Parachute Mortar Design

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Mortars are used as one method for ejecting parachutes into the airstream to decelerate spacecraft and aircraft pilot escape modules and to effect spin recovery of the aircraft. An approach to design of mortars in the class that can accommodate parachutes in the 20-ft–55-ft-diam size is presented. Parachute deployment considerations are discussed. Comments are made on the design of a power unit, mortar tube, cover, and sabot. Propellant selection and breech characteristics and size are discussed. A method of estimating hardware weights and reaction load is presented. In addition, some aspects of erodible orifices used in these high-low pressure systems are given as well as comments concerning ambient effects on performance. This paper collates data and experience from design and flight qualification of four mortar systems, and provides pertinent estimations that should be of interest for programs considering parachute deployment.

Nomenclature

A = deceleration of vehicle, ft/sec^2
C_1 = dimensionless velocity coefficient
C_2 = dimensionless power unit internal breech volume coefficient
C_3 = dimensionless reaction load coefficient
D = mortar tube bore, ft
F = maximum reaction load, lb
I = specific impulse of propellant, ft-lbs/lb
J = power unit internal volume, ft^3
K = cartridge body internal volume, ft^3
L = extended length of parachute, ft
M_a = accelerated mass, slugs
M_v = vehicle mass, slugs
P_p = peak pressure of power unit, lb/ft^2
P_v = pressure in power unit at "vent time" or the time when sabot exists tube, lb/ft^2
S = stroke, ft
ΔV = ejection velocity, fps
W_m = total mortar assembly hardware weight, lbs
W_p = weight of propellant, lb
$\dot{x}_{bs}$ = residual velocity at bag strip, fps
γ = propellant density, lb/ft^3

Introduction

PROBABLY the most prevalent deceleration device utilized for aircraft or spacecraft is the parachute. A mortar is a reliable means of imparting enough velocity to the parachute package to assure deployment. Mortars are characteristically used in applications where performance of drogue or pilot chute may be questionable and in applications where deployment time should be minimized, as in aircraft spin recovery. Alternate means are other forced ejection systems using the catapult or pressure bellows and extraction by a rocket. This paper encompasses pack ejection velocity determination, hardware design, reaction load and weight estimation, and ambient effects on performance. Information and data are primarily from the flight qualification tests of four successful flight systems.

Mortar elements are shown on Fig. 1. The sequence of operation is shown in Fig. 2. Energy to operate the mortar is obtained from a propellant which is normally contained in a replaceable cartridge. Upon initiation, a hot gas is generated and the internal volume within the power unit is pressurized to a high pressure, as depicted in Fig. 2a. The gas in the enclosed breech volume is bled through an eroding orifice into the tube volume behind the sabot until the force of the gas pressure acting on it compresses the pack and shears the pins, as shown in Fig. 2b. In Fig. 2c, the pack is accelerated along the tube and imparts the desired velocity at vent time, as shown in Fig. 2d. A goal is to achieve the desired ejection velocity while maintaining a minimum reaction load.

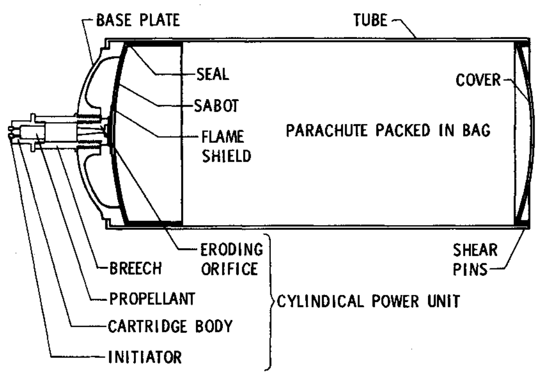

Fig. 1 Parachute mortar elements.

Ordnance devices using the high-low system have typically employed a constant area orifice in transferring hot gasses from the high pressure to the low pressure chamber. The resulting reaction load has an inherent initial peak. An eroding orifice when dilating presents an increasing orifice area which provides an increasing gas mass flow rate. Proper configuration of the eroding orifice can result in a relatively constant pressure in the rapidly increasing volume of the mortar tube, thus effecting a near uniform reaction load over the entire stroke. Characteristic

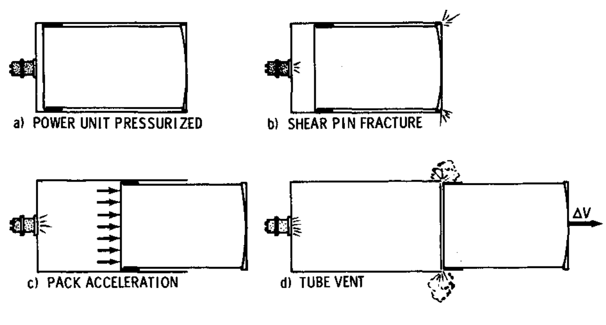

Fig. 2 Mortar operation process.

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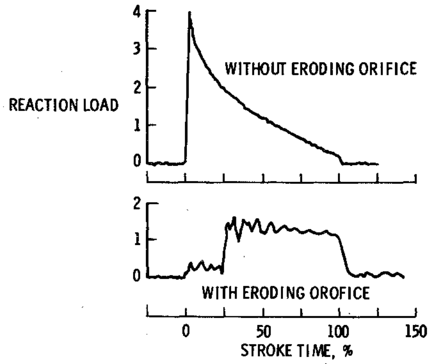

Fig. 3 Orifice effects on characteristic reaction loads.

reaction load curves for both types of orifices are shown on Fig. 3. Note that for an equal impulse, the maximum reaction load employing the eroding orifice is significantly lower.

A mortar has been successfully used in flight to eject a 55-ft nominal diam parachute weighing 118.6 lb at a velocity of 154 fps. Based on this and related experience, it appears reasonable to eject parachutes twice this size.

Parachute Ejection Velocity

An approximation to the minimum parachute ejection velocity was derived in Ref. 1. Neglecting bag and line strip forces and bag drag, and incorporating velocity coefficient (C_1), the approximation reduces to

$$\Delta V = C_1\left(\frac{1}{1-2M_a/M_v}\right)^{1/2}(\dot{x}_{bs}+2AL)^{1/2} \qquad (1)$$

The dimensionless empirical velocity coefficient (C_1) represents the ratio of the ejection velocity obtained from mortar qualification tests to the ejection velocity (ΔV) needed. This coefficient is a means of incorporating variations in mortar performance due to a spread in ambient conditions from trajectory dispersions as well as statistical variations in mortar performance. This coefficient (C_1) for the Type IV mortar was determined to be 1.17. The remainder of the term represents the approximation to the minimum required parachute ejection velocity.[1] The primary factors affecting ejection velocity are the deceleration of the vehicle (A) and the extended length of the parachute (L). The residual velocity ($\dot{x}_{bs}$) is the velocity of the bag relative to the parachute at bag strip representing parachute removal from the packing bag after extending full length. Suggested $\dot{x}_{bs}$ is 5 fps for decelerations on the order of 30 fps. Significantly greater $\dot{x}_{bs}$ is desirable in the presence of higher deceleration rates in order to provide increased stretchout margins. Shown in Fig. 4 are typical ejection velocity curves for two parachutes at various vehicle decelerations; the vehicle mass (M_v) was chosen as 68.94 slugs and the development velocity at bag strip ($\dot{x}_{bs}$) was 5 fps. The average ejection velocity obtained in nine qualification tests for the 125-ft-long parachute was 110 fps.

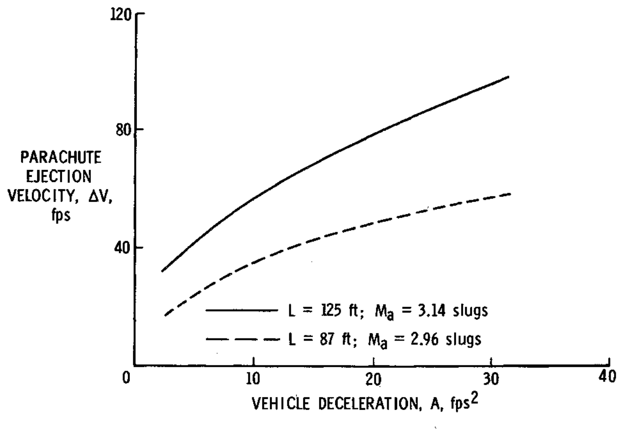

Fig. 4 Typical ejection velocity curves for an entry vehicle employing a parachute.

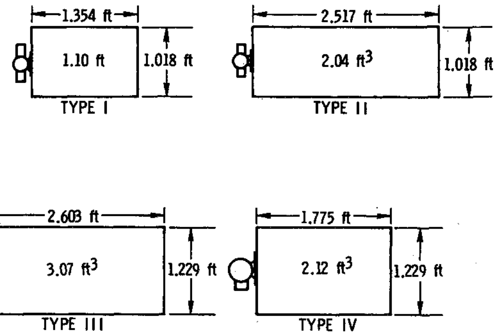

Fig. 5 Relative mortar size.

The ejection velocity in Eq. (1) varies primarily as the square of the vehicle deceleration and of extended length of the parachute. Both quantities should be minimized, insofar as is practical, without adversely impacting other major considerations, in order to minimize the ejection velocity. As will be seen in a later section, the reaction load varies directly as the square of the velocity. Since it is necessary to absorb the reaction load in the supporting structure, it is desirable to minimize ejection velocity and thus eliminate any requirement for additional structural weight.

Mortar Component Design

A mortar system is designed to eject a parachute of known weight at a specific minimum ejection velocity. The general approach is to size the tube to accommodate the packed parachute, size the breech and cartridge to provide the required energy to operate the system, and tailor the eroding orifice design during testing to achieve desired performance.

Performance data presented are derived from the qualification firings for each of four mortar systems. Relative size is shown in Fig. 5. Application and major performance characteristics of each are presented in Table 1. Table 2 provides more detailed mortar physical characteristics, coefficients, and other information of interest.

The Type I mortar was lightweight over-all and very efficient, as characterized by its flat reaction curve. The Type II mortar ejected a parachute approximately twice as large as the Type I. It employed the Type I mortar power unit; as a result, it was underpowered as evidenced by the low pressure in the power unit at vent time (P_v) and the disproportionately high reaction load (F). The Type III mortar performed adequately; no attempt was made to weight optimize the system inasmuch as the vehicle carried approximately 1 ton of ballast. The ejection velocity was probably higher than was needed. The Type IV mortar represents the best effort to date in weight optimization.

Table 1 Parachute mortar performance

Mortar type	Application	Accelerated weight (M_a), lb	Ejection velocity, (ΔV) fps	Maximum reaction load (F), lbf
I	DC-9 & TA4E aircraft	35	118.5	6,380
II[a]	PEPP	87.4	131.0	17,260
III	SPED II	123.7	140.7	24,520
IV	Mars vehicle decelerator	97.0	110.0	11,990

[a] Data typical of several flights.

Table 2 Parachute mortar characteristics

Type	Parachute packed density, lb/ft³	Component weights: Cover, lb	Sabot, lb	Tube assembly, lb	Breech assembly, lb	Total (W_m), lb	Shear pins: Number used	Single shear force, lb
I	31.8	2.00	1.25	9.93	5.00	18.2	12	500
II	36.8	2.00	2.44	13.81	5.00	23.3	40	500
III	38.6	2.58	5.52	55.15	18.85	82.1	40	510
IV	42.2	1.70	2.70	13.50	4.30	22.2	0	...

Type	Power unit: Volume behind sabot, in.³	Peak pressure (P_p), lb/in.²	Pressure at vent (P_v), lb/in.²	Internal volume (J) in.³	Coefficients: C_2	C_3	Propellant: Quantity, g	Basic type	Ambient pressures, Atmospheres
I	19.0	15,700	5,100	17.6	0.491	...	28.014	M-2	1
II	19.0	20,800	830	17.6	0.794	0.53	40.70	M-2	1
III	122.0	16,400	1,160	38.5	0.778	0.60	67.5	M-5	1
IV	34.7	13,380	1,500	25.0	0.741	0.86	56.3	PL6670	0.002

Parachute Container

In addition to mortar elements shown in Fig. 2, a photograph of Type IV mortar hardware is shown in Fig. 6. The parachute is folded and packed in a parachute bag before being inserted into the tube.

Packed density of the parachute impacts mortar performance. Compressibility of packs less than 35 pcf is high, resulting in a reduction of the effective stroke. Most mortar ejected parachutes are packed with the aid of a hydraulic press. Densities of 40 pcf are desirable but are more difficult to obtain because the amount of pack compressive force and packing time increase as the solid density of the parachute material is approached. Densities to 47 pcf have been achieved with elaborate packing equipment, as reported in Ref. 2.

The configuration of a packed parachute is sometimes dictated by considerations external to the mortar such as vehicle volume constraints. To facilitate handling, a parachute is generally packed in a deployment bag which is open at one end. The bag opening should be large enough in diameter to allow the parachute skirt to be stripped out of the bag during chute stretchout. For parachute volumes less than 2 ft^3, a 12-in.-diam bag opening has proven adequate to allow the parachute skirt to be stripped out of the bag. For parachute volumes larger than 2 ft^3, a stroke (S) to bore (D) ratio of 2.5 should be maintained to remain within the limits of S/D experience (Type II mortar) to date and to minimize the reaction load. Reaction load estimates will be discussed in a subsequent section.

The mortar tube assembly is designed to accommodate the packed parachute and provide a means to accelerate the pack and to transfer the reaction load. Aluminum has proven to be an adequate lightweight material for tube design. Minimum thicknesses of approximately 0.1 in. are dictated by the ability of the tube to maintain its shape during machining. Walls 0.060 thick have been achieved by the Chem-Mill R† process after machining, in order to reduce weight. The aluminum base plate employing a truncated section having a spherical radius of 10–20 in. offers a closure having a reduced meridional stress. A knuckle joint at the periphery transfers the longitudinal load from the base plate to a lip on the end of the tube. A room-temperature vulcanizing rubber effectively seals the joint, allowing refurbishment.

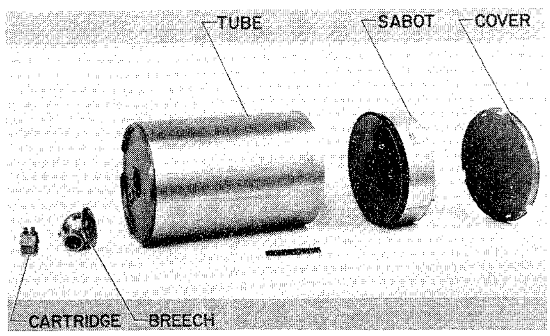

Fig. 6 Typical mortar hardware.

† R registered trademark of North American Aviation, Inc.

During ejection, the sabot provides the internal pressure seal and protects the parachute from the expanding hot gasses. The sabot shown in Fig. 6 is basically an aluminum piston employing a rubberlike, half-chevron seal on its periphery. The seal is most effectively placed on the trailing edge of the sabot to maximize the stroke. The seal and tube bore are lightly coated with silicone grease to enhance sealing qualities and to provide lubrication. Since this seal retains air in the volume behind the sabot during launch ascent depressurization, it may be vented with a short wedge on the tube at the lip of the seal. The peripheral teflon bearing on the leading edge reduces friction and aids in keeping the sabot aligned during operation. A sabot length of approximately 5 in. has been used successfully on all four mortar systems. A silicone rubber or thin metal disk attached to the back of the sabot protects it from the initial impingement of the breech gasses.

The sabot encompasses one end of the packed parachute and pushes the pack out of the mortar tube. The sabot should be thrown aside or retained after venting to prevent it from impacting the decelerating vehicle after chute opening. The sabot is thrown aside as the suspension lines become taut when they begin to pay out of the bag. An alternate means is to employ a break string to impart a lateral motion to the sabot. If necessary, the sabot can be retained at the end of the tube after vent by internally connecting the sabot to the base plate with straps capable of withstanding the flame temperature; this weight penalty is approximately 3 lbs.

The cover holds the parachute in the tube during handling and flight. It is usually aluminum and can be attached to and remains with the apex of the parachute. The cover is initially fastened to the tube with pins that shear upon firing. An external lip positions the cover with respect to the tube and aids in assembly following parachute installation. Cover and shear pins are shown in Fig. 2. An additional method, a cloth cover employing a break string at the confluence point, has been used successfully. Parachute bridle lines are effectively brought out of slots in the cover rather than slots in the end of the tube to maximize the effective stroke.

Shear strength of the pins is established by the total load that the cover will be subjected to during ground handling, launch, and flight prior to parachute deployment. That is, the shear strength required is the product of the accelerated mass and the maximum acceleration along the axis of the tube that can produce ejection. The accelerated mass is comprised of the mass of the parachute, bag, portion of bridle, sabot, cover, and miscellaneous attachments to the cover. Ideally, shear strength of the pins is the minimum permissible in order to minimize pack compression at mortar fire prior to pin shear. Shear pins have been designed to withstand up to 80 g accelerations.

Clearance between cover and tube affects the load at which the pins shear. The failure mode tends to shift from pure shear with no clearance to combined shear and bending with increased clearance. In addition, the clearance between the hole and the shear pin affects the shear load. The force required to shear 2024-0 aluminum pins in this mode was 6% greater than the calculated force.

Power Unit

The power unit is the device in which the potential energy is generated to impart the needed impetus to the chute. A typical vortex power unit[3] is illustrated in Fig. 7. Actuation of the system is accomplished by electrically energized initiator(s) which ignite the propellant. The burning propellant pressurizes the power unit internal volume with high-temperature gas. The hot gasses and burning propellant particles are introduced into the breech through the deflector tangential to the breech walls to create a

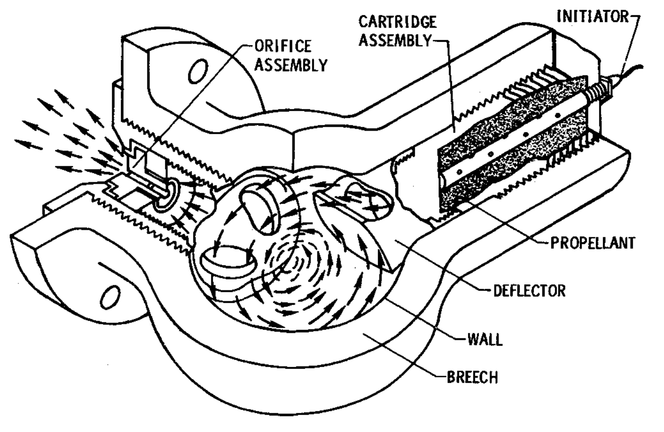

Fig. 7 Typical vortex power unit.

rotation or vortex action in one plane. The heavier propellant particles are forced out against the walls by the resulting centrifugal force. The gas, free of the heavier burning propellant particles, then passes through the eroding orifice on an axis perpendicular to the plane of rotation into the mortar tube. This uniform gas produces a consistent orifice erosion resulting in repeatable mortar performance; the gas, free of heavier burning propellant particles, is potentially less damaging to a parachute packing bag after vent.

In power unit design, estimating the power unit internal volume (J), is of prime consideration. It is this volume when pressurized to its peak pressure (P_p) that provides the potential energy to power the system. This volume is a function of the kinetic energy of the accelerated mass (M_a), peak breech pressure (P_p), and amount of reserve pressure desired at vent time (P_v). An expression to establish this power unit internal volume can be formulated by equating the potential energy of the pressurized breech to that required to eject the parachute. The equation expressing this is

$$C_2(P_p - P_v)J = \tfrac{1}{2}M_a(\Delta V)^2 \quad (2)$$

The internal volume coefficient (C_2) is a measure of over-all efficiency. These values listed in Table 2 were derived empirically from flight qualification test data. In order to provide for more flexibility in the hardware during the development phase, chute size increases, orifice erosion characteristics, etc., which will affect the power unit internal volume, it is suggested that a larger volume than would be calculated in Eq. (2) be used. Therefore a value of 0.5 for C_2 is suggested rather than indicated values in Table 2. Pressure in the breech at vent is typically 5000 psi to assure an adequate supply of hot gasses at the end of the stroke.

Sizing the breech body of the power unit for a pressure of 12,000–15,000 psi is found to provide a compact, lightweight unit.

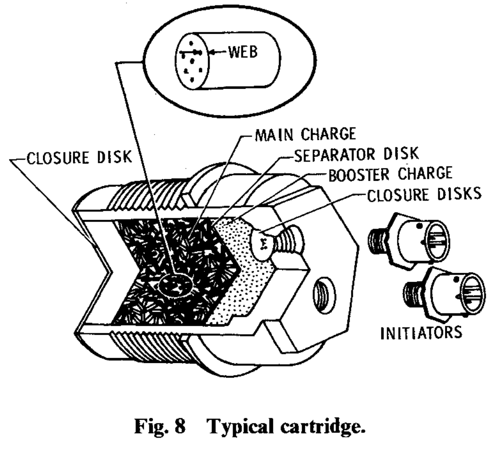

Fig. 8 Typical cartridge.

Maraging steels, such as VascoMax 300 R,‡ providing ultimate tensile strengths to 300,000 psi, are desirable for the breech body. Material hardnesses of Rc 35-38 provide a material capable of withstanding the pyrotechnic shocks generated by the combusting propellant. The smallest feasible thread sizes for mating power unit components result in reduced disassembly problems. Both cylindrical and spherical breeches have been used successfully. Material strength allowances need not be made for temperatures in the 5500°F range.

The solid propellant represents the primary source of the potential energy required. It is generally contained in a cartridge[4] and is flight qualified as a separate piece of hardware. A typical cartridge is shown in Fig. 8. The body is generally made of 17-4 PH steel. The cartridge is hermetically sealed to a maximum leak rate of 1×10^{-6} cc of helium at a pressure differential of 1 atm. Hermetic sealing assures that the contents of the cartridge do not sublimate and escape during long-term vacuum storage. Sealing is achieved by welding a thin steel disk over the closure end and also inside the initiator openings. The cartridge generally accommodates one dual bridge-wire initiator, or two single or dual bridge-wire initiators. A booster charge is contained at the initiator end of the cartridge by a cemented-in combustible separator disk or is contained in a perforated metal stem on the cartridge volume center line. The internal volume of the cartridge (K) needed to store the propellant is established by the specific impulse (I) produced upon burning and by the packed density (γ) of the propellant. This quantity is estimated by the following formula:

$$K = 2P_p J / I\gamma \quad (3)$$

Twice as much volume results as is theoretically required which provides a cartridge volume capability for accommodating propellant to compensate for heat losses and for accommodating additional propellant for any further requirements.

Standard solid propellants are usually selected for use because of their extensive test history, high reliability, availability off-the-shelf in a large number of configurations, and continuous sampling and testing of each lot while in storage. Some of the properties of selected propellants useful for mortar operation are tabulated in Table 3. Flame temperatures of 5000°F resulted in very few hardware temperature problems, while temperature in the region of 6500°F resulted in severe erosion of the breech wall and subsequent rupture after 8 to 10 firings. The most significant aspect of the propellant configuration is the burning surface area which is controlled by the quantity, size, and location of perforations through the propellant particles; this is illustrated in Fig. 8 as the web. The propellant and configuration are selected to achieve a near linear rise time in 3–5 msec to peak pressure; a web of 0.02–0.04 in. will generally accomplish this.

Design of the typical eroding orifice assembly illustrated in Fig. 9 encompasses orifice, augmentor, throat, and body. The body is made of 17-4 PH steel; its function is to hold the components intact and to permit assembly to the power unit. The throat is a replaceable element that reduces the possibility of erosion damage to the body. The limit of internal erosion varies from $\frac{1}{2}$ in.–1 in., depending upon the application; therefore, the throat internal diameter should be large enough to allow unrestricted flow of the gasses for that application. Eroding orifices

Table 3 Standard propellant characteristics

Propellant	M-2	M-5	PL6670
Isochoric flame temperature, °F	5,515	5,380	6,479
Specific impulse, I, ft-lb/lb	360,000	355,000	156,000
Web. in.	0.030	0.040	0.025
Heat of combustion, cal/gm	1,080	1,047	1,732
Density, γ, lb/ft^3	103	103	146

‡ R registered trademark of Teledyne-Vasco.

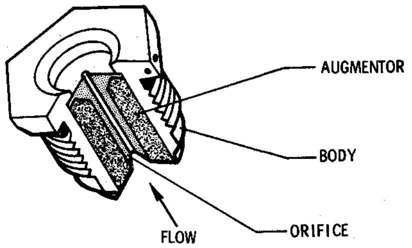

Fig. 9 Typical eroding orifice.

to date have been made of half-hard brass (QQ-B-626B). A 0.090-in.-diam hole through the 1-in. over-all length orifice having a $\frac{1}{4}$-in.-diam tip is suggested as an initial design. Tolerances on the order of ± 0.0005 in. on the diametrical and concentricity specifications of the tip are necessary to assure repeatable erosion rates and consistent results. The augmentor is typically 2024-T4 aluminum. The bars should be ultrasonically inspected for inclusions and imperfections prior to manufacture of the orifices and augmentor.

Mortar Performance

Desired mortar performance is achieved during development testing. Basically, the configuration of the orifice is altered in test iterations in such a manner as to achieve the desired pack velocity and reaction load combination. Measurements of tube pressure and power unit pressure are used to assist in the empirical process. Figure 10 shows these various parameters for a typical test. These parameters, their interrelationships, and how to achieve the desired results are discussed.

The reaction load-time curve indicates the reaction force encountered in accelerating the mass. Initially, a varying reaction load persists, indicating a movement of the pack c.g. during pack compression, until the shear pins fracture. Just prior to fracture, the load typically goes to zero or is greatly reduced until the force of the tube pressure acting on the sabot becomes great enough to fracture the shear pins. It then generally increases rapidly to its maximum amount and then ideally remains constant to vent time. After vent it drops off very rapidly, but retains a positive value indicating that the pack is still being accelerated by the escaping gasses impinging on the sabot.

The tube pressure-time curve typically increases at a varying rate to shear pin fracture and continues increasing until reaching a maximum. It then ideally remains constant to vent time, after which it goes to zero as the gasses escape.

The initial power unit pressure vs time curve should have a sharp departure from zero pressure and a near linear rise to peak pressure. The sharp departure is an indication that a large portion of the propellant particles have ignited simultaneously. The linear rise is indicative of the propellant particles burning uniformly. The pressure then drops off at a linear, relatively low rate to orifice tip burnout. As a guide, this point should generally occur at approximately half-stroke time. Subsequently, the pressure-time curve should have a near linear decay to the time of venting.

The eroding orifice is very significant to system performance inasmuch as it controls the release rate of the hot gasses into the tube which, in turn, accelerate the pack and consequently directly affect mortar performance. An empirical approach to orifice design has been used historically, where an initial design as described previously has been used and the design modified in subsequent firings until the desired performance is obtained. Functionally, an eroding orifice provides an increasing orifice diameter and resultant exponentially increasing gas mass flow rate to the increasing tube volume as the pack accelerates up the tube. A small initial orifice hole will provide a low initial gas mass flow rate to pressurize the volume behind the sabot, compress the pack, and shear the shear pins. After this initial flow the hot gasses begin to melt the brass orifice and enlarge the hole, thus increasing the gas flow rate to accelerate the pack. The brass tip should have eroded away completely when gas is needed at a rapidly increasing rate, thus allowing the aluminum augmentor to start eroding or burning very rapidly. A well-developed orifice approaches the ideal case when the gas mass flow rate maintains a constant pressure in the rapidly expanding tube volume.

Several options can be exercised in altering the orifice and augmentor to achieve desired eroding orifice flow control. Changing the orifice tip outside diameter will shift the tip burnout time shown on Fig. 10, thereby providing flexibility in real time at which gas begins dumping into the tube at a rapidly increasing rate. Shielding the orifice tip from a higher flame temperature (PL6670) is sometimes necessary to control a rapid initial erosion rate by reducing the exposed area. An anodized surface on the augmentor may delay and slow erosion rate. The hole in the augmentor to receive the orifice tip can sometimes be used to dramatically increase the gas mass flow rate by enlarging the clearance gap between the two parts. Ignition of the augmentor will occur if the hot gas isochoric flame temperature reaches or surpasses the adiabatic flame temperature of the aluminum (6370°F at equilibrium) and if the oxidizer surplus in the hot gas is rich enough to support combustion. The aluminum can be utilized to augment the energy output. Silicone lubricants or other contaminants on eroding surfaces will cause very erratic eroding characteristics by altering the heat-transfer characteristics and should be avoided.

Reaction Load Estimate

Reaction loads must be absorbed by the supporting structure and consequently are of primary interest. Reaction load estimates are based on work performed in accelerating the pack. The maximum reaction load is proportional to the kinetic energy imparted to the pack. The expression is

$$C_3 FS = \tfrac{1}{2} M_a (\Delta V)^2 \tag{4}$$

The dimensionless reaction load coefficient (C_3) represents the ratio of theoretical reaction load to peak reaction load. It indicates the variation in the maximum reaction load from the average. Values of C_3 for three mortars are listed in Table 2. Values of C_3 of 0.7 should be readily attained and 0.8 or higher are attainable with a well-designed and perfected system. The stroke (S) is that distance the contacting edge of the seal moves to vent.

Several options are available to minimize the reaction load in a mortar system. The stroke can be physically maximized in the tube by keeping the seal as far back on the trailing edge of the sabot as is feasible and by taking the parachute bridle lines out through the cover instead of out through a slot in the end of the tube. For chutes having a packed volume larger than 2 ft^3, the S/D ratio of 2.5 should be maintained in order to maximize stroke. The total force required to fracture the shear pins should be held to the minimum required in order to reduce pack compression and thereby increase the effective stroke. Packing densities of 40 pcf result in reasonable pack compression.

Reaction load and stroke can be related to mortar volume.

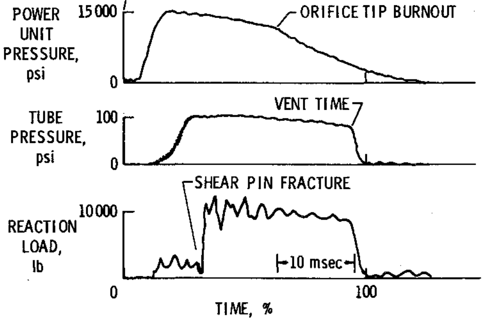

Fig. 10 Typical qualification test data.

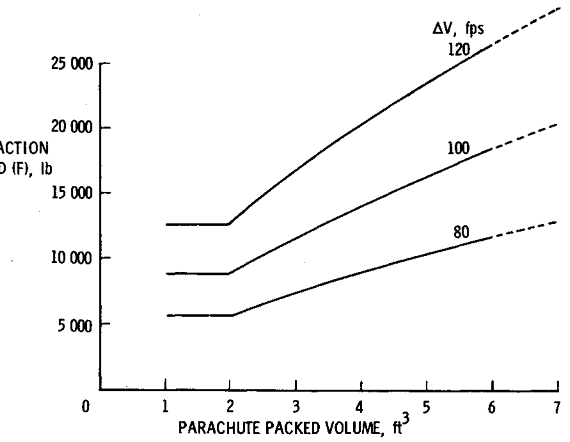

Fig. 11 Reaction load vs parachute packed volume.

Figure 11 depicts reaction load vs mortar volume at three velocities for a typical system having a C_3 of 0.714, a packed density of 40 lb/ft^3, and a S/D ratio of 2.5; for chutes below 2 ft^3 and over 1 ft^3, the minimum 12-in. bore was used.

Mortar System Weight Estimate

Flight hardware weight estimates are of interest. Component weights of four mortar systems are shown in Table 4. The Type IV mortar represents the best effort to date in providing a lightweight system; consequently, it was used as the basis in arriving at an empirical equation for estimating mortar system weights. The primary variables affecting weight are the kinetic energy desired to be imparted to the mass accelerated (M_a), tube bore (D), and the stroke (S). Weights of the mortar components are found in Table 4 by summing the terms adjacent. The sum of these terms comprise the total mortar assembly hardware weight (W_m) and is

$$W_m = 8.6\times 10^{-5} M_a(\Delta V)^2 + 2.623SD + 3.142D^2 + 5.994D + 2.818 \qquad (5)$$

This equation is plotted in Fig. 12 for a typical mortar system for S/D ratios of 1.0 and 2.5. Both curves employ a $87\frac{1}{2}$-lb parachute packed at a density of 40 pcf and ejected at a velocity of 112 fps.

Miscellaneous Comments

Ambient conditions at mortar fire must be considered. Ambient pressure, temperature, vehicle acceleration, and flight-path angle relative to the horizontal affect muzzle velocity.

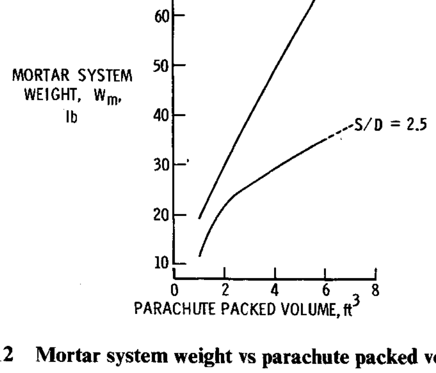

Fig. 12 Mortar system weight vs parachute packed volume.

Table 4 Mortar component weights

Component	Kinetic energy	SD	D^2	D	Additional weight[a]
Cylindrical power unit	$8.6\times 10^{-5} M_a(\Delta V)^2$				1.700
Tube		$2.623SD+$		$1.283D$	
Base plate			$1.489D^2+$	$3.168D+$	0.157
Sabot			$0.514D^2+$	$1.129D+$	0.128
Hard cover			$1.139D^2+$	$0.414D+$	0.323
Miscellaneous					0.510

[a] Weight regardless of mortar size.

Ambient pressure affects ejection velocity more than the sum of the others, which can generally be ignored. An ambient pressure differential of 1 atm represents a significant change in the pressure differential across the mortar tube since tube pressures of 40–100 psig are normally used. Development testing should be done at representative flight ambient pressures to assure a representative tube pressure-time history.

Development testing to achieve ejection velocity should be conducted at maximum anticipated ambient pressure. Alternatively, measuring maximum reaction loads, after achieving desired ejection velocity, is conducted at lowest ambient pressure. Firing horizontally from a suspended mass equal to the flight vehicle mass has the advantage of more closely simulating the two-body flight conditions and of eliminating the need of transmitting the reaction load into the wall of the vacuum test chamber.

Accurate velocity measurements are obtained by impulse-momentum method, whereby the reaction-time curve is integrated to obtain impulse and equated to pack momentum. Cover excursions and pack axial oscillations after vent due to pack compression during acceleration induce relatively large inaccuracies in the photographic and break-wire method of velocity measurement. A chute normally contains 2–3 lb of moisture when packed. At reduced ambient test pressures, this moisture evaporates; it should be accounted for in simulating accelerated mass.

Conclusion

This paper has presented some of the fundamental principles in design of parachute mortars. The spherical vortex generator power unit provides a uniform gas which results in repeatable mortar performance and is free of burning propellant particles potentially damaging to a parachute. In high-low pressure systems, use of eroding orifices produce significantly lower reaction loads than do equivalent constant area orifices. Proper alterations to the orifice during development testing can result in desired performance. Reaction loads are inherently minimized by establishing a minimum ejection velocity. Mortar system weights are minimized for a stroke-to-diameter ratio of 2.5. System testing should be conducted at representative ambient pressures and ejection velocity computed from reaction load impulse data. The designer is afforded latitude and flexibility in the design of the system and components. Straightforward engineering computations complemented by good design practices should provide a near-optimum mortar system.

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