IRIS Public Record

Key Information

Main: AIR MATERIEL COMMAND

Rcvd:		Rel	1987/12/07
Indexer ID: 38	Entered Date:		
QC ID:	QC'd Date::		
Scanner ID:	Scanned Date:		
Acc ID	Acc Date:		

Document Type:
Call Number: **203.1 V.13**
IRIS Number: **00142362**
Accessions Notes: REF 00142350
Old Accession Nbr: **4937-81**
Title:
Beginning Date:
End Date:
Publication Date: **1945/06/26**
Classification *UNCLA*
Media Roll #: **3862** First Frame: **716** Last Frame: **739** Linear Feet: **0**
Old MFlm Roll # **A2092B** Audio Rec:
NUMPAGE **0**
Title Extensions: **VOL 13 OF 14**

Abstract DOCUMENT CONTAINS REPORT COVERING GENERAL PROPERTIES OF PROPELLANTS WHICH ARE CRITICAL FOR THEIR USE IN ROCKETS AND JET PROPELLED DEVICES, AND SPECIFIC PROPERTIES OF EXISTING PROPELLANTS.

Descriptive Notes: ACTUAL INCLUSIVE DATES SEP 39 TO MAY 45.

Title Added Entries SOLID PROPELLANTS FOR ROCKETS AND OTHER JET PROPELLED DEVICES

Author: EXPLOSIVES RESEARCH LABORATORY
Subject:
Major Command:
Doc Link:

Administrative Markings

No Administrative Markings Listed
Security Review Information:

[illegible]

Fuels 1368

[redacted] copy 3

Solid Propellants for Rockets and Other Jet Propelled Devices

Report prepared for the

Scientific Advisory Group

Army Air Forces

P.R.C.

by

Louis P. Hammett
Research Director

Explosives Research Laboratory
Bruceton, Pennsylvania

June 26, 1945

DECLASSIFIED
DOD DIR 5200.9, 27 Sep 58

49378-81

[redacted]

I. Summary

There is much opportunity for the improvement of existing solid propellants for rockets and other jet propelled devices in the sense of making possible the use of a lower ratio of motor weight to propellant weight. A decrease in this ratio can increase materially the pay load or the velocity of the rocket or decrease the total weight of the motor required to yield a given performance. There are also large opportunities for improved methods of production, especially of large charges, which will decrease the cost of the product and lessen the burden on the country's manpower and ability to produce heavy machinery. In both these directions promising lines of attack are already apparent and have been partially explored.

II. Introduction

This report is primarily concerned with the lines of research and development which may profitably be pursued in the search for better solid propellants for rockets and other jet propelled devices. For this purpose it discusses first those general properties of propellants which are critical for their use in such devices and second the specific properties of existing propellants.

III. Properties of Solid Propellants

1. Critical Properties of Solid Propellants

(a) Basic Prerequisites for a Useful Propellant

In order to come into consideration as a solid propellant for jet propulsion a material must be capable of being formed into masses, called grains, of a suitable size and geometry. These grains must when ignited undergo a self-sustaining combustion reaction which produces hot gaseous products, and the reaction must maintain itself at rocket pressures and preferably at pressures of 500 p.s.i. or less. The combustion reaction must occur only on the surface of the grain and the linear rate of recession of the surface must be essentially constant under constant external conditions. The burning must therefore not go over to detonation or penetrate through pores in the solid. The grain must have a certain minimum resistance to distortion under slowly applied forces and to rupture under impact. The composition must satisfy the same requirements of chemical stability and resistance to ignition from impact and friction as a high explosive does (See Report "Properties of High Explosives" by D. P. MacDougall).

These properties cannot be predicted in advance of experiment. The combination is rare enough so that the first sifting of candidate materials for use as propellants may well be by way of the preparation of grains and investigation of their burning properties. For instance it has so far been impossible to burn at rocket pressures many materials which are thermodynamically suitable for propellants even though in some cases they are useful gun propellants (e.g. RDX-nitrocellulose compositions).

(b) Effective Gas Velocity or Specific Impulse

The velocity V imparted to a rocket or other jet propelled device is given by

$$V = w \ln \frac{M+m}{M} \approx \frac{mw}{M + (m/2)}$$

in which M is the mass of the object propelled exclusive of propellant and m is the mass of propellant. The effective gas velocity, w, is the momentum of the gas issuing from the jet per unit weight of propellant consumed. (Specific Impulse $I = w/g$). The value of w depends on the geometry of the nozzle and on the pressure in the motor chamber. It is, however, always possible to

employ a nozzle which for a given pressure yields the maximum value of $\underline{w}$ (optimum expansion ratio) and this maximum value is not very sensitive to the pressure. (It increases by 17% between 300 and 1500 psi and the effect is essentially the same for all propellants.)

The effective gas velocity is, therefore, a characteristic measure of the ability of a propellant to impart momentum to a rocket projectile or other object and the highest possible value is desirable. The values for propellants currently in use range from 5500 to 7500.

Given sufficiently complete and precise thermochemical data a theoretical effective gas velocity may be calculated with a high degree of precision if all of the products of combustion are gaseous, and to a rough approximation if some are solid or if the thermochemical data are incomplete. In most cases these computed values, with small corrections for heat losses and the like, agree well with experiment; some large discrepancies are attributed to a failure of the system to attain chemical equilibrium, to which state alone the calculations apply. With these reservations the value of $\underline{w}$ is to a useful approximation proportional to $\sqrt{n\, T_c}$, where $\underline{n}$ is the number of moles of gas produced per unit weight of propellant and T_c is the flame temperature. With carbon compounds T_c cannot be greatly increased over values already available with double base propellants because of heat absorbing dissociation reactions. The value of $\underline{n}$ might be increased by employing compounds of high energy and hydrogen content such as cyclonite or Nitroguanidine if their reluctance to burn can be overcome. It seems most unlikely, however, that an increase of as much as 10% over the effective gas velocity of double base powder can be attained in this way. The use of materials with high heats of oxidation such as aluminum, boron, or beryllium or of oxidizing agents of high energy and oxygen content such as potassium perchlorate does not appear to offer much prospect of large increases in effective gas velocity because much of the reaction product is not gaseous. It appears, therefore, probable that the upper limit of effective gas velocity obtainable from ordinary chemical reactions has already been nearly, if not quite attained.

(c) Factors Affecting Loading Density and Motor Weight

There are a variety of ways in which better propellants can improve rocket performance without any increase in effective gas velocity over values now available. For existing types of artillery rockets projectile velocity at constant pay load or pay load at constant velocity is increased nearly as rapidly

by an increase in weight of propellant as by an increase in effective gas velocity and is increased about half as rapidly by a decrease in motor weight. The percentage effects of given changes in these factors upon velocity and pay load are illustrated in Figures 1 and 2 using the existing 5.0" HVAR as a point of reference. Similar effects would be obtained with any other currently used rocket.

It is obvious that any change in propellant properties which decreases the ratio of motor weight to propellant weight has an effect comparable to that produced by an increase in effective gas velocity. That there is room for much variation in this ratio is evidenced by the data of the following table for various existing rocket motors.

Table I

Designation	Powder	Motor Wt. Mm	Propellant Wt. Mp	Mm/Mp
5".0 HVAR (CIT)	Double base dry extruded	64.4	24.0	2.68
11.75" Tiny Tim (CIT)	"	445	146	3.05
115 mm. Rocket (ABL)	Double base solvent type	47	14	3.35
115 mm. Rocket (ABL)	Solvent composite MJ	47	20.5	2.29
Galcit 12 sec. 1000 lb. thrust unit	Galcit	137.5	64.5	2.12
JB-2 Launching motor, current	Molded Comppsite 492	204	121	1.69
JB-2 Launching motor, projected	Molded Composite 492	125	121	1.03

The profit derivable from this source does decrease at very high projectile velocities for which the ratio of propellant weight to total weight is large, but remains important for any probable rocket projectiles. It also decreases for airplane

Figure 1

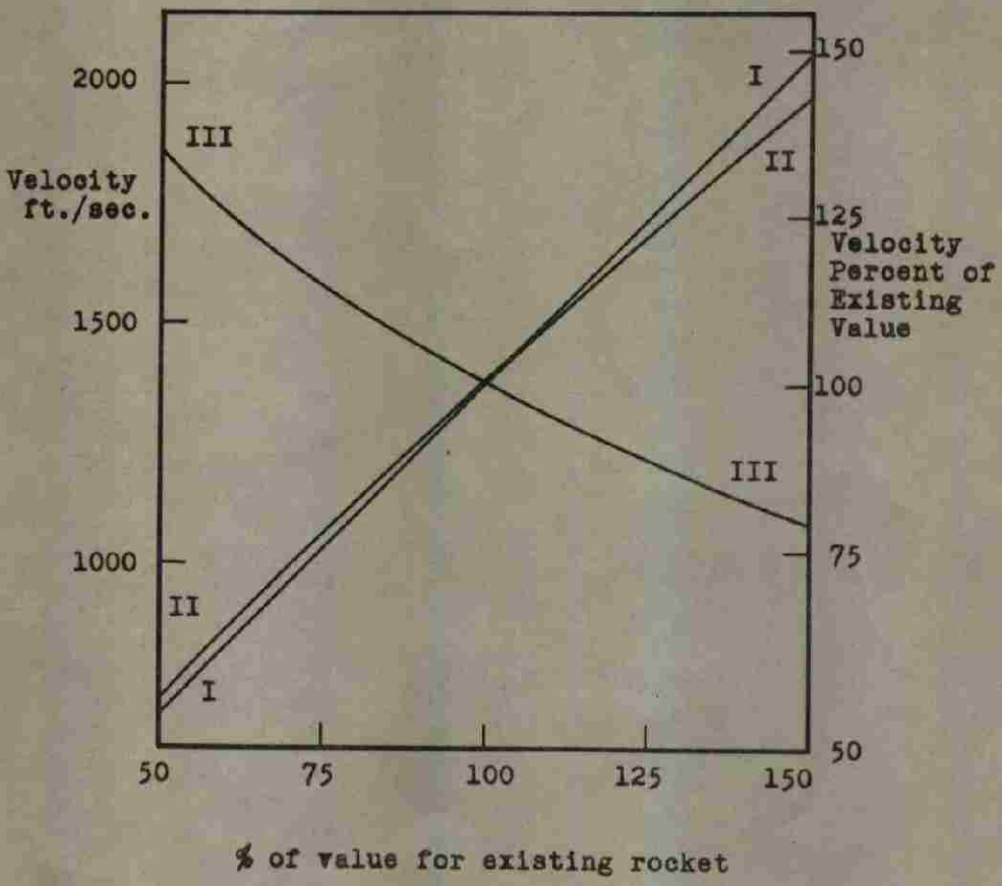

2000
1500
1000
Velocity ft./sec.
III
I
II
III
II
I
150
125
100
75
50
Velocity Percent of Existing Value
50
75
100
125
150
% of value for existing rocket

Figure 1

Effect of changes in effective gas velocity in propellant weight, and in motor weight on velocity of 5.0" HVAR. Ordinates are rocket velocities.

Curve I. Effect of variation in effective gas velocity over range from 50% to 150% of value for existing rocket (7130 ft/sec). All weights constant.

Curve II. Effect of variation in weight of propellant over range from 50% to 150% of value for existing rocket (24.0 lb). Effective gas velocity (7130 ft/sec) pay load (48.2 lbs.) and motor weight (64.4 lb) constant.

Curve III. Effect of variation in weight of motor over range from 50% to 150% of value for existing rocket (64.4 lb.). Effective gas velocity (7130 ft/sec), pay load (48.2 lb) and propellant weight (24.0 lb) constant.

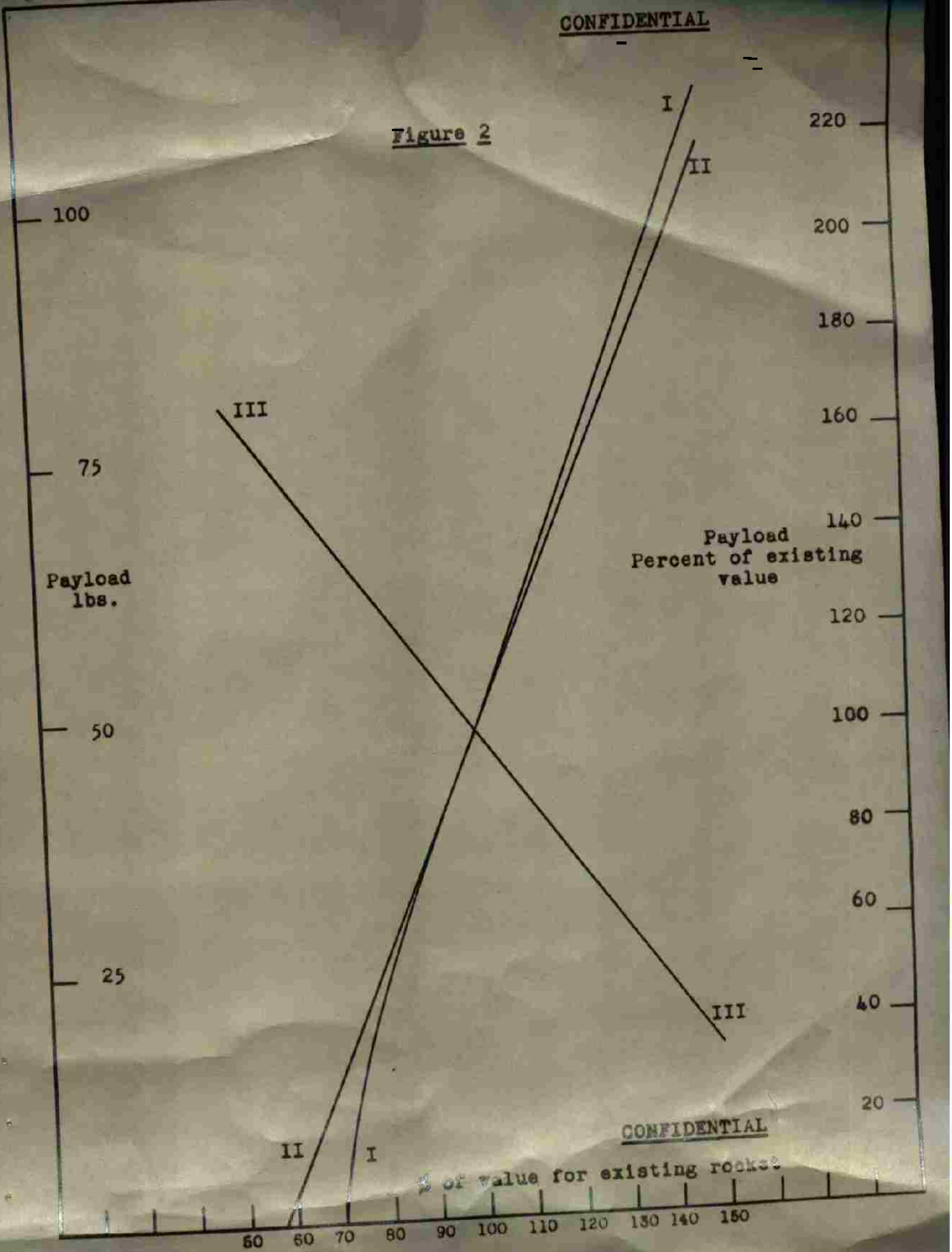
Figure 2

Effect of changes in effective gas velocity, in propellant weight, and in motor weight on pay load of 5.0" HVAR. Ordinates are values of pay load

Curve I.	Effect of variation in effective gas velocity over range from 50% to 150% of value for existing 5.0" HVAR (7130 ft/sec). Motor weight (64.4 lb.) propellant weight (24.0 lb.) and projectile velocity constant (1375 ft/sec).
Curve II.	Effect of variation in weight of propellant over range from 50% to 150% of value for existing rocket (24.0 lb). Effective gas velocity (7130 ft/sec), projectile velocity (1375 ft/sec) and motor weight (64.4 lb.) constant.
Curve III.	Effect of variation in weight of motor over range from 50% to 150% of value for existing rocket (64.4 lbs). Effective gas velocity (7130 ft/sec), projectile velocity (1375 ft/sec) and propellant weight (24.0 lbs) constant.

CONFIDENTIAL

Figure 2



CONFIDENTIAL

take-off and similar systems in which the weight of the rocket motors is a small fraction of the total weight. Here, however, the logistic advantage of a low motor-propellant weight ratio is obvious since both motor and propellant must be shipped to the point of use.

The following properties of propellant materials are important in this respect:

1. Since the weight of a rocket motor increases approximately in direct proportion to the gas pressure, while the effective gas velocity varies much less rapidly, a decrease in operating pressure is favorable until it reaches the point where other forces than bursting pressure become important factors in motor design; certainly as far down as 500 psi. In general solid propellants possess a lower pressure limit, which depends on size and geometry of motor as well as on the propellant, below which they fail to burn or burn irregularly and incompletely. Obviously a low value of this limit is a desirable property of a propellant. In some cases, as in the bazooka, high operating pressures (10,000 psi) are employed to keep the burning time short. A faster burning propellant would permit a lower operating pressure.

It is clear that the advantage of operating at a low pressure at low temperatures vanishes if the pressure becomes four or five times greater at temperatures in the upper part of the operating range. This is one of the advantages of a powder of low temperature coefficient.

2. The rate of burning of a solid propellant varies as a power $\underline{n}$ with the pressure of the gas surrounding it, while the flow of gas through the nozzle varies as the first power of the pressure. This situation admits of a stable steady state only if $\underline{n}$ is less than unity, and the state is the more stable and the less sensitive to disturbing influences such as variations in the burning surface the greater the value of 1-n. In this sense the difference between the exponent 0.75 of most double base powders and the 0.4 - 0.5 exhibited by composite propellants is a large and important one which leads to materially greater reproducibility and reliability with the latter material. A lower factor of safety and a lighter motor are therefore permissible.

The value of a low exponent is especially great in the usual type of artillery rocket in which a tubular or cruciform grain burning over all or nearly all of its surface is contained in a long motor of small diameter. When the attempt is made to

reach the highest possible ratio of propellant weight to motor weight the limiting factor becomes the space available for flow of gases toward the nozzle (the port area). If this is small a pressure differential is set up, the burning rate increases in the high pressure region, and the whole effect is magnified by an amount which is greater the greater the exponent. Consequently a low exponent permits a higher propellant-motor weight ratio for a specified time of burning. A high density propellant is of course desirable for the same reason, as is one resistant to distortion under applied forces, since any bulging of the grain under the forces of set back and pressure drop reduce the port area.

3. By all odds the most effective way of obtaining a high loading density and hence an optimum propellant-motor weight ratio is to employ a cylindrical grain burning from one end only. Such a grain can fill the cross section of the motor completely and the whole cross section is likewise available as port area in the region between the burning surface and the nozzle. Furthermore the material need not be stiff since bulging will not infringe on the port area. This arrangement requires a method of restriction to prevent burning on other surfaces than the cylinder base. Restriction appears to be practicable with the propellants now available and is a desirable property for a new one.

With currently available propellants rates of burning are such that end-burning charges are entirely suitable for the long-burning charges (8 to 40 seconds) required for assisted take-off of airplanes and for propulsion of guided missiles, mine-clearing snakes, hydrobombs and the like. For artillery rockets burning rates of from one to two orders of magnitude greater than those now available will be necessary if the total burning times of such charges are to be brought down to the necessary 1 to 2 seconds.

For end burning charges, and hence at present only for take-off and similar applications, there is much advantage in a single large diameter charge as compared to a multiple of smaller cylinders. In the latter case the motor diameter and hence the motor weight must be materially greater. For purposes requiring large thrust the possibility of fabrication in charges of large diameters (8 to 16") is therefore an important property of a propellant. The advantage of a single charge largely disappears in artillery type rockets in which the requirement of sufficient port area enforces a low loading density which can be met either by a single or by a multiple charge.

4. Another method by which motors might be lightened is to reduce the temperature to which the motor walls are heated by the propellant gases, since the strength of metals decreases materially at temperatures easily reached by the motor walls in conventional designs. By all means the most effective insulating material is the propellant itself. If this burns from a central perforation and the exterior is essentially in contact with the walls light but low melting and inflammable materials like magnesium and plastics become practicable. If the perforation has a star shaped cross section sufficiently near neutral burning to give reasonably constant pressure may be attained with a propellant of low exponent. The propellant requirements are therefore low exponent and the practicability of restricting the external surface and bringing it in close contact with the motor wall.

(d) Temperature Coefficient

The rate of burning of a propellant increases with increasing temperature of the solid material. With the usual double base propellants the pressure in a rocket motor and the thrust obtained from it are 5 times as great at 140°F as at -40°F, and the time of burning is 1/5 as great at the higher temperature as it is at the lower. With the composite propellants and with Galcit the corresponding factors are 1.5 and 0.67. A low coefficient is indispensable for airplane take-off applications and other cases in which the individual values of thrust and burning time and not merely the thrust-time product are important. With artillery rockets it simplifies design, lightens motors and eliminates or greatly reduces the aiming correction for the temperature of the propellant.

(e) Miscellaneous

Smoke is an undesirable feature for some applications, as for ground fired rockets, but is unimportant for others, such as airborne missiles. The same considerations apply to flash, i.e., a luminous jet.

For long burning charges for assisted take off, guided missiles and the like a low gas temperature is desirable, since it eases the problem of materials for the construction of nozzles and other metal parts. The decrease in flame temperature may generally be compensated partially by an increase in the number of moles of gas formed per unit weight of propellant so that the loss in effective gas velocity which results is not large. A cool propellant is usually, however, a slow burning one, which is frequently a disadvantage. The nozzle problem does not however appear to be insoluble even for the hottest existing

propellants, although highly refractory and relatively expensive materials such as molybdenum may be required.

In so far as tests have been made all known solid propellants as loaded in metal motors can be ignited by the impact of a rifle bullet. It would be desirable to eliminate this sensitivity.

2. Properties of Existing Propellants

(a) Double Base Powders

Double base powder is a plastic material containing Nitrocellulose and Nitroglycerin or a Nitroglycerin equivalent, such as diethylene glycol dinitrate. It always contains a small proportion of a stabilizer such as Centralite and may contain up to 20% of other plasticizers called coolants, such as Centralite, phthalate esters, triacetin, dinitrotoluene or the like. The product is stiffer the higher the proportion of Nitrocellulose, the usual proportion being from 40 to 50%. It is not brittle, not easily ignited by impact, except when very finely subdivided, and its chemical stability is adequate but could be improved with advantage. The effective gas velocity of a 40% nitroglycerine, 60% nitrocellulose powder (7500 ft/sec) is not likely to be exceeded to any large extent by any new propellant composition depending upon ordinary chemical reaction. The value drops somewhat but not very rapidly as the content of Nitroglycerine is decreased or as coolants are added.

Until recently all known double base powders had high exponents (0.70 to 0.75) and high temperature coefficients (1.5%/°C.). Lately a powder has been developed by the Allegany Ballistics Laboratory and the Hercules Powder Company with an exponent of 0.5 and a temperature coefficient of 0.5%/°C. An investigation of a captured Japanese propellant has shown it to possess a similarly low temperature coefficient. Both of these propellants are relatively slow burning ones, which somewhat limits their usefulness, and the effective gas velocities are about 10% below that of hotter powders. The fact that they differ only by very small variations in composition from other powders with high exponents and temperature coefficients suggests strongly that these limitations may be removed by further investigation. It has further been pointed out by Pauling that a charge containing particles or strands of small diameter composed of a fast burning powder of low temperature coefficient embedded in a matrix of slower burning powder of high temperature coefficient possesses as a whole the low coefficient of the particles. In this case the grain does not burn by recession of a plane surface but by the formation of a

broken surface whose magnitude is determined by the behavior of the faster burning powder. This procedure, already proven experimentally, makes it possible to eliminate the undesirably high temperature coefficient of double base powder by the addition of a proportion of solvent extruded composite propellant so small as to produce negligible amounts of smoke.

The lower pressure limit below which double base powder will not burn regularly and completely is undesirably high, especially where small grains are concerned. The available range of burning rates is from 0.1 to 4 in/sec, the higher values being attained only at undesirably high pressures. Restriction of the burning surface by application of a plastic material such as cellulose acetate is possible, although the ability of restricted grains to maintain the desired properties over long periods of storage has not been completely proven.

There are four available methods for forming grains of double base powder:

(1) In the solvent extrusion process the ingredients are mixed with volatile solvents to a soft dough and pressed through a die to form strands. These are then dried to remove the solvent. The machinery required for this process is relatively easily constructed and is currently available for the production of very large quantities of powder. Unfortunately, the process is limited to the preparation of grains of not much over 1" in diameter, because larger sizes crack or distort badly during the removal of the solvent.

(2) In the dry extrusion process the ingredients of the powder are mixed on roll mills and the product is pressed warm through suitable dies. In order to obtain a satisfactory product a certain minimum ratio of press diameter to grain diameter must be maintained. Since the presses are destroyed, apparently inevitably, at intervals and since their cost and the damage produced by an explosion increase rapidly with the size of the press it is perhaps impracticable to produce grains of much larger diameter than 5" by this process. In addition to the presses, which are heavy and expensive equipment, large numbers of expensive roll mills are required. Because the material must be soft enough to extrude at a reasonable pressure at a temperature which is limited by the instability of the material dry extruded double base powder is not as stiff at service temperature as is desirable. A propellant used by the Germans has the remarkable property of becoming much stiffer on storage

after extrusion than when freshly extruded. This property appears to depend upon some very special choice of the type of Nitrocellulose used in this composition.

(3) The cast double base process invented by Kincaid and Shuey of the Explosives Research Laboratory is still in an experimental stage but offer every promise of successful development. In this small particles of a Nitrocellulose-Nitroglycerine powder are mixed with a sufficient quantity of a mixture of Nitroglycerine with an active solvent for Nitrocellulose, such as triacetin, to form a pourable slurry. This is cast in a mold, or in a plastic tube which serves as a restricting material where this is desired. On heating for one day at 60°C the mass sets up to a tough grain with completely satisfactory burning properties. There appear to be no limits to the size and shape of charge that may be produced by this process, and it is particularly advantageous for very large charges. The actual casting process requires no heavy equipment of any sort and should be an exceptionally cheap and simple manufacturing technique. The small granules which are the raw material may be made by the solvent process in the same way as rifle powder is manufactured and can probably be made by an even simpler and cheaper process developed by the Western Cartridge Company (ball powder). The casting process is exceptionally suitable for the preparation of charges of low temperature coefficient of the Pauling type.

A SECRECY ORDER has been issued by the Commissioner of Patents prohibiting unauthorized disclosure under penalty of Public Laws Nos. 700 and 239

(4) In the molded double base process of the Western Cartridge Company small granules of "ball powder" are mixed with a few percent of a plasticizer and compression molded to form grains. Details of the process are not available for publication and the product has not been tested on any large scale. The process deserves further investigation.

Double base powder is smokeless, except that some of the cooler powders produce limited amounts of black smoke. The flame temperature and hence the destructive effect upon nozzles roughly parallels the burning rate.

The raw materials required for double base powder, namely Nitroglycerine and Nitrocellulose, are articles of commerce prepared in very great quantities, and the cellulose, glycerine, and the nitric and sulphuric acids from which they are prepared are widely available.

Solvent extruded powder is currently used in the Bazooka and in the 4.5" Army rocket. Dry extruded powder is employed in enormous quantities in rockets now widely used in service and

notably in the 5.0" HVAR, the Tiny Tim and in various spinner rockets. Cast double base powder is being developed with the immediate aim of producing a unit for airplane take-off delivering 1000 lbs. thrust for 8 secs. or more.

(b) Cast Perchlorate Powders

The Galcit propellant is prepared by stirring together finely ground potassium perchlorate and a hot asphalt-oil mixture, pouring into the motor which has been lined with a layer of asphalt, and allowing to cool. Alternatively it may be cast in a mold, removed and coated with asphalt and tape. The product is too soft at the higher service temperatures to be employed in applications where it is not directly supported by the motor wall. It is not brittle enough even at low temperatures to be easily fractured by rough handling. It is extremely stable and is difficult to ignite. The effective gas velocity is of the order of 5400 to 5900 ft/sec, but its high density partially compensates for this. The exponent is undesirably high, 0.75, which leads to considerable variability in performance. The temperature coefficient is low (0.5%/°C). The powder produces large quantities of white smoke (potassium chloride). The greatest weakness of the propellant is inherent in the nature of asphalt, namely that it flows at high temperatures and becomes hard and cracks from shrinkage at low ones. Consequently the range of temperatures over which it may be used is undesirably narrow. It does not burn satisfactorily below 1000 psi and the motors must, therefore, be relatively heavy. It has a high burning rate (1.0 to 1.6 in/sec), which is suitable for end burning grains for airplane take-off and similar applications. Restriction of the burning surface is practicable by methods already described.

The outstanding advantage of the material is the extraordinarily simple process by which it is produced. The supply of potassium perchlorate is currently limited but it could be very largely expanded, since it is produced by an electrolytic process from potassium chloride. It is of interest that this is the only solid propellant known whose preparation does not depend ultimately upon nitric acid.

The propellant produces a great deal of white smoke and the flame temperature is high enough to make nozzle erosion a problem which has, nevertheless, been solved for burning times up to 30 secs. The Galcit propellant is currently in service use for the assisted take-off of Navy planes.

It has been found at the Explosives Research Laboratory that the substitution of materials containing long chain polymeric molecules for the asphalt of the Galcit propellant materially widens the temperature range over which it may be used, and furthermore that the addition of 5% of flake aluminum reduces the exponent to approximately 0.60. A mixture of potassium perchlorate, aluminum, and a fusible ethylcellulose-castor oil composition may be cast in the same way as Galcit and shows a material increase in the range of temperature over which it may be used. If the GE Permafil resin is employed instead of the ethyl cellulose castor oil composition the composition may be cast at room temperature and hardens without shrinkage by chemical action to a rubbery material of essentially unlimited temperature range. These materials are still in the experimental stage but should be capable of very rapid development and application. The necessary raw materials are available in large quantities and the costs are not prohibitive.

(c) Molded Composite Propellants

These propellants, developed by the Monsanto Chemical Company and the Explosives Research Laboratory, are prepared by milling together in edge runner mills a mixture of ammonium picrate, alkali nitrate, and a small proportion of a resinous binder. The powdery product of the mills is then formed by compression molding at about 10,000 psi into grains of the desired shape and size. The material is exceptionally hard and resistant to distortion but is somewhat brittle. By the use of compressed cork supports, however, the grains may be made to withstand any reasonable rough handling. The effective gas velocity is of the order of 5500 ft/sec, but the high density and low exponent make it possible to obtain the same velocity with this propellant in a given rocket as with a double base powder charge of the same burning time. Substitution of alkali perchlorate and nitroguanidine for alkali nitrate and ammonium picrate would bring the gas velocity approximately up to that of double base powders, but these compositions have been investigated on the laboratory scale only. The compositions burn completely and smoothly at pressures at least as low as 500 psi. Restriction of the burning surface can be carried out with relative ease and is thoroughly proven. By varying the proportions of alkali nitrate and ammonium picrate and the particle size of the nitrate a range of burning rates from 0.25 to 1.0 in/sec at 1000 psi is readily accessible, and a still wider range of rates may be attained by operation at low and high pressures.

The propellant produces considerable amounts of white smoke,

the quantity being smaller with the slower burning compositions which contain smaller proportions of alkali nitrate.

The fabrication of this propellant requires large numbers of small edge runner mills, although improved techniques may probably be developed by further investigation. It also requires large presses, but a press capable of producing not over 3" diameter double base charges is suitable for the production of 8.5" diameter composite propellant charges. The press operation is, however, materially slower in terms of powder produced per unit time with the composite propellant than with double base powders.

The raw materials for this propellant are all currently manufactured in large amounts and ammonium picrate is perhaps the only available raw material for propellants in which a surplus exists.

This powder is currently employed in the experimental launching of JB-2 bombs. The launching requires four rockets, each containing an 8-1/2" O.D. 2-1/2" I.D. 37" long grain weighing 120 lbs. and burning 1.75 sec. Applications involving end burning grains of 8-1/2" or 12" O.D. and with burning times up to 50 sec. are also being developed.

(d) British Plastic Propellant

This is similar in composition and in ballistic properties to the molded composite propellant which indeed derives historically from early British experiments on picrate propellants. In contrast the resinous binder is larger in amount and more fluid. The materials are milled on roll mills and pug mills to yield a putty-like product, which is molded directly into the motor at relatively low pressures (ca. 1000 psi). The presses may therefore be lighter and more easily constructed than with the molded composite propellant. It is currently being developed in the form of central burning charges which insulate the motor wall and are restricted from burning on the outer surface of the charge by the wall itself (See Section 1-c-4).

(e) Solvent Extruded Composite Propellants

These consist of a filler composed of carbon black and either potassium perchlorate or potassium nitrate dispersed in a binder (35% or more of the total) composed of double base powder. They have the ballistic advantages of low exponent and temperature coefficient characteristic of composite propellants but are prepared in the standard equipment and by the normal methods

used for solvent extruded double base powder. As such the grain diameter is limited but the limit is probably higher than with straight double base powder because these powders shrink less on drying. Some experiments indicate that the solvent extruded powder may be reextruded by the dry process in any granulation desired. The powder produces white smoke in an amount dependent upon the proportion of potassium salt present.

EJA powder contains 56% potassium perchlorate and 9% carbon. It was developed for use in the Army 4.5" rocket in which it gave excellent performance, but the development has been sidetracked by decreased interest in the use of the rocket. The powder is also important for use as fast burning low temperature coefficient particles or strands in charges of the Pauling type (see Section 2-a).

MJA powder contains 43% potassium nitrate and 7% carbon. In the Allegany Ballistic Laboratory 115 mm rocket it permits a rocket velocity of 1200 ft/sec compared with 950 ft/sec for a double base charge, because its low exponent and temperature coefficient and high density permit a higher loading density.

BBP powder contains only 7.8% potassium perchlorate and 1.2% carbon and is nearly enough smokeless to be employed in the Bazooka for which it has been adopted for service use. The temperature coefficient is approximately one half of that shown by double base powder in the same weapon. With it the bazooka may be employed in cool weather without the injury to the gunner and the high dispersion which occur when burning is not completed inside the projector. These advantages are retained even with a 15% increase in propellant weight which permits the use of a higher pay load and a materially greater effectiveness of the projectile.

(f) The Aberdeen Propellant

This consists of a mixture of potassium perchlorate metallic aluminum and metallic titanium with a resinous binder. It may be molded directly into a metal motor to form an end burning charge and is claimed to have a burning rate of the order of 50 in/sec. If these claims are substantiated the material is an answer to the problem stated in Section 1-c-3.

IV. Conclusions and Recommendations

The following recommendations serve only to indicate that numerous lines of investigation which have high promise of developing improved performance are immediately obvious. Any active and effective research organization may be expected to uncover further directions of advance which would be more profitable than those listed. Since the effect of improved propellants upon rocket performance is for the most part indirect, and by way of permitting improved motor design, it is most desirable that any research group working on propellants should cooperate closely with workers in the field of rocket design.

(1) Artillery rockets

In this field the present situation is that nearly all American rockets in service use employ a single propellant, a particular composition of double base powder. There has been during the war the most effective activity in designing motors around this powder contrasted with relatively little progress in the direction of using better powders. It is, therefore, probable that the limit of performance of this powder has been reached, but, as the above discussion shows, materially improved performance may be expected from the use of different powders. Promising lines of investigation are:

(a) The design of motors and projectiles around the propellants of low exponent, low temperature coefficient, high density and low pressure limit which already exist in order to exploit to the fullest the potentialities of these powders.

(b) The development of powder charges of the Pauling type which combine the advantages of low temperature coefficient and of high effective gas velocity and burning rate with an essentially complete absence of smoke.

(c) The development of rocket charges burning outwardly from a central perforation in which the propellant insulates the motor tube from the hot gases.

(d) The search for propellants of much higher burning rate than are now available so that end burning charges may be employed in artillery rockets.

(e) Studies looking toward the elimination of flash.

(2) Large and long-burning charges

The techniques of production of charges of this sort are in their infancy. The only fully developed and demonstrated types are Galcit units of 1000 lb. thrust and 8 or 12 sec. burning time and Monsanto units of 11,000 lbs. thrust and 2 sec. burning time. The possible applications of larger and longer burning charges are myriad and their military importance is extremely high.

(a) The cast double base process for producing charges of the Pauling type is still in an experimental stage. A successful development will permit the production at relatively low price of units of any desired thrust and burning time which are essentially smokeless and which have a low flame temperature.

(b) The replacement of the Galcit asphalt by other materials can eliminate the objectionable narrowness of the temperature range within which the Galcit propellants are usable, and a decrease in the exponent may be expected to improve the reproducibility of these units. The simple and inexpensive casting process by which these charges are produced justifies a great deal of effort to improve the quality of the product.

(c) The Monsanto molded composite propellant has been made in units burning up to 50 secs. on an experimental scale. Completion of this development is clearly desirable.

(d) In view of the difficulties encountered from nozzle erosion investigations looking toward the development of compositions of low flame temperature are most desirable.

(3) General

(a) The most important advance that may be hoped for in solid propellants in general is the development of techniques of production which will materially reduce the cost of preparing the charges and the requirements in manpower and heavy machinery. The Galcit propellants and the cast double base process clearly indicate the possibility of very great economies in this direction which should be applicable to rocket charges as well as to larger units. It appears probable that the cost of cast double base powder charges will be not over 1/5 of that of dry extruded powder.

(b) The existence of isolated compositions of double base powder having low temperature coefficients and low exponents indicates the desirability of a continuing search for other compositions

which possess these qualities but which have higher effective gas velocities and burning rates.

(c) In this direction and generally for the whole field of solid propellants the most serious deficiency is the complete lack of any satisfactory theory of the factors which determine the burning rate. Theoretical investigations of this problem carried out in connection with empirical studies of rates, exponents and temperature coefficients should be of extreme value.

(d) The Nitrocellulose-Nitroglycerine plastic of double base powder is not in principle the only composition which would have similar mechanical properties and a sufficiently high effective gas velocity. It has the disadvantage inherent in compositions consisting of nitrate esters of a relatively low stability. The search for plastic or high polymer materials based upon other structures is desirable. Particularly from the side of the Navy there is interest in the development of propellants which do not contain Nitroglycerine, shows volatility is a potential hazard.

(e) A search for solid propellant compositions which are not ignited by the impact of a rifle bullet is desirable.