality of current supplies. The quality of nitrocellulose is dependent

upon many variables including, for example, the nature of the washing water, the source and purification of the cellulose, minor impurities and many others which cannot yet be adequately covered by specification requirements. A constant requirement therefore exists to control the ballistics and other properties of our formulations to cope with changes in the raw materials so that the standard performance is maintained.

24 The major change in research effort of this team is the development of very fast-burning rocket charges in support of GST 3566 (now GSR 3568; this work is shortly expected to be accorded "development" status). Until a decision on operating pressure and acceptable signature can be made, the choice of propellant cannot be finalised. Very fast-burning compositions (a) platonised and free from smoke, (b) composite-modified cordites giving oxygen balanced and freedom from flame, (c) HTPB composite type suitable for casting in complex shapes, are being developed. Some difficulties are to be expected in providing plateau ballistics at the expected high operating pressures and work will be done to try to extend platonisation to higher pressures. This will include work on more stable redox catalysts such as the transition metal oxides.

25 There are still important problems which are not included in the programme due to lack of staff. These include work on metriol trinitrate as a partial replacement for NG and work on cordite processing which still uses equipment developed in the 1920s and which could undoubtedly be done much more cheaply if sufficient effort were available to establish new techniques.

26 CDB

Much of the work is back-up effort in conjunction with IMI, and close collaboration is maintained. Thus the ERDE trials on compositions which should be free from problems of ballistic drift are essentially complete, and NEC are currently making casting powders for further joint trials. Work is planned on improved processes for pressure casting, on the powder/liquid ratios and on platonised propellants containing RDX to give smoke-free power cartridges of adequate energy. Work will also be done on the influence of viscosity on casting liquid hazards as it has been suggested that worthwhile reductions in sensitiveness can be achieved by viscosity increases. This might enable us to reduce the triacetin content and to achieve higher performance.

27 Rubbery Composite Rocket Propellants

During the past year further experience has been gained with the castable HTPB type of rubbery composite propellant. This has confirmed its superiority to the older CTPB type in regard to low temperature behaviour and burning rate range but there are several areas in which investigation is required. These include the bonding of the propellant to metals, insulants and case liner materials, the use of so-called bonding agents for promoting adhesion between matrix and filler so as to obtain the best possible low temperature behaviour, and a comparison between the various types of HTPB prepolymer which are now available. In addition it is necessary to examine the effect on ballistic and physical properties of compositional variants so that compositions can be offered covering a wide range of burning rate. Full size comparison trials of the performance of HTPB, CTPB, and old and new plastic propellant formulations are planned (see Field 3B below).

28 Plastic Rocket Propellants

Before research on plastic propellant is reduced to the PDS level in 1976, it is hoped that work on the promising new type of polyisoprene binder propellant will

have reached the stage at which it can be confidently recommended for any suitable motor applications which may arise. This will necessitate the successful demonstration of usage characteristics and of feasibility of large-scale manufacture.

29 Considerable progress in demonstrating usage characteristics has already been made and excellent results are being obtained from rheological studies, temperature cycling, storage and small motor firing trials. The indications are that the usage characteristics are comparable in most respects, including low temperature behaviour, with those of the best rubbery composite propellants.

30 As far as the conventional polyisobutene type of plastic propellant is concerned, an effort will be made to characterise the physical properties and storage behaviour of a range of compositions using recently developed testing methods which enable fundamental rather than empirical rheological parameters to be determined. The data from this work will enable "on the shelf" compositions to be selected for particular motor applications with a greater degree of assurance than has been possible in the past.

31 Gun Propellants

The reduction in research effort is simply the result of the majority of the work passing over to development - particularly in relation to the FMBT gun. A small residual research effort will be maintained on combustible cartridge cases and on the propellant needed for the MRCA gun.

32 Vulnerability of Rocket Motor Propellants

A review paper summarising the results to date from trials on the ignition of rocket motors when attacked by fragments or bullets has been prepared and is being used as a basis for a further programme using a standard rocket motor target which will allow the individual variables of case materials, propellant type and configurations to be studied. This work is regarded as being of great practical importance and may well have an important bearing on future policies for the choice of propellant. Preliminary indications are that only fires can be produced with liquid propellants and that the likelihood of detonation is significantly lower in composites than with CDB.

FIELD 3B THE APPLICATION OF SOLID PROPELLANTS TO ROCKET MOTORS, GAS GENERATORS AND POWER CARTRIDGES

33 Ignition

The need to increase effort in this area was brought out in last year's review. New work at RPE will be integrated with that proposed for SRS and the basic studies at Cranfield Institute of Technology. The role and significance of hot particles on the overall ignition process remains uncertain but work at Cranfield in 1971 implied that the size of the hot particles impinging on the propellant surface was of first importance. Initially work at RPE will aim to answer these questions using practical hardware (eg the Imp motor for ignition and the 2 inch aircraft rocket motor as the standard test motor).

34 Inhibition

The inhibition of propellant charges (both extruded and CDB) is giving problems due to supply difficulties with thin walled ethyl cellulose tubing and with cellulose acetate sheet. ERDE propose to take over the fabrication of the small quantities of ethyl cellulose required for rockets. We shall be able to provide beakers for

small rockets but RPE will have to use tape wrapping for larger motors. This will involve work on both tape production and on its application to charges. It will however give us greater flexibility in the use of less smoky formulations than has been available in the past.

35 The work on smokeless inhibitors has been successful and we are now in a position to recommend effective solutions for future projects.

36 Combustion, Unstable Burning and Erosive Burning

Fundamental studies of the mechanism of combustion of propellants will be terminated in order to concentrate on problems of immediate importance. Combustion instability remains a problem in some project motors and the several techniques developed at RPE for its characterisation and study merit further exploitation. Effort will be concentrated on the high frequency instability that occurs with some motors using double-base propellant (VU and PU) and the low frequency instability that occurs with some motors using composite propellant, in particular highly aluminised plastic propellant.

37 Techniques are also available at the RPE to study erosive burning and acoustic erosivity and although some work has been done to measure the effects of acoustic erosivity and pressure-coupled instability on the burning rates of VU, PU and an aluminised CTPB propellant more work is required before the data can be applied to practical motor conditions.

38 Complete Motor Studies

Very little has been done on this in recent years. In the current year it is proposed to fill realistic size motors with all types of composite propellant available in the UK so that strictly comparable trials can be made to evaluate relative performance etc. These trials will provide some essential background which will be valuable in assessing the relative merits of competitive designs of either UK or foreign motors. Part of the work will be carried out on rocket motors of a size directly applicable to RS80 and will therefore have an immediate use in projects.

39 Work will continue on the 160 mm bipropellant motor to evaluate the possibilities of achieving two thrust levels and also on short burning time motors for man portable anti-tank weapon where such high accelerations and short burning times are involved that very high stresses will be imposed on fragile charge sections. The stability of such charges under velocities of 2000 m/sec and accelerations of 1000 g will be studied.

40 Power Cartridges and Gas Generators

The development of new propellant and inhibition suitable for use in gas generators for weapons such as Swingfire, giving greatly reduced smoke and longer life, has been completed.

41. The use of HMX/polymer compositions being developed by extramural work at NEC will be studied. These represent the only clean-burning candidates likely to withstand the temperature conditions imposed by severe aerodynamic heating.

FIELD 3C THE APPLICATION OF LIQUID PROPELLANTS TO ROCKET MOTORS

42 During the past year work in support of project KH793 and to a lesser extent Lance, has absorbed a large proportion of the specialist effort available on liquid propellant motors. The main highlights of the past year on the packaged liquid

bipropellants have been the three technically successful flights of a representative motor with imposed lateral accelerations. These trials have now demonstrated the capability of our current motor design concepts to satisfy this aspect of GW requirements. Other flight trials have demonstrated the ability of a packaged propellant motor to function normally after long term storage and extensive temperature cycling over wide environmental limits (-40 to +60°C). All available evidence indicates that a Service Life for filled tankage well in excess of 10 years is feasible for a properly designed system, even under adverse environmental conditions.

43 Very little progress has been made on research topics which could lead to improved performance, reliability and cost effectiveness of future packaged liquid motors. Therefore the two main areas where research is still needed are (1) gelled propellants which could lead to improvements in performance or safety, and (2) a study of bladder-type expulsion systems which would give greater freedom in design. There is also a need for continuing effort on topics related to safety and handling under Service conditions to establish confidence in the acceptability of liquid propellants and to develop appropriate procedures in accident situations.

44 Investigations continue into the use of isopropyl nitrate (IPN) as a monopropellant for ATGW propulsion where exhaust cleanliness and minimum radiant intensity are essential. The Plessey Company have the main responsibility under an RPE contract for a programme, started in mid-1974, aimed at demonstrating feasibility and acquiring design criteria for a complete IPN rocket motor by mid-1975. RPE is providing test facilities for this work and supporting research. During the past year studies at RPE have led to a better understanding of the dieseling phenomenon, and to the successful demonstration in laboratory-type apparatus of a method for reducing, or eliminating this problem.

45 A new work item (3C9) refers to the small effort to be devoted during 1974/75 to feasibility studies of concepts which could extend the versatility of liquid propellants in GW applications. Short term theoretical studies, using data from recently completed work at Southampton University, will assess whether air augmentation offers any real advantage in likely GW applications. Other work will consider the potential advantages of integrating a liquid propellant rocket into a composite propulsion system involving an air-breathing gas turbine or solid propellant motor. Preliminary studies indicate that this could offer a very attractive solution in terms of performance, size and cost for requirements demanding long range (eg 150 km) and flexible operation.

46 The major objectives of the RPE programme to develop a UK source of catalyst as an alternative to the US Shell 405 and to investigate some of the parameters that influence the operating characteristics of catalytic thrusters using hydrazine will have been achieved by the end of the current Financial Year. Work on resistojets at RPE has been terminated. There are, however, residual EMR commitments to be honoured (at Oxford contracts AT/2057/038 and AT/2057/044, and at Southampton contract AT/2040/115). These commitments will be carried under work item 3E1.

FIELD 3D THE APPLICATION OF MATERIALS TO ROCKET MOTORS

47 Improvements in the ballistic performance of rockets are more likely to be achieved through reductions in the structural weight and reliability of components than through improvements in propellant performance. Current work covers rocket motor cases, refractory materials for nozzles and thermal insulants.

48 Structural Materials

Most of the work on motor bodies and highly stressed structural components is carried out under contract by BAJ with only limited supporting work at RPE and ERDE. The work covers high strength maraging steels, high strength aluminium alloys and carbon fibre composites. Associated welding and jointing techniques are also studied.

49 Nozzles

The grades of graphite used for many projects is becoming difficult to obtain and alternatives are being sought. Some promising materials have been found and are in course of full evaluation. Improved mechanical strengths are obtainable for the use of carbon/carbon composites which would save weight but currently have poor ablation resistance. Some promise of improvement has been shown by treatments which give a silicon carbide surface and this will be further explored.

50 Work will be reduced on the design and manufacture of pyrolytic graphite nozzles as the manufacturing principles are now well understood but assessment will continue in collaboration with the USA where the RPE product is being actively considered for future US motors.

51 For aluminised propellants tungsten throats are essential and new ways of depositing tungsten layers have been explored. A cheaper material using tungsten chloride has given much promise but cracking at the entry section of the throat developed in firing trials so that further work is needed.

52 Thermal Insulants

Work aimed at producing a more consistent and reliable asbestos/phenolic insulant using the ERDE patent fibres technique is giving products with less variability and better structural properties and this, together with work on glass fibre/phenolics and silicon/phenolics will continue. Some smoke formulations will also be evaluated.

FIELD 3E ROCKET EXHAUST AND PLUME TECHNOLOGY

53 Rocket Exhaust Properties

The need for reliable prediction and measurement of rocket exhaust plume properties as an essential aid to design of guidance and detection systems remains high. The predictive methods are now well founded in experiment and are proving invaluable for (i) calculations when measurements are prohibitively expensive or impractical, (ii) extrapolation of static test results to flight conditions and (iii) identifying means of controlling and modifying exhaust properties.

54 Major interest will continue to be centred on the IR radiation emitted by the exhaust and its application to the launch detection of enemy missiles, trajectory tracking, counter-measure missile homing and IR fusing. Plume structure predictions will be made with current mathematical models. Subsequent developments will include the use of program BAFL, capable of dealing with the base flow region important in determining in-flight forward hemisphere IR radiation for missiles with high base/nozzle exit area ratios, and program REP3, for predicting plume shock structures (including shock ignition). Methods for predicting spectral structures of IR bands will be improved for discrimination application. Experimental work on the effects of metal combustion inhibitors on plume IR signals will continue.

55 The changing needs for work on plume technology are reflected in certain work items; namely an increasing interest in exhaust luminosity and decreasing effort on microwave applications, but some Rf expertise will be maintained. The general systems requirements for the minimisation of exhaust luminosity from solid or liquid propellant motors, without excessive loss of ballistic performance, will be studied theoretically and experimentally in collaboration with RARDE, IMI and ERDE. These will include investigation of propellant energy, nozzle size and configuration, inert chamber components and possible new additives to suppress secondary combustion.

56 Currently predictions of many aspects of exhaust plumes are being requested for a considerable number of British and foreign rocket motor exhausts. Advice has also been sought, and no doubt will continue to be required, for similar data for aircraft engine exhausts, turbine exhausts and re-entry bodies.

57 Thrust Vector Control

This work is now terminated with the exception of a minor item (swivelling nozzles on the 160 mm bipropellant motor) which is carried on from last year as completion was delayed by staff shortages. Thereafter any further thrust vector control work required will be centred at IMI.

58 Smoke and Flame

Although most of the ERDE work on smokeless inhibitors and propellants is largely complete, work at RPE aimed at reducing the critical puff of smoke at end-of-burning will continue. A design of a charge with very small sliver has been completed. A sharp cut-off was obtained, as predicted, and probably some reduction in smoke at burn-out. Further extrusions are being made for comparison trials in a motor of the Blackcap type (used in Seawolf). The evaluation of such charges under fully representative conditions poses severe technical problems.

FIELD 3F ROCKET INSTRUMENTATION AND NON-DESTRUCTIVE TESTING

59 The requirement for high precision methods for the measurement of short duration thrusts and thrust alignment continues and demands new and exacting standards of rig design and calibration. A new hydraulic thrust calibration system is being proven which will cover the range up to 600 kN and be free from the trouble and expense of frequent recalibration. Even so, tests with a lower range experimental version indicate a probable accuracy of 1 part in 5000 which is only just sufficient for the current demand for thrust measurement to ±0.1% on site; further development may be necessary.

60 Higher standards of quality control and inspection of motors of complex design will demand a significant advance in non-destructive test techniques. Ultrasonic holographic methods have moved from the equipment development stage to experimental examination of samples and have already demonstrated the ability to delineate defects more clearly than other ultrasonic techniques. The present system involves scanning and optical processing, a rather slow process, but the development of a "real time" technique shows great promise as a powerful and feasible method of charge inspection.

61 The acoustic emission work is also moving from equipment development to sample testing, but it is too early to pronounce on its usefulness. It promises to be an extremely powerful technique. However, a large amount of work still remains to be done to ensure that results are correctly interpreted.

62 The NDT research work on Polaris first stage motors at RPE has suffered from switches in emphasis from one part of the motor to another. At present we are

concentrating on the parallel section where debonding problems are well known. It is hoped to demonstrate the use of through transmission to detect gas cracking but at the same time the possibility of working from inside the motor should be explored. An array of transducers along the conduit to steer the ultrasonic beam may be possible but space is limited in other directions so that imaging methods, including holography are severely curtailed. The sample motor available is in poor condition with no known propellant defects so work must be carried out with scaled laboratory specimens containing specified defects which, with suitable changes of ultrasonic wavelength, should give realistic results.

FIELD 3G EXPLOSIVES

63 Difficulties with the 155 mm shell filling programme led to the introduction of a new item last year on factors affecting the quality of RDX/TNT castings. Things have gone well and we now have a better understanding of at least some of the factors which may lead to failure. It has been found that rapid cooling of the melt results in the formation of an hitherto unknown TNT polymorph which may well be responsible for the cracking which occurs on ageing. The suppression of this crystal form by additives has been studied with useful results. The current programme will concentrate on attempts to obtain high strength castings with sufficient elasticity to absorb the stress due to thermal cycling. Valuable results on the effects of beeswax on the adhesion to the shell wall have also been obtained.

64 New plastic bonded explosives compositions have been prepared specifically for use as shaped charge fillings, for penetrating and for cratering warheads. Performance trials are now in progress and further optimisation will depend upon the degree of improvement achieved. Work on torpedo warheads has been concluded and is confined to the provision of charges to NCRE for further target trials. A new slurry explosive for cratering has been developed and is undergoing trials at RARDE. Further work will be done to improve the high and low temperature storage properties of these.

65 The evaluation work is directly related to the above and to the determination of shock at blast pressures of new compositions. Attempts to focus blast effects under water have been disappointing and will be discontinued unless some new more promising line of approach is found. Work on explosives for penetrating missiles (ie Martel) is also progressing more slowly than we would wish. Experience has shown that the shock of impact can in some instances cause immediate detonation or deflagration so that the proper performance is not achieved. However a ranking order of the tendency of individual explosives to respond in this way to shock does not correlate with projectile firings at AWRE and we shall need to understand the reasons for this before any further progress can be made.

66 The search for more stable and compatible detonants continues with emphasis being placed on tetrazole and nitrotetrazole salts. Silver nitrotetrazole has been evaluated and although it has greatly improved compatibility and stability when compared with lead and silver azides, its explosive performance is not fully adequate to meet requirements in very small detonators. As well as assessing other salts of the nitrotetrazole and tetrazole anions, further work will be directed towards developing combinations of two chemically stable explosives which can be used in these small detonators to give performance equivalent to the existing azide/tetryl combination. Work is being directed towards development of a new cap composition which will meet the manufacturing and functioning requirements for the new generation of small calibre weapons, and attempts are being made to produce lead azotetrazole in a form suitable for replacement of the stab sensitive L mixture and NOL130 by a single chemical entity rather than a complex mixture of ingredients.

67 The US Government has now signed an agreement allowing them to operate the ERDE process for the production of styphnic acid and lead styphnate for US military purposes. They already have a similar agreement for the ERDE process for lead azide RD1333. Such agreements bring us considerable returns in US co-operation and know-how in other areas.

FIELD 16 MATERIALS

68 Field 16J Non-Metallic Materials

For many defence applications polymeric materials are proving deficient in properties for the exacting conditions of use which they are expected to withstand. The ERDE programme aims to produce materials with improved properties for use as moderately high temperature, oil-resistant elastomers, as high strength flexibilised adhesives, and as matrix resins for carbon and other fibre composites. During 1973, novel flexibilised epoxy resins have been tested as matrix resins for CFRP with improvements of 15-20 per cent in shear strength over those given by composites made with unmodified resins. When used as an adhesive for CFRP/CFRP bonding, improvements of up to 100 per cent in the lap shear strengths have been obtained. Work is progressing to evaluate the long-term high temperature ageing behaviour and solvent resistance of these materials, and on the flexibilisation of high strength structural adhesives currently used as metal-to-metal adhesives. A major review of the progress of the work is planned for the end of 1974. The programme has produced a number of elastomers with superior properties to those possessed by commercially available rubbers, but the improvements are not sufficient to warrant commercial production.

69 ERDE continues to be responsible for UK administration of trials at the Joint Tropical Research Unit, Queensland, Australia, where the rocket motor devices trial is now nearing completion. When the complete results have been analysed, it should be possible to establish statistically-valid correlations between thermal history and standard meteorological data, and enable predictions to be made for the many other sites for which meteorological data is available but where it would not be practical to accumulate real-life data for ordnance stores. It should also provide a firm basis for defining the upper temperature limit which stores must withstand in service. Many of the results indicate that the present upper temperature limit is higher than necessary.

70 ERDE continues to evaluate new materials as they become available commercially so as to be able to advise designers on their suitability for use in service. As the properties and ageing behaviour of mouldings can depend critically on the moulding history, the effects of fabrication variables such as injection moulding pressure and temperature, use of reworked scrap and position and size of "gates" in the mould are being studied so that the significant parameters can be understood and defined as a basis for quality assurance inspection. In order to improve the resistance of thermoplastics to solvent and environmental stress cracking, fracture and crystallisation under these conditions are being examined in detail, and limiting operating stress values have been determined for a range of materials and solvents. During 1973, the phenomenon of "fingerprint" cracking has been observed in polycarbonate samples exposed under tropical conditions; as this is used in aircraft glazing, the phenomenon is being examined urgently.

71 During 1973 ERDE has become increasingly a centre of expertise consulted by the Ordnance Factories and Army Department R & D Establishments on problems of materials selection and for advice on the design and prototype manufacture of components in rubbers and plastics, much of it in support of projects. During the year many manufacturers have been disinclined, or unable, to take on limited run production

work for service equipments, either because of the complexity of the design or the difficulty of fabricating the material chosen for the store, or because the small numbers required are uneconomic for a commercial fabricator to produce. To ease this situation ERDE has, during 1973, undertaken the manufacture of 55 designs in rubbers and plastics, involving the production of over 50,000 components.

72 Field 16E Composite Materials

ERDE is concerned with the development of short fibre composites as distinct from those with continuous filaments. These have been shown to have a very high potential due to their ease of moulding from prepreg mats, to the low costs and to the high performance which can be achieved by ordering the fibres to follow the lines of stress. Very useful improvements in the initial fibre alignment process have been made over the year by the use of centrifugal techniques which increase the speed of processing and result in a better alignment. The improvement of alignment in turn permits a greater volume fraction of fibres to be used and so gives a further rise in performance. The current objective is to raise the fibre volume to 45% with carbon fibre and this will allow us to tackle such projects as the helicopter gear box casing.

73 The foreign mining company who have licenced our grading patents have now successfully built a plant under ERDE guidance and an inexpensive source of high grade asbestos fibres will become available for defence applications such as rocket nozzles, launcher tubes, etc. The expectation is that a gain of about twice the stiffness of the composite as compared with glass fibre can be achieved at lower cost.

74 Studies will continue on fabrication techniques and prototype mouldings made of a number of defence components such as rocket nozzles. As a result of increased interest in the aerospace industry in discontinuous carbon fibre composites a joint programme has been initiated with RAE and DR Mat 2 to provide a critical comparison of the strengths of continuous and discontinuous fibre composites.

75 Work on silicon carbide whisker reinforcement continues at a low level because the bulk of the work can be done by industrial labour. ERDE has ceased to prepare whiskers as our licencee has improved the process and has demonstrated a viable continuous production plant which is capable of producing high quality whiskers. Their cost will be proportionate to their usage and although it remains high at this time, the process is capable of producing cheap whiskers if there is sufficient commercial demand. ERDE work is concentrated on fabrication techniques with metals to produce composites in a form which require no further machining, and panels as large as 30 × 30 cm have been prepared with assistance from RAE. These showed an improved multi-hit capability and ballistic resistance to 7.6 mm and AP shot but further improvements will be required before composite armour becomes a practical proposition. Experimental cermet armours have also been prepared for BCRA and test panels of material suitable for turbine containment rings are currently being assessed by Rolls Royce.

THE DEVELOPMENT PROGRAMME

76 The detailed work programme is set out in Appendix G and the current position is summarised below. However there is one general comment which needs to be made on project management and prime contractorship as it affects a small Establishment such as RPE. Each project manager or prime contractor is concerned exclusively with one item in the programme and he naturally wants to monitor progress regularly and press for immediate action to avoid delays. However in an establishment such as RPE where there are only a few senior technical project staff and many projects, this

can result in so large a number of meetings and visits to the Establishment, that these senior staff are spending more time in discussing what they ought to be doing than they can actually devote to doing it. No-one likes to refuse to attend project meetings or to fail to entertain visitors but I would use the medium of this review to appeal to those concerned to recognise that their own best interests will be served by cutting down the meetings and keeping paper work to an absolute minimum, so that we can get on with the job.

77 The changes in quality assurance requirements are also causing us much concern. Responsibility for the quality control which previously fell on the QAD branches now falls to RPE and ERDE in their roles as design authority or as producers and this also will eat into the staff available to ensure that the quality standards comply with the exacting requirements of the QAD Authorities.

78 Under-Surface Launched Missile

Major changes in the performance requirements of this project have led us to recommend a change of propellant from extruded cordite to CDB. This has transferred some of the load from ERDE/RPE to IMI. However RPE will need to provide support, particularly in the area of thrust measurement under water and of underwater noise.

79 RS80

The volume of direct project work has been reduced but this programme, if it continues, will benefit considerably from the research work on complete motor studies under which the performance of various composite propellants will be compared in motor sizes directly appropriate to the RS80 project.

80 KH793

This continues to absorb a major share of the total RPE effort. It is broadly on schedule. Details of the project are provided separately for those who have a need to know.

81 Blowpipe - Crake Motor

The firing trials of the RPE design have now been successfully completed and the design sealed for production.

82 Lance

RPE is involved in both safety and storage trials aspects and is studying methods of emergency detanking of the propellants.

83 Helicopter Launched Missile CL834

A shortened version of the Blackcap motor which was so successful for Seawolf will be employed for this project. Design drawings are complete and preliminary firings have started.

84 Foreign Weapons

The major tasks on life assessment techniques for the Polaris motor have now been completed, but studies of NDT methods for the detection of flaws, and of gas evolution rates will continue at low priority. A service will continue to be required from both Establishments on such aspects as safety, OB trials, life assessment etc of foreign missiles.

85 Guns

The effort on guns has been increased. It now covers a team of 4 SSP at ERDE on the development of new propellants for the FMBT gun, the supply of the fine grist RDX which is required for this, and work on the development of combustible cartridge cases in conjunction with ROF Bishopton. Difficulties are being experienced with the last due to variations in the latex supply and a diminishing interest by the manufacturer in its production. Alternative sources are being sought but in the last resort ERDE will undertake manufacture.

86 Work is also done on the development of a new process for picrite for gun ammunition in aid of ROF Bishopton. Preliminary trials of the proposed process have worked satisfactorily and an extended 3 shift production run is currently in progress which should highlight any unforeseen difficulties, or validate the process.

87 Support for the ROFs

ERDE is required to supply bulk quantities of some minor chemicals to the ROFs, it assists them in safety and quality assurance matters and develops new processes and plant as required. Amongst the more important of the plant scale work is that on the development of new initiating and delay compositions where a very close liaison is maintained between research and production.

88 Post Design Services - Minor Projects

Both establishments have been, and will be involved in PDS work on a wide variety of projects, such as Seaslug (2), Swingfire, Rapier, Seadart, Crake, Seawolf etc. It is also necessary to carry out work to maintain a constant ballistic performance in cordites used in projects, to allow for the unpredictable minor variations which can result from changes in supply sources etc.

89 Miscellaneous

ERDE performs a variety of services which have no research content but which serve many projects and cannot be identified with one alone. Examples are service life assessment, compatibility and safety studies and hazard appraisal. Apart from the specific process development items mentioned above it acts as a supplier of bulk quantities of unusual or dangerous chemicals for many different uses, and also as a production centre for special moulded plastic or rubber components which are unobtainable from industry.

90 Work for Other Departments

This covers work for the DTI and Science Research Council at RPE, a group of 7 SSP working on special duties for the Foreign and Commonwealth Office at ERDE, and a variety of small tasks such as the advisory service to industry on adhesives and the maintenance of the British Calibration Service work on thermal conductivity until such time as it can be taken over by DTI. Full details of the deployments are given in Appendix E.

EXTRAMURAL EXPENDITURE

91 ERDE

(a) There are long standing contracts with Nobels Explosives Co for (i) research on cast double base propellants, mainly in support of IMI, Summerfield (£135,000 pa),

(ii) the improvement of small arms propellants (£29,000 pa) and (iii) research on propellants for power cartridges (£31,000 pa). Giving further support to Field 3 are three contracts with industry and Research Associations (£18,000 pa), and 18 agreements with Universities (£25,000 pa).

(b) On the Field 16 (Materials) side there are fifteen contracts with Universities (£30,000 pa) and three with Research Associations (£9,000 pa).

(c) Details are included in Appendix F under the relevant Work Packages.

92 RPE

During 1973/74 RPE spent £506K on EMR contracts and agreement; £425K was with industry mainly for hardware work at Bristol Aerojet, Banwell, and £81K with various Universities. The estimated total spend for the current year is expected to be £565K of which £505K will be with industry and £60K with Universities. Details are shown on the detailed Research Programme sheets under the relevant Work Packages. The main reason for the apparent increase is the transfer of funds from intramural to extramural headings for hardware from BAJ.

MANAGEMENT

Line Management Charts for ERDE and RPE are attached at Appendices A and B. Statistical statements for each are at Appendices C and D and the combined statement at Appendix E.

93 BUILDINGS AND EQUIPMENT

The uncertainties of rationalisation have led to the deferment of all betterment schemes other than those essential for immediate use. At ERDE work has essentially been limited to maintenance of existing buildings and only very minor changes - usually adaptation to house equipment - have been made in the last few year. However the replacement of the existing boilers in the North Site boiler house cannot be deferred indefinitely.

94 At RPE, rather more has been done, or is in hand, as a result of project needs. However many other important items have been deferred pending a decision on the future. These include a new test bed and the canteen. However the dynamic balancing facilities required for KH793 have been installed and the restoration of one firing site which is in very poor condition is planed by DOE. We are also proceeding with a small facility to study the behaviour of rocket motors fired under water.

95 The Elliott 503 Computer was dismantled in January of this year and will be replaced by the more versatile ICL 1904S. This will eventually have data links direct to the firing sites, and other points. It is hoped that it will be operational by the middle of the year.

96 During the year the very substantial collection of foreign rocketry, including an ME 163 rocket aircraft, a V2 and a Kamakaze plane have been transferred to the RAF Museum at Cosford. This relieves RPE of the problems of maintaining a museum behind a security fence and, will give the public access to an important historical collection.

97 STAFFING AND RECRUITMENT

There appears to be a reasonably good supply of high quality Ph.D's available in chemistry so that recruitment at the SSO level presents no problems. However the real needs of both establishments are for young graduates of rather less ability who will do the work of the old type EO, and who will not all expect to become high flyers with rapid promotion. Here there is a real difficulty as the starting salary we are able to offer is not at all competitive with industry. There is little we can do except hope for improvement but it must be recognised that we are currently failing to recruit such staff.

98 The situation is even worse at ASO level. The numbers of people with suitable O levels seeking employment is not large and they can, for example, find a higher starting salary in the clerical or executive grades. Here again we can do nothing but hope. In the meantime we are having to use more senior staff to do the more menial tasks which is wholly inefficient. Because we are currently offering too little to get a job done, we are finishing up paying too much by using a higher grade.

99 The recruitment of industrials remains very difficult at both sites, but is especially difficult at RPE. The three-day week, with its resulting loss of over-time encouraged a drift outwards to better paid jobs and we are not able to fill the gap. RPE is an isolated Establishment and apart from the low relative wages our industrials have to pay for the transport we provide to bring them to work. Others in the area are offering free transport as well as many other perks such as free lunches, in addition to a substantially higher wage. If this trend continues for much longer the ability of RPE to sustain its programme will be restricted by the lack of supporting staff available. At present it relies heavily on older staff and the outlook for some years ahead is therefore bleak.

100 ERDE is also suffering from an inability to recruit. However a new GLC estate is being built in Waltham Abbey so that our prospects here may be better.

101 CAREER PROSPECTS

Staff Career Panels have functioned at both centres over the year, and Job Appraisal reviews have been completed down to PSO level and will be continuing. Both have been useful to both staff and management and, apart from internal moves, some staff from RPE have been moved elsewhere and limited exchanges between ERDE and RPE have been made.

102 The Job Appraisal reviews have highlighted a perennial problem - that of career opportunities for the specialist. The good PSO who has a wide range of experience in other Establishments and HQ has a wide range of opportunities for promotion but those of the good specialist in, for example, non-metallic materials, explosives, rocket design or liquid propellants, has a very limited horizon depending on the promotion or retirement of a very few individuals. If all are to be given an equal opportunity to advance their careers we will have no specialists and be unable to function. Some means must be found which will enable us to offer an adequate career to such people.

APPENDIX A

LINE MANAGEMENT

CHART OF ERDE

18/10/2022

LINE MANAGEMENT CHART - ERDE

Director
Dr L J Bellamy CBE (Under Sec)

Deputy Director
Mr G K Adams (DCSO)

Safety Officer	Chief Engineer	Secretary
Mr J V Griffiths (PSO)	Mr R Fisher (PPTO) Other SSP 9	Mr S F M Whiteside (Principal)

Propellants 1 (Colloidal)	Propellants 2 (Composite)	Process Research	Explosives	Non-Metallic Materials	General Chemistry Information Services Instrumentation
Dr C G Lawson (SPSO)	Mr P R Freeman (SPSO)	Mr H Ziebland (SPSO) Dr A W H Pryde (SPSO Merit)	Dr C A Beck (SPSO) Mr G W C Taylor (SPSO Merit)	Dr B L Hollingsworth (SPSO) Dr D H Richards (SPSO Merit)	Dr A R Osborn (SPSO) Dr N Uri (SPSO Merit)
Other SSP 21	Other SSP 20	Other SSP 21	Other SSP 30	Other SSP 17	Other SSP 33

A1

APPENDIX B

LINE MANAGEMENT

CHART OF RPE

LINE MANAGEMENT CHART - RPE

Director
Dr L J Bellamy CBE (Under Sec)

Deputy Director
Dr G H S Young (CSO(B))

Safety/TA Director
Lt Cdr W E D Hull (HSO)

Secretary
Mr W A Lawler (Principal)

Division L

Research and Development of Liquid Propellant Rocket Engines

Dr J D Lewis (SPSO)

20 Other SSP

Division S

Research and Development of Solid Propellant Rocket Motors

Mr N J Morris (SPSO)

29 Other SSP

Division C

Chemistry and Applied Physics

Dr J Powling (SPSO)
Mr D S Dean (SPSO-IM)

33 Other SSP

Division E

Engineering and Technical Facilities

Mr F Burnett (AD Eng)

21 Other SSP

B1

STATISTICAL STATEMENT - ATTRIBUTION OF RESOURCES - ERDE

	1972/73		1973/74		1974/75		1975/76		1976/77	
	RDS	£K	SSP	£K	SSP	£K	SSP	£K	SSP	£K
A. RESEARCH (DEFENCE)										
MAJOR FIELD 3 - Solid Propellants	40.0	820	41.0	920	38.9	910	39.1	930	39.3	940
Explosives and Initiatory Devices	27.0	380	27.0	370	26.6	380	27.0	390	27.0	400
MAJOR FIELD 16 - Materials	36.0	500	39.5	580	36.0	530	36.0	540	36.0	550
TOTAL FOR INTRAMURAL RESEARCH	103.0	1,700	107.5	1,870	101.5	1,820	102.1	1,860	102.3	1,890
Extramural Research Contracts and Agreements	-	225	-	235.5	-	279.5	-	245.5	-	246
TOTAL RESEARCH - FUNDED BY ERDE	103.0	1,925	107.5	2,105.5	101.5	2,099.5	102.1	2,105.5	102.3	2,136
B. DEVELOPMENT (DEFENCE)										
(i) Systems Controller - MGO										
Propellants										
Rocket Projects Support and PDS	-	-	3.25	48	1.75	35	1.75	35	-	-
Gun Projects Support	-	-	2.5	80	3.0	95	2.75	95	-	-
Quality Assurance and Service Life Extension	-	-	1.75	24	1.75	25	1.5	25	-	-
Explosives										
Hazard Studies, Compatibility, Stability	-	-	0.75	10	1.0	15	1.25	20	-	-
Materials										
Plastics and Rubbers Development and PDS	-	-	1.25	8	2.5	15	2.75	15	-	-
TOTAL FOR SYSTEMS CONTROLLER	10.0	180	9.5	170	10.0	185	10.0	190	10.0	200
(ii) Systems Controller - C of N										
Propellants										
Polaris	-	-	0.5	22	0.25	15	0.25	15	-	-
Rocket Projects Support and PDS	-	-	1.5	28	1.0	25	1.25	25	-	-
Gun Projects Support	-	-	-	-	0.25	10	0.5	10	-	-
Quality Assurance and Service Life Extension	-	-	1.75	25	1.75	25	2.0	25	-	-
Explosives										
Hazard Studies, Compatibility, Stability	-	-	0.75	13	1.0	15	1.0	15	-	-
TOTAL FOR SYSTEMS CONTROLLER	4.0	85	4.5	88	4.25	90	5.0	90	5.0	95

STATISTICAL TREATMENT - ATTRIBUTION OF RESOURCES - RDRE

	1972/73		1973/74		1974/75		1975/76		1976/77	
	RDE	AE	RDE	AE	RDE	AE	RDE	AE	RDE	AE
B. DEVELOPMENT (DEFENCE) Cont'd										
(iii) Systems Controller - CA										
MOD's Gun Ammunition										
Propellants										
Rocket Projects Support	-	-	-	-	0.25	10	0.25	10	-	-
Quality Assurance and Service Life Extension	-	-	0.25	6	-	-	-	-	-	-
Explosives	-	-	-	-	1.0	15	1.0	15	-	-
Hazard Studies, Compatibility, Stability	-	-	0.75	12	1.0	15	0.75	15	-	-
TOTAL FOR SYSTEMS CONTROLLED	2.0	34	1.0	18	2.25	40	2.0	40	2.0	40
(iv) Systems Controller - MO/RDF's										
Propellants										
Rocket Projects Support and PDG	-	-	0.5	20	2.25	45	2.0	45	-	-
Gun Propellants and Gun Projects Support	-	-	3.0	50	2.75	30	2.5	30	-	-
Synthesis and Analysis	-	-	0.5	4	1.5	20	1.5	20	-	-
Explosives										
Initiators and Delay Compositions	-	-	3.25	40	4.0	55	4.0	55	-	-
TOTAL FOR SYSTEMS CONTROLLED	9.0	140	7.25	114	10.5	170	10.0	170	10.0	180
(v) Future work - Not yet defined										
TOTAL DEVELOPMENT (DEFENCE)	25.0	419	22.25	390	27.0	485	27.0	490	27.0	515
C. OTHER WORK										
Special Services for Foreign and Commonwealth Office	6.0	87	7.0	100	7.0	100	7.0	100	7.0	105
Advisory Service on Adhesion	1.0	6	0.5	5	0.5	5	0.5	5	0.5	5
Maintenance of BCS Centre for Thermal Measurements	2.0	21	-	5	1.0	11	1.0	11	1.0	11
Assistance to Overseas Sales	0.5	8	1.0	12	0.5	12	-	-	-	-
Setting up of Capital Facilities	-	54	-	36	-	43	-	48	-	42
TOTAL - OTHER WORK	9.5	176	8.5	154	9.0	169	8.5	162	8.5	163
TOTAL - DIRECT R AND D (INTRAMURAL)	137.5	2,315	138.25	2,414	137.5	2,474	137.6	2,512	137.8	2,568
Directing Staff and Common Services	24.0	-	26.5	-	26.5	-	26.5	-	26.5	-
GRAND TOTAL - INTRAMURAL R AND D	161.5	2,315	164.75	2,414	164.0	2,474	164.1	2,512	164.3	2,568
Extramural Research Contracts Funded by ERDE	-	225	-	235.5	-	279.5	-	245.5	-	246
TOTAL - R AND D FUNDED BY ERDE	161.5	2,540	164.75	2,649.5	164.0	2,753.5	164.1	2,757.5	164.3	2,810

DEVELOPMENT (DEFENCE) - SUMMARY OF SSP EFFORT AND EXPENDITURE

Item No.	Project		SSP			
			1973/74	1974/75	1975/76	1976/77
1	Blowpipe	RPE	2.8	2.4	1.8	1.1
2	Lance		0.6	2.0	2.0	1.0
3	RS 80		0.5	0.2	2.3	2.3
4	KH 793		21.0	20.5	16.0	14.0
5	Under-surface launched missile		3.5	3.6	4.5	5.0
6	Seawolf		1.6	0.9	0.2	0.1
7	Seaskua CL 834		0.4	1.6	0.8	0.5
8	SG 357		0.3	1.3	2.0	2.2
9	Skynet II/III		1.2	0.4	0.4	0.3
10	Power cartridges		2.6	2.6	2.5	2.7
11	Instrumentation and test equipment		1.3	2.4	2.2	2.5
12	Sundry Minor Projects Bloodhound II Thunderbird II Red Top Firestreak 2" Aircraft Rocket Knebworth USD 501 Stiletto Target Hawkswing		5.0	4.0	4.1	4.4
13	Future projects, not yet defined		-	-	-	4.4
	TOTAL	RPE	40.8	41.9	38.8	40.5
14	Plastics and rubbers	ERDE	1.25	2.5	2.75	2.75
15	Polaris		0.5	0.25	0.25	0.25
16	MRCA Gun		-	0.25	0.25	0.25
17	Gun propellants - Picrite		1.5	1.5	1.5	1.5
18	Synthesis and analysis		0.5	1.5	1.5	1.5
19	Initiators and delay compositions		3.25	4.0	4.0	4.0
20	Rocket project support		4.0	3.5	3.5	3.5
	C/fwd		11.0	13.5	13.75	13.75

6	1976/77
	-
	8.5
	6.5
	0

APPENDIX F

DETAILED RESEARCH PROGRAMME SHEETS

RESEARCH PROGRAMME SHEET

Package Reference No: 3A/74

TITLE	Responsible Authority HQ Director(s)		Previous 1973/74	Current 74/75	+1 75/76	+2 76/77	To Objective
SOLID PROPELLANTS	Establishment(s) ERDE/RPE	TOTALS (£k)	922.5	959	943.5	953	
		MSF (a)	31	31.4	31.0	31.0	ERDE
		Intramural (£k) (b)	740	780	790	800	ERDE
		Extramural (£k) (c)	182.5	179	153.5	153	ERDE

OBJECTIVE(S):

To study all types of solid propellants for rocket motors, gas generators, power cartridges and guns in order to improve their overall performance and to provide an adequate range of compositions to meet future needs.

To maintain expertise to enable the Department to fulfil its responsibilities to the Royal Ordnance Factories and to the Ordnance Board in respect of both U.K. and foreign weapons.

WORK ITEMS

Ref & Title:					
3A1 Double Base Rocket Propellant	(a)	10.5	14.5	14.5	14.5
Extruded Propellants (Rocket Cordites)	(b)	245	320	320	330
The range of standard rocket cordites will be maintained and will continue to be improved and extended as obsolescent compositions are replaced and further compositions, with better performance and Service life, and developed to meet new requirements from RPE and elsewhere.	(c)	119.5	142	122.5	123
Fast-burning, thin-web charges with improved mechanical strength are needed for future anti-tank weapons. Novel designs will be investigated; solvent processing will be employed to achieve better physical properties (1976).					
New techniques of solvent-treatment and compositing will be investigated with the aim of reducing the brittleness of star-centred charges if effort permits (1976 or later).					
New ballistic modifiers may be investigated with the aim of extending the range of burning rate/pressure plateaux currently available, particularly cupric succinate (1975). An alternative nitric ester (TMETN) may also be examined (1976). The nitrocellulose situation is being appraised, particularly to ensure continuity of ERDE expertise.					
As a start to work on improved processing methods, foreign processing will be reviewed.					
Cast Propellants (CDB)					
Further evaluation between NEC/SRS/ERDE of F452/702/4 case-bondable boost propellant will continue (1974). A propellant with a higher plateau burning rate will be more extensively evaluated (1975). Trials of various compositions for rocket jet luminosity will continue (1975). Cupric succinate platonising catalyst will be evaluated in a sustainer composition. Further minor improvements in processing techniques will be studied (pressure curing, automatic casting). A manual on ERDE CDB propellants will be prepared (1974/5). Work on a much cheaper and less laborious method of casting powder ballistic assessment will continue (1976). Possible methods of reducing the hazard of casting liquids will be studied (1974).					
Rheology: the dynamic mechanical properties of double base propellants will be measured over a wide range of strain rate and temperature; correlations will be sought between the results of these measurements and the usage characteristics of propellant charges in rocket motors. A comparison will be made between compressive and tensile test methods for the measurement of propellant modulus.					
Synthesis of ingredients for propellants, studies of incompatibility, X-ray crystallographic work on ballistic modifiers, and analysis of double-base propellants will continue.					

NOTES (1) Draw a line under each Work Item. (2) Give (a), (b) & (c) figures for each work item.
(3) Further Work Items should be entered on a Continuation Sheet.

TITLE: SOLID PROPELLANTS

WORK ITEMS		DATE: Previous 1973/74	Current 74/75	75/76	76/77	To Completion
Ref. & Title: 3A2 Rubbery Composite Rocket Propellants						
Work will be continued on castable rubbery propellants based on hydroxy-terminated polybutadiene (HTPB) binders.	(a)	7.5	10.0	9.5	11.5	
Various types and combinations of HTPB prepolymer, curative and bonding agent will be assessed in gumstocks and propellants so as to provide the data required for the selection of binder systems giving the best compromise between propellant mechanical properties, processability and cost (1976).	(b)	160	200	250	300	
Propellant compositions based on HTPB will be formulated, manufactured and assessed using a variety of burning rate catalysts, coolants, oxidant particle sizes and size distributions so as to determine the effect of compositional variants on the properties of uncured slurries and on the mechanical, ballistic and storage behaviour of cured propellants. The aim of this study is to provide a range of "on the shelf" compositions with known characteristics covering as wide a range of burning rates as possible (1978).	(c)	4.0	4.0	4.5	4.5	
The effect of the precise nature and source of propellant ingredients will be examined to enable adequate quality control procedures to be established. Quality control and manufacturing methods will be developed and specified (1978).						
Suitable HTPB compositions will be developed and filled into motors of various sizes for usage trials to demonstrate the capability of this type of propellant for meeting Service requirements (continuing item).						
Copolymers of vinyl ferrocene and butadiene terminated with carboxyl or hydroxyl groups will be made on a sufficiently large scale for their assessment as binders with built-in burning rate catalyst (1976).						
The solvent/non-solvent precipitation method for the production of sub-micron size ammonium perchlorate will be modified so as to eliminate coatings which react with isocyanate curatives. The process will be scaled up to the extent needed to provide sufficient quantities of this oxidant for assessment in HTPB propellants (1976).						
The dynamic mechanical behaviour of rubbery propellants over a wide range of strain rates and temperature will be measured and results will be correlated with conventional rheological measurements and rocket motor behaviour (1978).						
3A3 Plastic Rocket Propellants	(a)	4.5	3.9	4.0	2.0	
Compositions will be selected and optimised to meet the motor design requirements of RPE and others. Small batches of these compositions will be manufactured and assessed. Support will be given to ROF Bridgwater for all compositions currently in use (continuing item).	(b)	170	190	150	100	
The effect of manufacturing and compositional variables on ballistic, physical and storage properties will be systematically assessed and correlations will be obtained between measured mechanical parameters and usage characteristics determined from motor trials (1976).	(c)	5.0	4.0	4.5	3.5	
The low temperature capability of plastic propellant can be considerably improved by the use of a binder based on plasticised polyisoprene instead of polyisobutene. The high viscosity of this new binder requires a modification to normal binder preparation and a method suitable for large-scale processing will be developed. Compositions of this type covering a wide range of burning rates will be formulated, manufactured and assessed. A decision as to whether or not work on this type of propellant will be continued, will be made in 1976.						
The possibility of developing a process for isolating sub-micron ammonium perchlorate from the product of a fluid energy will be investigated.						
3A4 Gun Propellants	(a)	3.0	1.0	1.0	1.0	
The main effort on gun propellants is devoted to development for the FMBT gun.	(b)	50	30	30	30	
Collaboration will be maintained with RARDE in the development and supply of propellants for use in tank guns in conjunction with combustible charge containers so as to optimise barrel erosion and overall performance. Particular attention will be paid to temperature coefficients with the aim	(c)	24	29	22	22	

RESEARCH PROGRAMME SHEET (Continuation Sheet No)

Package Reference No: 5A/74

TITLE: SOLID PROPELLANTS

WORK ITEMS		YEARS: Previous 1973/74	Current 74/75	+1 75/76	+2 76/77	To Objective
Ref. & Title: 3A4 Gun Propellants (continued) of improving ballistic prediction and accuracy over the wide Service temperature range for Land Service guns. Due to the probable replacement of displacement type nitrocellulose by the mechanically nitrated type, re-formulations of current compositions will be manufactured and tested (continuous). The current process for the manufacture of combustible charge containers needs improvement and alternative styrene/butadiene resins will be evaluated. The use of RDX to replace nitrocellulose will be investigated with the aim of improving temperature resistance and minimising NG absorption (1976). Supply of experimental small arms propellants by NEC and ERDE to RSAF as required. The development of small arms propellants with improved performance, subject to barrel wear requirements. Emphasis will be placed on improvements in bulk density and ingredients which increase the force constant without increasing flame temperature (1975). A copy will be made of features of MRCA gun propellants, which have an unusual negative temperature coefficient of ballistics above about 45°C (1976). A new closed vessel equipment is working well; quartz transducers for use over a temperature range will be introduced (1974) and methods of assessing new high-energy propellants reviewed with RARDE.	(a) (b) (c)					
3A5 High Temperature Resistant Propellants See under 3B9; Gas Generators and Power Cartridges	(a) (b) (c)	- - 30	- - -	- - -	- - -	
3A6 Quality Assurance Included under Work Items 3A1 to 3A4, as appropriate, from 1974/75 onwards.	(a) (b) (c)	4.5 90 -	- - -	- - -	- - -	
3A7 Hazard Evaluation and Sensitiveness Studies on the sensitiveness and potential hazard of all new propellants developed within ERDE and provision of data for safety certificates covering such materials when they pass to the ROFs for production. Advising other Government Departments and Establishments on safety aspects of work with propellants and co-ordination of sensitiveness testing methods through the Sensitiveness Collaboration Committee. Work directed towards the improvement of methods of assessment of quantity-distance categorisation of propellants (continuous). Factors affecting the vulnerability of rocket motors to fragment and bullet attack are being investigated. A preliminary survey of known UK fragment attack trials will be issued (1974) and firings of idealised fragments from a smooth bore gun against representative propellant and rocket motor casing materials will be completed (1974). Further work in collaboration with RPE will involve firings against model scale rocket motors (1975), and will possibly later involve firing against full size rocket motors. This work is co-ordinated by a Working Party and involves DG Ships, DN Ord S, Ordnance Board and others.	(a) (b) (c)	1.0 25 -	2.0 40 -	2.0 40 -	2.0 40 -	

	University/Contractor	Agreement or Contract No	Estimated Payments 1974/75
			£K
EXTRAMURAL - UNIVERSITIES			
ERDE			
3A1 Study of Propellant Casting	Aston	AT/2097/021	1.1
Self-heating and Criticality in Explosive Decompositions	Leeds	AT/2062/052	2.9
Oxides of Nitrogen - Stabiliser Interactions	Heriot Watt	AT/2195/02	1.0
			5.0
3A2 Properties of Ammonium Perchlorate	Aberystwyth	AT/2110/05	1.0
High Frequency Dynamic Characteristics of Rocket Propellants	Umist	AT/2044/051	3.0
			4.0
3A3 Effect of Transition Metal Compounds on Odixation and Combustion of Olefinic Polymers	City	AT/2090/012	1.0
Mixing of Composite Propellants	Salford	AT/2101/012	3.0
			4.0
	Total - Universities		13.0
EXTRAMURAL - INDUSTRY			
ERDE			
3A1 CDB Propellants	Nobels Explosives Co		137
3A4 Small Arms Propellants	Nobels Explosives Co	KA/82A/180	29
	Total - Industry		166
	GRAND TOTAL		179

Classification: SECRET

RESEARCH PROGRAMME SHEET							Package Reference No: 3B/74
TITLE The Application of Solid Propellants to Rocket Motors, Gas Generators and Power Cartridges	Responsible Authority HQ Director(s) DRArm		Previous 1973/4	Current 1974/5	+1 1975/6	+2 1976/7	
	Establishment(s) ERDE-RPE	TOTALS (£k)	314	427	433	426	
OBJECTIVE(S): 1 To establish technology for solid propellant rocket motors mainly for use in tactical weapons, but with some limited space application. 2 To establish technology for the use of solid propellants in gas generators and power cartridges. 3 To maintain expertise to advise the Royal Ordnance Factories and the Ordnance Board in respect of U.K. designed weapons. 4 To advise the Service Authorities about the properties and serviceability of rocket propelled weapons containing solid propellants purchased from foreign suppliers.		SSP (a)	4.2 7.5	4.4 10.2	5.0 9.3	5.0 8.7	ERDE RPE
		Intramural (£k) (b)	65 220	70 277	80 258	80 240	ERDE RPE
		Extramural (£k) (c)	- 29	39 41	31 64	31 75	ERDE RPE

WORK ITEMS

Ref & Title:						
3B2 Ignition Imp motors will be used as the standard igniters in a programme designed to investigate the role of hot particles in the ignition of solid propellant motors. In initial experiments a basic plastic propellant will be used followed by compositions containing known amounts, and known particle size ranges, of highly refractory materials. The particulate content of the motor efflux will be determined to establish whether the original particle size is maintained during combustion (1975). The Imp motors will also be used to ignite 50 mm aircraft rocket motors and the efficacy of particulate matter on the ignition of PU (extruded cordite) propellant will be evaluated (1975). Experiments with other small motors filled with other types of propellant will start towards the end of the year (1976). Work at Cranfield Institute of Technology will use pyrotechnic compositions SR44 and SR371C and will attempt to establish the fraction of the total heat generated by the igniter which is absorbed by the propellant surface and the fraction and particle size of the solid matter captured by the propellant surface. Measurements of the surface heat fluxes in the different modes of heat transfer will also be made (1975). Work aimed at the reduction of sensitiveness of SR44 by the use of additives will be undertaken (1975).	(a)	0.8	3.0	3.0	3.0	RPE
	(b)	27	71	69	69	RPE
	(c)	4	4	-	-	RPE
3B3 Inhibition and Case-Bonding of Propellant Charges OB-type assessment trials of low-smoke polyacetal and polyacetal cellulose acetate moulded inhibitors, used in conjunction with Swingfire-type CDB propellant charges, will be completed and reported (1974). Castable minimum smoke polyurethane potting compositions for the inhibition of small-extruded charges will be optimised (1974). The tape wrapping method for inhibiting DB charges will be examined and suitable adhesives checked. Improved ethyl cellulose inhibitor formulations will be manufactured and assessed with the aim of reducing smoke from cordite charges (1975). Evaluation of loaded CA and EC compositions and production of experimental CA and EC inhibitors. Preliminary assessment of the alternative techniques for applying Silcoset as an inhibitor to radial-burning cordite charges is complete and charges are being prepared for environmental trials, using pre-formed tubing (1975). As an alternative to the stress-relief technique, tape-winding has been selected for development particularly for inhibition of large diameter extruded charges.	(a)	1.4 0.4	1.3 1.0	2.0 1.0	2.0 1.0	ERDE RPE
	(b)	20 15	20 26	30 24	30 25	ERDE RPE
	(c)	-	-	-	-	

NOTES (1) Draw a line under each Work Item. (2) Give (a), (b) & (c) figures for each work item.
(3) Further Work Items should be entered on a Continuation Sheet.

RESEARCH PROGRAMME SHEET (Continuation Sheet No. 1)

Package Reference Number: 3B/74

TITLE:
The Application of Solid Propellants to Rocket Motors, Gas Generators and Power Cartridges

WORK ITEMS		YEARS: Previous 1973/4	Current 1974/5	+1 1975/6	+2 1976/7	
Ref. & Title: 3B4 Combustion, Unstable Burning, Erosive Burning	(a)	4.7	2.2	2.2	2.2	RPE
The combustion instability problem of the Crake second stage has been resolved by a minor change in conduit design but some areas of doubt remain and the motor will continue to be used to obtain general data on the effect of charge design on instability (1974).	(b)	124	82	84	85	RPE
Dimensional control of extruded charges becomes critical at high loading densities and low conduit to throat ratios and a better knowledge of the variability of the dimensions of extruded charges is essential. It is proposed to accumulate such data for charges from both short and long parallel dies.	(c)	8	7	16	17	RPE
The combustion instability characteristics of VU propellant will be studied in some detail using the T burner. The effect of minor compositional changes, such as the addition of carbon or copper oxide or the partial removal of lead compounds, and the possible differences between cast and extruded propellant will be measured (1974).						
PU propellant has somewhat different instability characteristics than VU and because of evidence from the Wagtail motor the effect of batch-to-batch variations will be studied (1974).						
Following the problems of combustion instability experienced with the Raven XI motor a systematic study will be made using a modified T burner. Factors to be investigated include changes in propellant formulation especially the quantity of aluminium, operating pressure, the effect of tube liners and changes in head-end geometry such as the addition of acoustic baffles (1974). The effect of changes in the type of aluminium added will be studied at a later stage (1975).						
A number of project motors will be assessed for signs of instability and some work concerned with the use of baffles will be undertaken. Measurements will also be made of the burning rate under conditions of erosive burning, acoustic erosivity and pressure coupled instability (1975). Some work on an aluminised CTPB propellant will be completed by measurements of the burning rate under erosive conditions (1974).						
The U.S. computer program on the prediction of acoustic modes in rocket motors will continue to be applied to the analysis of complex modes. Because of the change of computer at the RPE, work concerned with modifications to the data reduction system used at present will be required. (Target, Autumn 1974).						
An EMR study on "Combustion instability of solid propellants" at Sheffield University is proposed to give some theoretical backing to the largely experimental programme at the RPE. This will study the interpretation of propellant burning rate data measured under a variety of ballistic conditions including combustion instability and erosion.						
The study of the effect of flaws on motor burning will be extended to include HTPB propellant and repair techniques will be evaluated (1974).						
3B5 Mechanical Properties of Propellant Charges	(a)	1.1	0.3	0.1	-	RPE
In association with Stress Engineering Services Ltd., the technique of measuring stress in case-bonded propellant charges by means of miniature photoelastic stress inclusion gauges will be further developed and applied to the measurement of stress distribution in certain types of charge design (1976). This technique will subsequently be applied to project motors during controlled storage (1977).	(b)	36	19	5	-	RPE
Annealed and non-annealed charges from the same extrusion lot have been prepared, and drop trials of charges conditions to -32°C are programmed for the ETC. The trials will be extended by the inclusion of charges subjected to solvent processing in the conduit, as well as to other propellant compositions. This is a collaborative exercise between ERDE, RPE and ROF Bishopton.	(c)	- 9	8 2	- 5	- 4	ERDE *

RESEARCH PROGRAMME SHEET (Continuation Sheet No. 2)

Package Reference Number: 3B/74

TITLE:

The Application of Solid Propellants to Rocket Motors, Gas Generators and Power Cartridges.

WORK ITEMS		YEARS Previous 1973/4	Current 1974/5	+1 1975/6	+2 1976/7	
Ref. & Title: 3B7 Complete Motor Studies						
Trials in 125 mm motors will be carried out on various types of composite propellant (polyisobutene and polyisoprene plastic propellants. HTPB and CTPB rubbery propellants) with the object of obtaining an assessment of usage characteristics under strictly comparable conditions. Initially low temperature firing limits will be determined using similar charge shapes and propellants of similar burning rate; both fully case-bonded and stress-relieved charges will be investigated (1976).	(a)	1.8 0.4	2.0 3.3	2.0 2.6	2.0 2.0	ERDE RPE
	(b)	25 14	30 63	30 60	30 43	ERDE RPE
	(c)	8	23	38	49	RPE
An HTPB composition with ballistics and mechanical properties suitable for the RS80 project will be filled into 200 mm and 264 mm motors which will be subjected to appropriate firing, storage and temperature cycling trials to demonstrate the capability of this composition for meeting the Service requirements (1974).						
CTPB Linnet The environmental trials have been completed successfully with the exception of the vibration trial which has been delayed by the need to manufacture a suitable holding rig and by motor filling.						
The reproducibility trial has been completed and results are being assessed. The value of the trial may have been affected by the withdrawal of 5 motor tubes for another project and the loss of 4 motors rejected after filling due to severe damage to "boots". (Completed by end of 1974).						
160 mm Bipropellant Motor Work on the 160 mm bipropellant motor has been held up by various difficulties. The original insulation was butyl rubber and this was inadequate in erosion resistance. An attempt to fill a motor tube lined with Hypalon with a thin butyl rubber overlay was unsuccessful. When these problems have been overcome, filling and firing motors will be resumed. Swivelling nozzles will be fitted to some motors to complete the RPE thrust vector control programme (1976).						
Short Burning-time Motors Initial experiments on effects of high acceleration are being prepared using a modified Crake motor capable of generating accelerations of the order of 1000 g and terminal velocities of 200 m/sec. Attempts will be made to assess methods of measurement of total impulse, velocity and thrust for motors with burning times less than 10 m/sec. Simultaneously, assessments are being made of designs to achieve higher velocities and accelerations in shorter burning times.						
HTPB Propellant Motor Work has started on a motor of 260 mm diameter for trials with HTPB propellant. It is proposed to simulate a scaled version of the RS80 motor. Manufacture of motor hardware has started at Bristol Aerojet Ltd. The operating pressure will be 16 MN/m^2 with a burning time of about 2 sec. It is intended to fill 12 motors for evaluation over the temperature range -40 to +60°C (1975).						
3B8 Service Life Extension						
A paper on this subject will be prepared for the TTCP/W4 Sub-Group, based on experience gained with current in-Service solid propellant motors. (Continuing).						
3B9 Gas Generators and Power Cartridges	(a)	1.0 0.1	1.1 0.4	1.0 0.4	1.0 0.5	ERDE RPE
The development of new types of propellant charge for GW gas generators will continue, including slow-burning CDB containing RDX. The main aims are to achieve cleaner gases and longer Service life. These propellants will be inhibited with appropriate new minimum-smoke inhibitors.	(b)	20 4	20 16	20 15	20 18	ERDE RPE
The development of HMX/organic polymer propellants will continue with the object of achieving more reliable and longer-life compositions for use in airborne power cartridges subject to aerodynamic or other heating. Following study of the basic formulation principles, work will now concentrate on improvement and scale-up of processing methods and establishing the range of ballistic, mechanical and storage properties achievable (1976). These propellants are used in ejector release units being developed by NEC under DA Arm contracts, and for the IPN emergency power unit for MRCA.	(c)	-	31	31	31	ERDE
The evaluation of propellant and inhibitors as replacements for the existing smoky and short lived gas generators in service will continue.						

RESEARCH PROGRAMME SHEET (Continuation Sheet No. 3)

Programme Reference Number: 3B/74

Title:

The Application of Solid Propellants to Rocket Motors, Gas Generators and Power Cartridges.

			Estimated 1973/74	Estimated 1974/75	Estimated 1975/76	Estimated 1976/77	
	MAIN ITEMS						
	Ref. & Title: Nine months' storage at 50°C of EI charges inhibited with various materials has been completed. Other materials will be evaluated as they become available from trade or EMDE.						
	3B10 Rocket Motor and Propellant Manual	(a)	-	-	-	-	
		(b)	-	-	-	-	
	See Research Programme Introduction, Page 4, paragraph 22.	(c)	-	5	5	5	RPE

Extramural - Universities	University/Contractor	Agreement or Contract No.	Estimated Payments 1974/75 £K
RPE			
3B2 Ignition research	Cranfield Institute of Technology	AT/2028/074	4
3B4 Properties of anhydrous perchloric acid	Royal Holloway	AT/2089/010	1
Combustion instability	Sheffield	AT/2031/065	2
			3
3B5 Failure mechanisms - rubbery propellants	Surrey	Not yet placed	2
	TOTAL UNIVERSITIES		9
Extramural - Industry			
RPE			
3B4 Design and Development of solid propellant rocket motor hardware	Bristol Aerojet	K/50B/94	4
ERDE			
*3B5 Photoelastic strain gauges	Stress Engineering Services	K/GW42B/155	8
RPE			
3B7 Design and Development of solid propellant rocket motor hardware	Bristol Aerojet	K/50B/94	23
ERDE			
3B9 Power Cartridges	Nobels Explosives Co.	KRF/44	31
RPE			
3B10 Preparation of Rocket Motor and Propellant Manual	Not yet placed	-	5
	TOTAL INDUSTRY		71
	GRAND TOTAL		80

* Contract K/GW42B/155 Funds to cover the extension of this contract in 1975/6 and 1976/7 will be transferred from RPE to ERDE.

RESEARCH PROGRAMME SHEET

Package Reference No: 3C/7A

TITLE
THE APPLICATION OF LIQUID PROPELLANTS TO ROCKET MOTORS

Responsible Authority (& Establishment(s)): DGW RAE

		Previous 1973/4	Current 1974/5	at 1975/6	at 1976/7	
Establishment(s) EXPLOSIVES	TOTALS (£k)	543	612	791	797	RPE
	DGW (£k)	10.4	11.8	14.5	14.5	RPE
	Contractual (£k) (a)	380	396	534	535	RPE
	Establishment (£k) (c)	163	218	257	262	RPE

OBJECTIVE(S):

1 To establish design and performance criteria for representative packaged liquid bipropellant rocket motors to meet future guided weapon propulsion requirements.

2 To establish design and performance criteria for liquid monopropellants to meet the requirements of gas generation and primary propulsion of guided weapons.

3 To demonstrate the ability of packaged propellant motors in operation and storage to meet the environmental and safety requirements of service use.

4 To evaluate the feasibility of new motor design concepts that offer significant improvements in performance and reliability, or reductions in production cost.

WORK ITEMS

Ref & Title						
3C1 Design of Combustion Chambers for Packaged Liquid Propellants	(a)	1.7	2.2	2.5	2.5	
There is a need to provide design criteria for combustion chamber and injection systems capable of increased burning time and wider thrust ratios than those considered previously in the PLTV programme. Also the special combustion chamber/injector requirements of gelled fuels need to be assessed before such propellant combinations can be considered for weapon applications.	(b)	77	103	125	125	
	(c)	4	11	35	43	
In 1974/75 it is expected to be able to:						
(a) conduct preliminary small scale motor testing with gelled fuels to determine practical performance and combustion system design criteria						
(b) conduct additional testing of improved thermal insulants and nozzle components to give longer burning times and/or reduced thrust axis variation						
(c) Resume reliability and performance testing of high thrust ratio engine designs in preparation for flight trials of a closely integrated propulsion system (the PLTV Type IIE) late in 1975/76.						
Work on the measurement of exhaust luminosity from liquid bipropellant motors is now transferred to 3I2.						
3C2 Storage Tanks and Flow Control Systems	(a)	1.1	2.1	2.5	2.5	
Some resumption of testing of improved piston expulsion systems will be possible during 1974/75. This work will study design proposals aimed at reducing the weight of piston assemblies and simultaneously improving the dynamic sealing to give reduced friction and greater compatibility with propellants by the use of metallic seals.	(b)	70	95	130	130	
	(c)	30	26	58	53	
For some applications the use of bladders as positive expulsion devices in the place of pistons offers greater design freedom and a possible reduction in cost. Preliminary tests with actual propellants will commence in mid 1974 of a prototype bladder design and, if successful, will be followed by performance measurements.						
Investigations on the feasibility of 'canning' solid propellant gas generator charges to provide added safety in damage situations will be complete early in 1974/75. Testing of modified solid propellant gas generators to meet the requirements of closely integrated propulsion systems will continue throughout 1974/75 at a low level of effort to meet						

NOTES (1) Draw a line under each Work Item. (2) Give (a), (b) & (c) figures for each work item.
(3) Further Work Items should be entered on a Continuation Sheet.

RESEARCH PROGRAMME SHEET (Continuation Sheet No 1)

Package Reference No: 3C/74

TITLE:
THE APPLICATION OF LIQUID PROPELLANTS TO ROCKET MOTORS

WORK ITEMS		YEARS Previous 1973/4	Current 1974/5	+1 1975/6	+2 1976/7	
Ref. & Title: the PLTV IIE flight trial dates in late 1975/76. The development of a liquid monopropellant gas generator as an alternative system will be taken to the stage where it can be tested with a complete packaged liquid motor by late 1974. In mid 1974/75 it is expected to begin testing of cavitating venturi control systems to confirm the basic results obtained at Southampton University (work completed in March 1974) and to extend data to actual rocket propellants.						
3C3 Safety, Rough Handling and Environmental Trials of Packaged Liquid Motors Long term storage, vibration and temperature cycling testing of representative liquid propellant tankage will continue throughout the current year with the object of establishing the probable life expectancy of filled rocket motors. Data obtained from actual tank assemblies will be correlated with laboratory tests of material samples (q.v. work Item 3C4). Safety hazard trials during 1974/75 will include trials to simulate the effects of (a) accidental drop (b) external fire and (c) fragmentation attack on filled tanks. A preliminary study will also be made of the safety characteristics of gelled fuels to assess whether these offer any reduction in hazard compared with conventional liquid propellants. Future trials will appraise the safety implications of new design concepts e.g. bladder expulsion systems, and evaluate palliative procedures or additions. A small effort will be devoted to an assessment of the usefulness of leak detection equipment as a means of satisfying Service requirements for magazine surveillance.	(a) (b) (c)	0.7 35 14	1.7 61 20	1.5 60 19	1.2 48 19	
3C4 Compatibility of Materials with Propellants Long term storage trials of IRFNA and MAF-1 in various metallic containers will continue at temperatures of 20, 50 and 70°C. Other storage trials concern UDMH and IPN in containers and will also proceed (1975-1978). Particular attention will be given to the possibility of enhanced corrosion in crevices or under conditions of stress or with IRFNA of low inhibitor content (1975). Miscellaneous tests on the compatibility of non-metallic materials with amine fuels and IPN, of metals with IPN, the permeability of flexible non-metallic materials to IRFNA, MAF-1 and IPN and the thermal stability of amine fuels will continue. (Various target dates between 1974-76). The compatibility of testing of candidate rubbers made by the ERDE and intended for trial in soft-seat hydrazine control valves at RAE (Space Dept) will continue (1974). Storage trials at temperature of 60°C to 80°C of positive expulsion hydrazine tanks will be carried out as part of a contract from BAC and ESRO. The rubber diaphragms of the tanks will be made by the ERDE and the RAE work entails an assessment of the long term compatibility characteristics (1975). Bladder type feed systems offer significant advantages for certain packaged liquid applications and methods of coating selected plastics with aluminium by liquid phase deposition will be studied.	(a) (b) (c)	1.2 26 25	1.5 25 25	2.0 30 28	2.0 30 21	

RESEARCH PROGRAMME SHEET (Continuation Sheet No. 1)						Funding Reference No: 10/70
TITLE: THE APPLICATION OF LIQUID PROPELLANTS TO WEAPON SYSTEMS		£000				
		Previous 1973/74	Current 1974/75	1975/76	1976/77	
WORK ITEMS						
Ref. & Title: 305 Packaged Liquid Test Vehicles (PLTV's) No flight trials are planned for the current year. However, a very limited amount of design and development activity will be directed in support of future trials including (a) the application of lateral accelerations exceeding those previously tested (ie. x10 g) and (b) the possible flight evaluation of an IPN monopropellant rocket motor under representative ASGW flight profiles (ie. 306).	(a)	0.8	0.3	1.0	1.4	
	(b)	19	5	60	60	
	(c)	23	7	58	65	
306 GW Applications of Liquid Monopropellants In 1974/75 work will continue in collaboration with RPE on the joint ICI/[illegible] Company experimental programme to demonstrate the feasibility of a liquid monopropellant motor for ASGW applications by mid 1975. By late 1974 alternative design concepts for critical sub-assemblies will have been assessed experimentally so that integration trials can follow early in 1975. Work is aimed at obtaining basic design criteria, performance data and information on the exhaust luminosity of a complete IPN motor assembly of a standard suitable for flight trials in a test vehicle. Recent studies at RPE, supported by fundamental data from Leeds University, indicate that the IPN dieseling problem might be overcome by the addition of suitable high-specific-heat gases to the ullage volume. Early in 1974/75 these fundamental results will be evaluated on a practical scale to establish the practicability of using 'fixed' piston expulsion systems, as used on bipropellant motors, for IPN. If successful a prototype expulsion system will be developed by late 1974 for inclusion in the IPN motor. Laboratory studies of dieseling in IPN will be completed early in 1974/75 by which time a wide range of initial conditions will have been investigated. Fundamental investigations into the ignition of IPN at Leeds University are expected to be complete by late 1974.	(a)	2.4	3.0	2.5	2.0	
	(b)	67	79	65	52	
	(c)	38	102	39	15	
307 Space Applications of Liquid Monopropellants a. Hydrazine. The work at RPE on catalysts for hydrazine thrusters has been brought to a satisfactory conclusion and, subject to final discussion with DOI (Space Dept) concerning any residual activities required of RPE, no further work is planned. b. Resistojets. All the work on this subject has been summarised in a final report and no further work is planned unless a positive requirement emerges.	(a)	2.4	-	-	-	
	(b)	100	-	-	-	
	(c)	23	-	-	-	
308 Engineering of Packaged Liquid Bipropellant Motors Improved design features and manufacturing methods can lead to enhanced reliability, weight saving and lower production costs for packaged liquid rocket motors. Laboratory studies and design appraisals during the previous year at Bristol Aerojet into the use of castings will be implemented during 1974/75 by initial testing of selected motor components produced by this method. Alternative methods of tank production using one-piece long neck extrusions in high strength aluminium alloys produced by [illegible] will be evaluated by practical trials. This manufacturing technique offers the combined advantages of avoiding a weld in long term contact with propellants, improved grain flow in the material (hence longer storage life) and some reduction in production cost.	(a)	-	0.4	1.0	1.0	
	(b)	-	12	54	54	
	(c)	6	22	30	26	

Classification: SECRET

RESEARCH PROGRAMME SHEET (Continuation Sheet No 3)

Package Reference No: 3C/74

TITLE:
THE APPLICATION OF LIQUID PROPELLANTS TO ROCKET MOTORS

		YEARS				
		Previous 1973/4	Current 1974/5	+1 1975/6	+2 1976/7	
WORK ITEMS						
Ref. & Title: 3C9 Feasibility Studies of Novel Design Concepts	(a)	0.1	0.8	1.5	1.8	
The inherent flexibility of packaged liquid motors suggests a number of methods whereby this could be exploited to advantage to improve the performance of guided weapons.	(b)	6	16	30	36	
Early in 1974/75 it is expected to complete the initial theoretical assessment of air augmentation of both solid and liquid propellant rocket motors against typical propulsion requirements using the data derived by Southampton University.	(c)	-	4	-	-	
In collaboration with RARDE, further experimental studies may be conducted during early 1974/75 to establish the performance and practical limits of operation of a simple recoilless gun using packaged liquid bipropellants.						
Studies will also be made during the current year of the feasibility of combined propulsion systems whereby a liquid propellant rocket is used as an integral unit with an air-breathing gas turbine and/or solid propellant motor. Such systems offer potential advantages of low cost and size with high performance for long range tactical weapons.						

Extramural - Universities		University/Contractor	Agreement or Contract No.	Estimated Payments 1974/75 £K
RPE				
3C1	Liquid atomisation	Imperial College	AT/2037/111	1
3C6	Decomposition of IPN	Leeds	AT/2062/045	4
		TOTAL UNIVERSITIES		5
Extramural - Industry				
RPE				
3C1	Design and development of Packaged Liquid Rocket Motor Hardware	Bristol Aerojet	K/GW42B/159	10
3C2	Design and development of Packaged Liquid Rocket Motor Hardware	Bristol Aerojet	K/GW42B/159	21
	IPN Gas Generators	HSD Ltd	K/GW42B/187	5
				26
3C3	Design and development of Packaged Liquid Rocket Motor Hardware	Bristol Aerojet	K/GW42B/159	17
	Leak Detection Techniques	Sieger Ltd	K/A83A/766	3
				20
3C4	Compatibility of Materials	Bristol Aerojet	K/42B/107	16
	Elastomeric Materials	Fulmer Research Inst.	K/GW42B/139	9
				25
3C5	Design and supply of FTVs	Bristol Aerojet	K/GW42B/159	2
	Supply and sponsor FTVs	" "	K/GW42B/35)	
	Supply and sponsor FTVs	" "	K/GW42B/59)	5
	Supply and sponsor lateral G FTVs	" "	K/GW42B/133)	
				7
3C6	IPN Rocket Motor	Plessey Co.Ltd	K/GW42B/161	92
	Tooling for IPN Tanks	ROF Patricroft	Not yet placed	7
				99
3C8	Engineering Development of Packaged Liquid Rocket Motor Hardware	Bristol Aerojet	K/GW42B/159	9
	Tooling for IPN Tanks	ROF Patricroft	Not yet placed	13
				22
3C9	Combined Rocket/Turbojet Propulsion System	Plessey Co.Ltd	Not yet placed	4
		TOTAL INDUSTRY		213
		GRAND TOTAL		218

RESEARCH PROGRAMME SHEET

Package Reference No: 3D/74

TITLE
The Application of Materials to Rocket Motors

Responsible Authority HQ Director(s): DPA/rm

Establishment(s): ERDE-RPE

		Previous 1973/4	Current 1974/5	+1 1975/6	+2 1976/7	
DOMAS (MM)		460	455	528	552	
SSF (a)		2.0 5.3	3.0 6.0	3.0 7.0	3.2 7.0	ERDE RPE
Intramural (MM) (a)		35 171	50 142	50 187	50 187	ERDE RPE
Extramural (MM) (c)		- 254	8 255	- 291	- 315	ERDE * RPE

OBJECTIVE(S):

The use of new materials and/or new manufacturing methods offer possibilities of weight saving on rocket motor hardware and of minimising cost. Designers require mechanical property information and reliability so that they can exploit new materials to the best advantage; this programme Item is accordingly directed to these aims.

WORK ITEMS

Ref & Title:

3D1 Structural Materials - Metallic

(a)	1.2	1.5	2.0	2.0	RPE
(b)	35	27	39	39	RPE
(c)	106	98	113	129	RPE

The evaluation and qualification of commercially available high strength steels for rocket motors will continue. Effort will be concentrated upon the maraging steels with strengths ranging from 1540 MN/m^2 to 2300 MN/m^2. Data manuals covering HS 171 (1540 MN/m^2) and DTD 5212 (1780 MN/m^2) are planned for 1974. Data manuals for G125 (1930 MN/m^2) and the new experimental alloy G150 (2300 MN/m^2) will follow in 1975 and 1976 respectively. These steels should provide high specific strengths with adequate toughness to meet the most stringent requirements of high performance motors.

Light alloy extrusions offer significant cost and stiffness advantages especially for motor bodies which include wing roots, launcher feet, etc. The strength and metallurgical characteristics of welded joints in DTD 5074 will be assessed (1975). The new alloy 3066, developed by DR/Mat 2, which has improved fracture toughness and stress corrosion resistance will be evaluated in extruded form (1976/7).

A study of the effects of aerodynamic heating on both aluminium alloys (1974) and high strength steels (1976) will continue.

Titanium could offer advantages for the construction of lightweight high strength cases applicable to new types of missile and space motor provided cost is not an over-riding factor. A critical survey is almost complete, a decision as to whether further research is necessary will be taken during 1974.

The evaluation of the friction welding process will be completed by mid 1974.

Brazing techniques for high strength steels have been developed and evalu tion of the stress corrosion and corrosion resistance of the joins will continue through 1975.

Direct numerically controlled (DNC) welding techniques are being developed to achieve improved consistency in the production of high quality welds with a consequent reduction in scrap. Work on circumferential TIG and pulsed TIG is almost complete. The development of DNC pulsed plasma and electron beam welding processes for longitudinal and circumferential welds will continue (1975). Ancillary equipment for use with DNC will be developed and commissioned when required.

Flow forming is a cost effective method of producing dimensionally accurate motor tubes. The effect of the flow forming process on the metallurgical characteristics of high strength steels and aluminium alloys will be studied.

NOTES (1) Draw a line under each Work Item. (2) Give (a), (b) & (c) figures for each work item.
(3) Further Work Items should be entered on a Continuation Sheet.

RESEARCH PROGRAMME SHEET (Continuation Sheet No 1)

Package Reference No: 3D/74

TITLE:
The Application of Materials to Rock t Motors

WORK ITEMS		YEARS Previous 1973/4	Current 1974/5	*1 1975/6	*2 1976/7	
Ref. & Title: The assessment of super-plastic alloys is now complete and awaits application. There is evidence to suggest that the bonding of elastomeric liners into high strength (1780 MN/m^2) steel cases has an embrittling effect and studies to establish the basic mechanism of failure will be started now. The philosophy of qualifying the structural integrity of RS131 rocket motor cases based on fracture toughness concepts has been accepted in principle by the JTRC. The work will now be extended to cover the maraging steels (1976).						
3D2 Refractory Ma'erials and Thermal Insulants The availability of Le Carbone grade P5890 graphite after 1977 is doubtful and an alternative material must be found. A contract has been placed with Anglo Great Lakes Corp Ltd to characterise and qualify two of their commercial fine grain graphites H585 and H590 (1975), both of which are cheaper than P5890. Methods of improving the performance of H585 and H590 will be investigated (1976). Evaluation of new or improved commercial graphite will continue. Work on the analysis and the establishment of the design principles for the manufacture of pyrolytic graphite coated throats up to 305 mm diameter has been completed. The limits of application of this form of nozzle will now be determined (1975). Collaboration with the US-AFRPL will continue (1974). The University of Aberystwyth will continue the study of the reaction mechanism of oxidising species with the basal plane of PG with the aim of suggesting methods by which the surface topography of PG can be modified to give improved erosion resistance (1976). Vapour deposited tungsten on graphite throats will meet the most severe erosion conditions associated with aluminised propellants. The deposition of tungsten coatings from tungsten chloride, in place of hexafluoride, will be developed to reduce manufacturing costs and provide an indigenous source of material (1974). Barrier layers to prevent the formation of tungsten carbide during long firing times will be developed. Brittle materials and coated nozzles can be susceptible to premature failure if the thermomechanical stresses generated during the firing are not considered carefully. A contract with the Engineering Department of the University of Nottingham will consider the prediction of failure probability in nozzle materials and components in an attempt to establish sound design principles (1976/7). Reliable physical and mechanical data at temperatures up to 2100°K will be required for this programme (1976). The results of test firings on carbon throats coated with silicon carbide will be analysed and reported (1975) for liquid bipropellant motor application in mind. Carbon fibre/carbon composite materials offer the possibility of developing nozzles with high temperature stability and high specific strength. A number of different nozzle shapes will be manufactured and evaluated to determine structural properties, erosion resistance and cost effectiveness. Formulations based on Royalene and other low density rubbers will be evaluated as flexible insulants for lining rocket motor cases (1976). The difficulties in obtaining asbestos-filled CL8903 commercially have indicated the need for a Royalene with an alternative filler; substitution by silica will be evaluated (1974). A heat transfer model will be developed to provide design information (1976). Alternative methods for lining rocket motor cases with elastomers (eg casting and spraying) will be assessed for cost effectiveness (1975). The materials will be based on liquid polybutadiene and silicones. Rigid insulants, using graded asbestos fibres developed by ERDE, with liquid resin systems will be evaluated with the aim of achieving higher composite strengths combined with reduced variability (1974). Alternative chamber lining materials with improved mouldability (eg glass/phenolic) will be assessed for use in packaged liquid bipropellant motors and methods of achieving better bonding of "in situ" moulded liners will be investigated (1975).	(a) (b) (c)	2.0 3.2 55 113 - 87	3.0 3.5 50 96 8 85	3.0 3.5 50 99 - 94	3.2 3.5 50 99 - 96	ERDE RPE ERDE RPE ERDE RPE

RESEARCH PROGRAMME SHEET (Continuation Sheet No. 2)

Programme Reference No: 55/75

TITLE:
The Application of Materials to Rocket Motors

WORK ITEMS		YEARS				
		Previous 1973/74	Current 1974/75	1975/76	1976/77	
Ref. & Title: Development of improved oxidation resistant carbon-carbon fibre and related composites for rocket nozzles by in-situ SiC formation on exposed surfaces. Examination of the ablation resistance and strength of improved asbestos composites for rocket nozzles, liners and motor bodies. The degradation of the mechanical properties of asbestos after exposure to air at elevated temperatures. Development and assessment of new and improved thermal insulants for rocket motors. Investigation of parameters affecting performance under rocket motor conditions. Investigation of the effect of ageing and compatibility on the properties of candidate materials.						
3D3 Structural Materials - Composites The programme aimed at qualifying carbon fibre reinforced plastics for motor cases suitable for tactical missile application will continue. Design and manufacturing techniques will be established for typical missile cases. The structural integrity of motor cases in Service environments will be examined, motor filled and fired (1974). Full environmental testing of filled motors will be completed, except for long term temperature storage trials (1976). An additional three lightweight carbon fibre reinforced plastic nozzle end-closures of modified design will be test fired. The objective remains to establish design principles and prove manufacturing techniques (1974). Design principles and material properties will be determined for the over-winding of blast pipes and expansion cones (1975). An initial laboratory evaluation of Kevlar 49 (PRD 49) will commence.	(a) (b) (c)	0.9 23 61	1.0 19 72	1.5 49 84	1.5 49 90	RPE RPE RPE
3D4 Adhesives for Motor Applications A Working Party to advise on the selection, quality control and R & D on adhesives appropriate for use in the rocket motor field will be set up. The Working Party will aim to co-ordinate and rationalise the requirements and activities in this area at ERDE, IMI and BAJ.						

Extramural - Universities	University/Contractor	Agreement or Contract No.	Estimated Payments 1974/75 £K
RPE			
3D2 Thermomechanics	Nottingham	AT/2024/048	4
Topography of Pryolytic Graphite	Aberystwyth	AT/2110/07	2
Nozzle Erosion	Not known	Not yet placed	3
Insulation	Not known	Not yet placed	1
			10
	TOTAL UNIVERSITIES		
Extramural - Industry			
RPE			
3D1 Design, development, supply of rocket motor hardware	Bristol Aerojet	K/50B/94	8
R & D. Solid propellant rocket motor hardware	Bristol Aerojet	K/GW42B/107	90
			98
3D2 Design, development, supply of rocket motor hardware	Bristol Aerojet	K/50B/94	8
R & D. Solid propellant rocket motor hardware	Bristol Aerojet	K/GW42B/107	44
Tungsten coated nozzles	Fulmer Research	K/GW42B/105	9
Synthetic Graphites	Anglo Great Lakes Corpn.	K/GW42B/163	10
Carbon, fibre/carbon composites	Fordath Ltd.	K/GW42B/149	4
ERDE			
* Elastomeric insulant materials	QMC Industrial Research Ltd	HRA/Z/1	8
			83
RPE			
3D3 Design, development, supply of rocket motor hardware	Bristol Aerojet	K/50B/94	29
R & D. Solid Propellant rocket motor hardware	Bristol Aerojet	K/GW42B/107	43
			72
	TOTAL INDUSTRY		253
	GRAND TOTAL		263

* Contract HRA/Z/1

Funds to cover the extension of this contract in 1975/76 and 1976/77 will be transferred from RPE to ERDE.

RESEARCH PROGRAMME SHEET								Package Reference No: 3E/75
TITLE Rocket Exhaust and Flume Technology	Responsible Authority (or Director(s))	DNArm		Previous 1973/4	Current 1974/5	+1 1975/6	+2 1976/7	
	Establishment(s)	ERDE=RPE	RPE(b) (kk)	370	274	237	218	RPE
OBJECTIVE(S): 1 To establish design and performance criteria used in the RPE type of lip seal nozzle for thrust vector control. 2 To measure smoke and luminosity from rocket exhausts, and to investigate means of minimising interference with day and night tracking techniques. Also to investigate such emissions as a means for identification of missile launch. 3 To refine the computer programs for calculation of the electromagnetic and gas dynamic properties of rocket exhaust plumes under flight conditions and to verify these, where possible, by comparison with measured values obtained in flight trials.			ESP (a)	10.0	10.0	9.7	9.0	ERDE RPE
			Intramural (kk) (b)	60 262	- 233	- 218	- 200	ERDE RPE
			Extramural (kk) (c)	48	41	19	18	RPE

WORK ITEMS

Ref & Title:						
3E1 Electrical, Radiative and Gas Dynamic Phenomena	(a)	9.3	9.5	9.5	9.0	RPE
i Chemistry Work will be done on the identification of the important chemical processes determining rocket exhaust structure and of practical methods of modifying such phenomena as secondary combustion. The investigation of metal-containing additives will continue. The results of the experiments will be applied to make quantitative predictions for motors of particular interest, and these predictions will be compared with test firing results. (Continuous).	(b)	230	181	196	200	RPE
	(c)	23	36	19	18	RPE
Calculations will be made at Exeter University of rate coefficients for reactions which occur in rocket exhaust plumes but which have rate coefficients difficult to measure experimentally (1974).						
For improved predictions of radio interference effects, mass spectrometric sampling of combustion plasma will be carried out at Sheffield University (1974).						
Effects of metals such as chromium on radical concentrations in flames will be studied at the University College of Swansea (1974).						
At the Imperial College techniques will be developed for the measurement of particle sizes of metal oxides in flames and number densities in flames (1975). The methods will be applied to determination of optical and IR radiation properties of hot media containing metal oxides and the results used in calculations of the radiative properties of exhausts (1976).						
At Aston University laser scattering measurements are being made of carbon particle size distributions in flames where the particles are being oxidised (1974). The results will be interpreted in terms of particle/oxidiser collision oxidation probabilities and applied to calculations of IR radiation continuum levels and smoke contents of rocket plumes (1975).						
ii Gas Dynamics The development of more accurate, and cheaper, predictive techniques for rocket exhaust structures will continue. Program BAFL will be applied in predictions for missiles with high base/nozzle exit area ratios. Programs REP2 (1974) and REP3((1975) will be used for situations where plume pressure gradients and shock structures are key features. Program BAFL2 (1975) will be used to handle generalised missile base geometries. Improved methods for predicting the effects of particles in nozzles and plumes will be developed.						
Calculations for specific requirements will be made for predictions of plume, electromagnetic and gas dynamic properties (continuous).						

NOTES (1) Draw a line under each Work Item. (2) Give (a), (b) & (c) figures for each work item.
(3) Further Work Items should be entered on a Continuation Sheet.

RESEARCH PROGRAMME SHEET (Continuation Sheet No 1)

Package Reference No: 3E/74

TITLE:

Rocket Exhaust and Plume Technology

YEARS				
Previous 1973/4	Current 1974/5	+1 1975/6	+2 1976/7	

WORK ITEMS

Ref. & Title:

The possibility of using the laser crossed-beam correlation techniques with multibeam apparatus for measuring local flow velocities in rocket plumes will be evaluated and - if suitable - the technique applied. At Southampton University the refinement of the technique will be made on laboratory jets, with a view to conducting field trials at RPE on the exhausts of selected rocket motors (1975).

In the collaborative programme with BAC on boost blast and impingement effects, pulse measurements of temperature and pressure in the Blackcap exhaust will be made at RPE (1974). Results will be compared with theoretical predictions as a test of the validity of the modelling (1975).

The experimental investigation of flow from low thrust nozzles at Oxford University will continue. An electron beam fluorescence technique will be used to measure the local values of velocity and rotational and vibrational temperatures in the jet issuing from the RPE 3 kW hydrogen resistojet. Comparison with predictions will be made where possible and the final report written (1974). (Transferred from 3C7 in the 1973/74 Programme).

The results of the study of high temperature insulating materials at Oxford University will be analysed and presented in a final report (1974). Final measurements of the properties of boron nitride in hydrogen at pressure above atmospheric will be made in a purpose-built high temperature furnace. In addition to sublimation, stability and thermal shock, particular attention will be paid to resistivity. (Transferred from 3C7).

The work on mixed thruster electric propulsion at Southampton University will be finalised with the analysis of the performance and economics of rocket-launched and shuttle-launched reusable mixed electric thruster systems, utilising hydrogen resistojets and ion motors, for geostationary and other missions (1975). (Transferred from 3C7).

iii Infra Red Radiation Emissions Calculations by existing computer methods will be made to identify emission features of interest, to predict IR radiations from exhausts of particular missiles and to determine the accuracy of the prediction techniques via comparison experiment (continuous).

Line-by-line methods of predicting detailed spectral structures of important molecular band emissions for discrimination applications will be evaluated and if necessary programmed (1975). Work will continue on atmospheric transmission of IR radiations and on updating spectroscopic input data (continuous).

Theoretical predictions for a variety of motors will be made as part of the work of TTCP J-AG 3 (1975).

Measurements on plumes of a number of static motors at long and short ranges will be made with a radiometer and with a high-resolution spectroradiometer. Results will be compared with theoretical predictions. Emission characteristics of missiles in flight will be measured and compared with theory (continuous).

A technique for measuring important optical and IR radiation characteristics of condensed particles will be developed (1975) and used to determine essential input data needed for predictions of continuum radiation emissions from rocket exhaust particles (1976).

iv Radiowave Interactions The test sites, Q and L, for making measurements of Rf interactions will be maintained; tests on motors will be made as required (continuous).

Operating manuals for calculating attenuation, amplitude- and phase-modulated noise and diffraction of Rf signals and radar echoing areas will be completed (1974) and updated as required to maintain a service facility (continuous).

The method developed for calculation of microwave insertion loss caused by a rocket exhaust plume will be modified to approximate more closely the plume geometry. Improved agreement between theory and experiment will be achieved and the generality and reliability of the method demonstrated at Queen Mary College (1974).

RESEARCH PROGRAMME SHEET (Continuation Sheet No 2)						Previous Reference No: 38/76	
TITLE: Rocket Exhaust and Plume Technology						Year	
						Previous 1975/76	Current 1976/77
Ref. & Title							
v Laser Beam Interactions Development of a correlation technique for spectra of plume-induced beam noise will continue (1976). Measurements of plume-induced noise and attenuation for static rockets will continue and will be compared with theory (continuous). Investigation of the theory of propagation of laser beams through rocket plumes will continue. Predictions of attenuations and induced noise in liquid propellant rocket motor exhausts will be compared with experiment (1976). vi Luminosity Improved methods for predicting the luminosity of rocket exhausts will be developed. Predictions will be compared with experiment and luminosity levels classified in terms of important propulsion system parameters (1976). Measurements of exhaust luminosity of selected static motors will be made and compared with theoretical predictions in an attempt to identify means of minimising visible radiation emissions (1976). (See also Item 3E4). Measurements will also be made of the luminosity of packaged liquid bipropellant and monopropellant motors.							
3E3 Thrust Vector Control No firings have been carried out due to lack of effort and difficulties with the supply of the 160 mm motor (see 3B7.2). Manufacture of 3 nozzles for deflections of ± 15 deg and 7 nozzles of ± 20 deg is completed and the nozzles have been delivered. Design of a uniplanar nozzle having a deflection of ± 25 deg is complete and manufacture has commenced. Two nozzles with poppet-type valves for hot gas injection designed for a deflection of 5 deg, have been delivered to complete this programme and are awaiting firing using plastic propellant.	(a) (b) (c)	0.7 25 25	0.1 15 5	- - -	- - -	22% 22% 22%	
3E4 Smoke and Flame An attempt to assess the effect of using Silcoset on end-of-burning smoke using the Crake motor in Blowpipe dart firings was rendered unsuccessful by interference from other parts of the missile system. The possibility of repeating this trial is under investigation. A charge to CD163 was produced for comparison with the existing CD142 charge used in the Blackcap motor. An appreciable reduction in the time of thrust decay was achieved but at the expense of a large increase in burning time. Further charges will be produced to reduce the burning time and assess effect on the cut-off in thrust. A flight trial to assess the effect on end-of-burning smoke will be required. A review of the UK position with regard to rocket motor signature (smoke and flame) will be prepared for the TTCP W/4 (KTA1). (Work on rocket flame is now reported under 3E1).	(a) (b) (c)	3.5 Neg 60 7 -	- 0.4 - 37 -	- 0.2 - 22 -	- - - - -	22% 22% 22% 22%	

Extramural - Universities		University/Contractor	Agreement or Contract No.	Estimated Payments 1974/75 £K
RPE				
3E1	Radiowave diffraction	Queen Mary	AT/2042/036	2
	Optical wave propagation	Queen Mary	Not yet placed	1.5
	Condensation studies	Imperial College	Not yet placed	0.5
	Optical properties of metal oxides in flames	Imperial College	AT/2037/134	4
	Optical measurements	Southampton	AT/2042/084	4
	Metal catalysed radical recombination	Swansea	AT/2081/028	3
	Sampling of combustion plasma	Sheffield	AT/2031/060	3
	Elementary reactions	Exeter	AT/2041/09	4
	Carbon particle oxidation	Aston	AT/2097/017	3
	Structure of turbulent flow	Southampton	Not yet placed	5
	High temperature insulation	Oxford	AT/2057/038	2
	Mixed thruster electric propulsion	Southampton	AT/2040/0115	2
	Future requirements - not yet defined	Not known	Not yet placed	2
		TOTAL UNIVERSITIES		36

Extramural - Industry				
RPE				
3E3	Development and supply of hardware for TVC	Bristol Aerojet	K/GW42B/108	5
		TOTAL INDUSTRY		5
		GRAND TOTAL		41

RESEARCH PROGRAMME SHEET

Package Reference No: 3F/74

TITLE
Rocket Instrumentation and Non-Destructive Testing

Responsible Authority
HQ Director(s): DRArm

Establishment(s): ERDE-RPE

		Previous 1973/4	Current 1974/5	+1 1975/6	+2 1976/7	
TOTALS (£k)		167	158	178	183	
SSP (a)		0.3 5.1	0.1 6.7	0.1 7.0	0.1 7.0	ERDE RPE
Intramural (£k) (b)		20 135	10 138	10 138	10 138	ERDE RPE
Extramural (£k) (c)		12	10	30	35	RPE

OBJECTIVE(S):

To improve the accuracy of the measurements of rocket performance data and to speed data reduction and evaluation.

To improve and extend techniques for non-destructive testing and examination of all components in rocket motors with special reference to case bonded systems.

WORK ITEMS

Ref & Title:

3F1 Test Bed Instrumentation

(a)		1.4	2.5	1.5	1.5	RPE
(b)		40	49	28	28	RPE
(c)		-	-	-	-	

The new hydraulic thrust calibration system, which will replace the existing "Denison" compression test, has been assembled but preliminary tests have shown unacceptably high leakage rate. Modifications to eliminate this are required and tests will be commenced to prove the accuracy of the system. If the target accuracy is achieved, the equipment should be in use by the end of the year.

Thrust alignment requirements for KH793 motors entail much more accurate measurements than were successfully obtained for Crake, Blackcap and Rapier. Test stands will be designed and constructed to overcome the problem. Because of the very short burning time of the motors, the dynamic performance is of particular importance. A stand now constructed for the packaged liquid motor will be tested and the firings carried out (mid 1974).

A new high sampling rate recording system will be adapted to deal with all RPE's digital recording requirements during the period when our main computer is being replaced (July 1974) after which extension to new sites will commence (1976/77).

3F2 Non-Destructive Testing

(a)		0.3 3.7	0.1 4.2	0.1 5.5	0.1 5.5	ERDE RPE
(b)		20 95	10 89	10 110	10 110	ERDE RPE
(c)		12	10	30	35	RPE

Rationalisation of the ultrasonic inspection equipment will be continued. The stepper motor control circuits that have been developed to control probe and plotter movements in an experimental tank will be applied to the rest of the scanners and plotters. The application of air-coupled systems to small motor and empty tube inspection will be extended and further applications are envisaged; the main part of this work should be completed in 3 years.

Considerable progress has been made in the application of ultrasonic holography to the examination of large volumes of material of high attenuation for defects. 15 inch cubes of polythene have been cast with intentional defects and these behave acoustically in a manner similar to propellant. The resolution of crack-like defects in these specimens is close to the theoretical limit, the images being distinct and easy to interpret. To date effort has been concentrated on development of equipment, but in the coming year the system will be applied to the inspection of motors. The contract with Mullards for an ultrasonic image plate to permit real time imaging has resulted in reasonably satisfactory samples and in the coming year large area samples will be produced which will be useable in holographic experiments. Initial application in routine testing will take about 2 years.

NOTES: (1) Draw a line under each Work Item. (2) Give (a), (b) & (c) figures for each work item.
(3) Further Work Items should be entered on a Continuation Sheet.

Classification: SECRET

RESEARCH PROGRAMME SHEET (Continuation Sheet No 1)

Package Reference No: 3F/74

TITLE:
Rocket Instrumentation and Non-Destructive Testing.

YEARS				
Previous 1973/4	Current 1974/5	+1 1975/6	+2 1976/7	

WORK ITEMS

Ref. & Title:

A comprehensive set of equipment has been assembled for experiments into the use of acoustic emission for testing of composite rocket motor cases. Preliminary tests were carried out with beam samples in three point bending and later tests have involved pressure testing of Durestos vessels. There appears to be a correlation between the emission observed and the mode of failure. It is now intended to test to destruction oblate spheroids in carbon fibre composite as a preliminary to proof testing of motor cases. The results obtained will be compared with those from ultrasonic and radiographic testing. Results are becoming available from the contract with AERE Harwell to investigate the detailed nature of the processes leading to acoustic emission. There is some evidence that different modes of failure produce a different pulse shape, but that within a short distance of the point of initiation the nature of the emission is controlled by the geometry and acoustic properties of the material through which it has passed. Work will continue to confirm these results and improve understanding of the phenomenon (1975).

Ultrasonic techniques have been applied satisfactorily to the detection of unbonding in Polaris first stage motors and effort will be concentrated on the detection of gas cracking which entails a very lengthy inspection if radiography is used; a holographic inspection technique might eventually prove feasible. Initial effort will be concentrated on a simple technique relying on interference between the main beam and reflections from defects. Some motors may have extensive unbonding along the parallel section, rendering through-transmission techniques impossible, but there is still hope that a reflection technique is possible from the motor conduit. A 1/5th scale motor will be cast in polythene to enable scale experiments to be carried out.

Work at Loughborough University will explore the use of synthetic aperture techniques in ultrasonic inspection. Satisfactory detection may be possible without the large aperture required for holographic imaging; it is hoped that a recommended design for practical use will be available by mid 1974.

A new 3000 kV X-ray set will be commissioned by ERDE for propellant NDT and liaison maintained with RPE, SRS, RARDE and Inspectorates.

Extramural - Industry	University/Contractor	Agreement or Contract No.	Estimated Payments 1974/75 £K
RPE			
3F2 Acoustic emission from composites	AERE	K/A83A/721	5
Ultrasonic image conversion	Mullard	K/A83A/750	2
New Techniques	Not known	Not yet placed	3
			10
TOTAL INDUSTRY			

Classification: SECRET

RESEARCH PROGRAMME SHEET

Package Reference No: 30/74

TITLE: EXPLOSIVES AND INITIATORY DEVICES

Responsible Authority HQ Director(s): DR Arm

Establishment(s): ERDE/RPE

		Previous 1973/74	Current 74/75	+1 75/76	+2 76/77	To Objective
TOTALS (£k)		383.5	392	405.5	416	
SSP	(a)	27.0	26.6	27.0	27.0	ERDE
Intramural (£k)	(b)	370	380	390	400	ERDE
Extramural (£k)	(c)	13.5	12.0	15.5	16.0	ERDE

OBJECTIVE(S):

1 To improve the overall performance of initiatory explosives and devices and of secondary explosives.

2 To evaluate and reduce hazards during the manufacture and Service use of explosives.

3 To improve techniques for the detection of explosives.

4 To improve techniques for the safe disposal of explosives.

5 To maintain expertise to enable the Department to fulfil its responsibilities to the Royal Ordnance Factories, the Ordnance Board and the Services.

WORK ITEMS

Ref & Title:

3G1 Secondary Explosives and Compositions	(a)	10.0	12.0	12.0	12.0
	(b)	130	160	165	170
	(c)	5.0	4.5	6.0	6.0

Work on the systematic study of RDX/TNT casting continues with particular emphasis being placed on determining the factors of importance in ensuring crack-free charges of high intrinsic strength and with good adhesion to the walls of the containing vessel. Specific factors being studied include controlled rates of cooling, the effect of TNT nucleating additives such as HNS, and the influence of temperature on polymorphic transition in TNT (1975). A study of the influence of plasticisers and waxes as crack inhibitors has commenced, particularly with regard to the influence that such additives may have on adhesion and exudation.

Development of cold cured, cast plastic bonded explosives based upon maximum solids loading of RDX and HMX is being concluded (1974) and samples have been supplied to RARDE and AWRE for evaluation. Further work on high energy cold cast PBX's containing energetic plasticisers will be dependent on demonstration of improvement in performance and on simplification of filling procedures over conventional compositions. Filled shaped charges will be supplied to RARDE for this purpose (1975).

Safety and storage trials of Poly-X compositions for torpedo warhead applications are almost completed (1974). Work to resolve cracking problems with Poly-X compositions on high temperature storage will be continued (1975). Development of Poly-X compositions for maximum performance under high confinement will be continued (1975) ie in penetrating and cratering warheads and their performance under high shock level loading evaluated.

Formulation of aqueous and non-aqueous thixotropic liquid and slurry explosives designed for demolition, cratering and mine clearance purposes will be terminated (1974) and further effort confined to supply of bulk samples required for trials and evaluation. Future work, particularly in respect of improvements in high and low temperature storage capabilities of these explosives, will be dependent on a firm requirement emerging from the user department (RARDE).

Laboratory synthesis, pilot plant investigation and manufacture of explosives and ingredients is a continuing requirement. Examples of work under this heading include synthesis and process studies on HNS, DATNB, TATNB, PVN and desensitised NG extraction.

3G2 Explosive Performance and Detonation Studies	(a)	6.5	5.7	6.7	6.7
	(b)	90	85	100	100
	(c)	5.0	4.5	5.5	6.0

Measurement and evaluation of the performance of experimental and conventional explosive compositions relevant to air and underwater blast, fragmentation and cratering applications to provide data for optimisation in composition development and in the designers' choice of fillings

NOTES (1) Draw a line under each Work Item. (2) Give (a), (b) & (c) figures for each work item.
(3) Further Work Items should be entered on a Continuation Sheet.

RESEARCH PROGRAMME SHEET (Continuation Sheet No)

Package Reference No: 93/74

TITLE: EXPLOSIVES AND INITIATORY DEVICES

WORK ITEMS		YEARS Previous 73/74	Current 74/75	+1 75/76	+2 76/77	To Objective
Ref. & Title 3G2 Explosive Performance and Detonation Studies (Contd) (continuing). A literature survey of methods of focussing blast underwater will be completed (1974) for Underwater Weapons Warhead Research Committee and the most promising techniques evaluated in practical trials (1975). Photographic and pyrometric measurements of detonation phenomena. Advice on blast simulators and blast damage to other Government Departments as required.	(a) (b) (c)					
3G3 Hazard Evaluation and Sensitiveness Studies on the sensitiveness and potential hazard of all new primary and secondary explosive compositions developed within ERDE. Improvements of methods of assessment of sensitiveness of potentially hazardous materials to impact, friction and electrical stimuli (continuing). Studies on the effect of low amplitude shocks on explosives to assist in determining vulnerability to deflagration and detonation of various candidate explosives for filling of warheads subject to severe shock loading during the target penetration process (first phase 1974).	(a) (b) (c)	2.5 55 -	2.0 50 -	2.0 50 -	2.0 50 -	
3G4 Initiatory Explosives and Devices Preparation and evaluation of silver nitrotetrazole has been completed and this material has been demonstrated not to be fully adequate in very small detonators. Study and evaluation of other salts of nitrotetrazoles will be completed (1974). Future work will involve study of detonant/base charge interaction for improvement in performance and life expectancy of small detonators (1975). Work continues to develop stab sensitive compositions of improved stability and performance with attention being concentrated particularly towards finding a replacement for tetrazene in such compositions. Efforts will be made to increase the sensitivity of lead azotetrazole and to examine promising candidates from the double salts of the nitrophenols with tetrazoles (1975). Investigations are continuing into new percussion cap compositions for the future generation of small calibre weapons. Candidate compositions will be assessed for reduced complexity and cost without compromising reliability and performance (1976). Preliminary studies on a replacement for VH2 composition and for a new smokeless cap composition have been completed. Improved compositions for coating of bridgewires used in fuzes and igniters are being sought and the most promising series of compounds in this application appear to be the potassium salts of the nitrophenols. The aim of this work is to produce fuze heads having high reliability in ignition but with less mechanical sensitiveness and thus greater safety than those currently in service. Requirements exist for precision medium delay (50-300 m sec) and short delay (5-50 m sec) elements for detonators and explosive devices in connection with future weapon projects for RARDE and RAE. For the medium delay elements attention is being directed to coprecipitated fuel-oxidant combinations (1975) and for the shorter delay single compositions such as the nitrophenols will be assessed (1976). Long term study of metal organic complexes having possible potential as detonants, flash receptive and delay elements, stab sensitive compositions and igniferous elements in fuze heads will be continued (continuous).	(a) (b) (c)	6.0 65 3.5	6.4 75 3.0	5.8 65 4.0	5.8 70 4.0	
Identification and Detection of Explosives lysis of explosives by mass spectrometry.	(a) (b) (c)	0.5 10 -	0.5 10 -	0.5 10 -	0.5 10 -	
FOOTNOTE The SSP and Intramural totals for 1973/74 include effort and costs, as shown, for work on Pyrotechnics (under MF9) during 1973/74.	(a) (b) (c)	1.5 20 -	- - -	- - -	- - -	

EXTRAMURAL - UNIVERSITIES	University/Contractor	Agreement or Contract No	Estimated Payments 1974/75
ERDE			£K
3G1 CRYSTALLOGRAPHY OF NITRAMINES	Lancaster	AT/2182/05	2.5
Preparation and properties of nitro-imide compounds	East Anglia	AT/2162/07	1.0
Synthesis of thermally stable polynitro-aromatic compounds	Kingston	AT/2055/03	1.0
			4.5
3G2 STRUCTURE AND STABILITY OF DETONATION WAVES	Aberystwyth	AT/2110/02	1.0
Thermal decomposition of organic nitro compounds	Essex	AT/2178/011	1.2
Initiation of fuel/air mixtures	Essex	AT/2178/014	2.3
			4.5
3G4 METAL COMPLEXES OF DIFUNCTIONAL NITROPHENOLS	North London Poly	AT/2212/01	1.0
Inorganic solid oxidants	Aberystwyth	AT/2110/06	1.0
Chemistry of decomposition processes	Cambridge	AT/2029/088	1.0
			3.0
	Total - Universities		12.0

Classification: SECRET

RESEARCH PROGRAMME SHEET

Package Reference No: MF16/74

TITLE
MAJOR FIELD 16
MATERIALS

Responsible Authority HQ Director(s): DR Mat 2

Establishment(s): ERDE/RPE

	Previous 1973/74	Current 74/75	+1 75/76	+2 76/77	To Objective
TOTALS (£k)	619.5	571.5	585.5	596	
SSP (a)	39.5	36.0	36.0	36.0	ERDE
Intramural (£k) (b)	580	530	540	550	ERDE
Extramural (£k) (c)	39.5	41.5	45.5	46.0	ERDE

OBJECTIVE(S):

To develop improved non-metallic materials for defence uses. This includes the search for better materials and the improvement of existing rubbers, plastics and adhesives in respect of both properties and durability.

To develop: (a) Stronger and stiffer materials to reduce the weight of civil and military aircraft and engines, and for other defence applications.

(b) Improved fibres and matrices, and to select the best components for composites. To apply these composites to a variety of military and civil uses.

WORK ITEMS

Ref & Title:						
1 (K6) Non-Metallic Fibre Composites						
1.1 Fibres and Fibre Processing Critical examination and optimisation of the basic ERDE processes for the efficient grading and aligning of discontinuous high strength fibres with a view to providing data for the design of efficient plants with emphasis on asbestos as an inexpensive material for Defence applications such as rocket motor nozzles and bodies, launcher tubes, etc (1976). Development of suitable non-destructive test methods for quality assessment of discontinuous fibre mats and prepregs (1975). Examination of the thermal stability of asbestos fibres (1975).	(a)	9.5	11.0	11.0	11.0	
	(b)	150	170	175	180	
	(c)	5.5	5.7	6.0	6.0	
1.2 Non-Metallic Discontinuous Fibre Composites Studies of fabrication techniques for composite production, such as compression and autoclave moulding (1976). Supply of bulk carbon fibre prepregs for trials in the fabrication of gear box cases, rocket nozzles and other components (1976). Investigation of selected mechanical, thermal and electrical properties of discontinuous carbon fibre and asbestos composites (1976) relevant to Defence applications. Provision of design data sheets. Examination of new matrix resins synthesised in ERDE.						
1.3 Materials and Processes for Non-Metallic Composites Study of fabrication techniques and the effects of structural parameters on the mechanical properties of fibrous composites. Development of mechanical test techniques for the evaluation of structural and geometrical effects. Measurement of specific mechanical properties of ERDE and commercially-produced carbon fibre composites. Evaluation of new matrix resins synthesised in ERDE.						
2 (K7) Metallic Fibre Composites Critical examination of the mechanical and certain thermal and electrical properties of Al-SiC whisker composites over a range of conditions likely to be encountered in Defence applications (1975). Fabrication techniques for whisker-reinforced laminates and evaluation of hybrid composites suitable for Defence use, eg light-weight armour, aero-engine containment rings, components for rocket engines and compressor blades (1976). Provision of design data sheets.	(a)	2.0	2.8	3.0	3.0	
	(b)	50	60	65	65	
	(c)	-	-	2.0	2.0	
3 (J3) Plastics and Rubbers 3.1/3 Support work for Army and Air Department Establishments on the selection and use of plastics and rubbers for use in Service equipments. Provision of mechanical property and design data on new non-metallic materials which appear to have promise for use in Service stores. Study of the stress-cracking behaviour of polymers in hostile environments,	(a)	10.5	8.8	8.5	8.5	
	(b)	160	130	125	130	
	(c)	26	27	28	28	

NOTES (1) Draw a line under each Work Item. (2) Give (a), (b) & (c) figures for each work item.
(3) Further Work Items should be entered on a Continuation Sheet.

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RESEARCH PROGRAMME SHEET (Continuation Sheet No)

Package Reference No: MF16/74

TITLE:
MAJOR FIELD 16
MATERIALS

WORK ITEMS		YEARS: Previous 73/74	Current 74/75	75/76	76/77	To Objective
Ref. & Title: (J3) Plastics and Rubbers (continued) their mechanical properties at high and low temperatures and at high strain rates. Evaluation of the degradation in properties of rubbers and plastics resulting from contact with explosives, propellants and hydrocarbon fuels and oils. Exploitation of the novel polymer synthesis pioneered in ERDE for the preparation of improved rubbers. Provision of design data sheets. 3.4 Research into metal catalysis of the autoxidation of polymers and polymer model compounds. Study of mechanism and kinetics of autoxidation.	(a) (b) (c)					
4 (J2) Tropical Testing and Stability The provision of temperate and tropical trial facilities for all Defence Departments. Measurement of the effects of heat, air, moisture etc on the properties of stressed and unstressed polymers. Further development of accelerated tests for the assessment of the stability and ageing properties of polymers and their correlation with the results of tropical exposure trials. Measurement of total solar radiation, UV content of solar radiation and surface temperatures of non-metallic materials exposed out-of-doors. Continued exploitation of the ERDE-developed thin film monitor for the world-wide assessment of the UV content of solar radiation.	(a) (b) (c)	2.5 20 3.0	3.0 30 3.4	3.0 30 4.0	3.0 30 4.0	
5 (J4) Adhesives and Sealants 5.1 Development of improved high strength, flexible metal-to-metal and composite-to-composite adhesives using ERDE-developed synthetic routes, and assessment of their long-term high-temperature and solvent-resistant characteristics. Development of modified epoxy resins specifically for use as new matrix resin in carbon and other fibre composites. Modified materials have been produced which give improvements in the interlaminar shear strengths of carbon fibre composites of the order of 15-20 per cent, and composite-to-composite adhesive lap shear strengths of the order of 100 per cent greater than those given by unmodified materials. Long term ageing in air over a wide temperature range, and testing resistance to water and common aircraft fluids is proceeding. The programme will be subjected to a major review in one year. 5.2/4 Research into the durability of structural adhesives by long-term exposure trials and the assessment of failure mechanisms by correlation of failure sites with surface properties. Study of adhesion between rubber-coated fabrics and between rubber and fabrics. Evaluation of new adhesives.	(a) (b) (c)	7.5 90 5.0	7.9 100 5.4	8.0 105 5.5	8.0 105 6.0	
6 (J10) Analysis Provision of analytical support for the Establishment's work on materials, particularly instrumental analysis of polymers by IR, UV and NMR spectroscopy, osmometry, chromatography, microanalysis, thermomechanical and thermochemical analysis and crystallography.	(a) (b) (c)	4.5 60 -	2.5 40 -	2.5 40 -	2.5 40 -	
Thermal Properties of Composites	(a) (b) (c)	3.0 50 -	- - -	- - -	- - -	

		University/Contractor	Agreement or Contract No	Estimated Payments 1979/80
EXTRAMURAL - UNIVERSITIES				£K
ERDE				
16.1	The Behaviour of Whiskers in Fluid Flow	Swansea	MT/2081/024	5.6
	Pyrolysis of Silicon-Carbon Polymers	Aston	MT/2097/015	1.5
	Fluid Dynamics of Dilute Polymer Solutions	Newcastle	MT/2043/027	1.2
				5.7
16.3	Application of ESR to Study of Free Radical Intermediates in Oxidation	Leicester	MT/2026/07	1.8
	Yield and Deformation Behaviour of Polymers	Leeds	MT/2062/050	1.7
	Fracture Mechanisms of Tough Polymers	Leeds	MT/2062/055	2.6
	Deformation Behaviour of Glass-filled Polypropylene	Cranfield	MT/2028/063	1.7
	Shock Loading of Glass-Reinforced Plastics	Queen Mary College	MT/2042/052	4.6
	Injection Moulded Crystalline Polymers	Bristol	MT/2034/029	2.0
	Flow in Plastics Injection Moulds	Umist	MT/2044/064	1.9
	Polymer Chain Flexibility	Strathclyde	MT/2065/014	1.1
	Reaction of Organic Halides with Carbonyl Compounds	Lancaster	MT/2182/06	1.3
	Synthesis of New Thermoplastic Elastomers	Liverpool	MT/2067/027	1.4
	Chemical Modification of Polydienes	Aberdeen	MT/2116/06	1.5
				21.0
16.4	Photo-oxidation of Olefin-Vinyl Co-polymers	St Andrews	MT/2061/012	1.5
	Photo-oxidation of Polymers	Southampton	MT/2040/0145	1.9
				3.4
16.5	Metal-Polymer Adhesion	Strathclyde	MT/2065/09	3.2
	Study of Fractured Surfaces	Queen Mary College	MT/2042/055	2.2
				5.4
		Total - Universities		35.5
EXTRAMURAL - INDUSTRY				
ERDE				
16.3	Evaluation of ERDE Co-polymers	RAPRA	K/43A/153	2.9
	Dynamic Properties of Rubbers and Plastics	RAPRA	KB/1/0685	0.2
	Rubber Dampers for Transient Loads	RAPRA	KA/83A/607	2.9
		Total-Industry		6.0
		GRAND TOTAL		41.5