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Contract Report

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EVALUATION OF PLASTIC MEDIA BLASTING EQUIPMENT

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ABSTRACT This report evaluates the design of plastic media blasting (PMB) equipment currently used in the military and private industry. Five PMB functional equipment groups were established: blasting, floor recovery, media recycling, ventilation, and dense particle removal.

Blasting tests performed with a glove box nozzle blast assembly were observed to effectively clean and recycle plastic media. Magnetic contaminants in the system were removed at the rate of 40 percent per pass. The coating removal rate was determined to be directly proportional to the media flow rate and the sine of the blasting angle of incidence.

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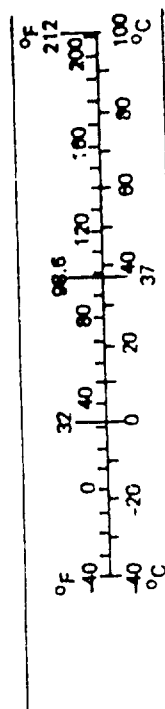
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Symbol	When You Know	Multiply by	To Find	Symbol	When You Know	Multiply by	To Find
in ft yd mi	inches feet yards miles	LENGTH		mm cm m km	millimeters centimeters meters kilometers	LENGTH	
		*2.5	centimeters			0.04	inches
		30	centimeters			0.4	inches
		0.9	meters			3.3	feet
in ² ft ² yd ² mi ²	square inches square feet square yards square miles acres	AREA		cm ² m ² km ² ha	square centimeters square meters square kilometers hectares (10,000 m ²)	AREA	
		6.5	square centimeters			0.16	square inches
		0.09	square meters			1.2	square yards
		0.8	square meters			0.4	square miles
oz lb	ounces pounds short tons (2,000 lb)	MASS (weight)		g kg t	grams kilograms tonnes (1,000 kg)	MASS (weight)	
		28	grams			0.035	ounces
		0.45	kilograms			2.2	pounds
		0.9	tonnes			1.1	short tons
tsp Tbsp fl oz c pt qt gal ft ³ yd ³	teaspoons tablespoons fluid ounces cups pints quarts gallons cubic feet cubic yards	VOLUME		ml l m ³	milliliters liters cubic meters	VOLUME	
		5	milliliters			0.03	fluid ounces
		15	milliliters			2.1	pints
		30	milliliters			1.06	quarts
		0.24	liters			0.26	gallons
		0.47	liters			35	cubic feet
		0.95	liters			1.3	cubic yards
		3.8	liters				
°F	Fahrenheit temperature	TEMPERATURE (exact)		°C	Celsius temperature	TEMPERATURE (exact)	
		5/9 (after subtracting 32)	Celsius temperature			9/5 (then add 32)	Fahrenheit temperature

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Magnetic contaminants in the system were removed at the rate of 40 percent per pass. The coating removal rate was determined to be directly proportional to the media flow rate and the sine of the blasting angle of incidence.

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FOREWORD

This work was sponsored by the Naval Facilities Engineering Command and the Naval Civil Engineering Laboratory as part of the program to minimize hazardous waste generation from paint stripping operations in the Navy. Typical paint stripping operations generate large quantities of hazardous sludges and wastewaters. Plastic Media Blasting (PMB) is an emerging alternative to chemical stripping which greatly reduces the amount of hazardous waste produced. This work is a basic technical evaluation of PMB blasting equipment emphasizing required design parameters for efficient equipment operation.

The results of this study are intended to be used to improve the general performance of future PMB equipment procured by the Navy. The use of alternatives such as PMB will help the Navy reach a 1992 goal of reducing hazardous waste generation by 50%.

If you are planning to implement or have a need for this technology please contact:

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EVALUATION OF PLASTIC MEDIA BLASTING EQUIPMENT

SUMMARY OF RECOMMENDATIONS

Plastic media blasting (PMB) is a new technology introduced as a candidate to replace wet chemical paint stripping of airframes and component parts. This report evaluates the performance of blasting equipment currently in use and presents minimum design requirements for PMB equipment. The performance evaluation includes equipment design, ease of operation, maintenance and operating parameters such as pressure and feed rate accuracy, nozzle selection, and feed cone angle. A good training program for blasting equipment operators is required to ensure that the equipment is used correctly to obtain maximum performance.

Plastic media blasting equipment for a blasting room should include the following features to obtain the best system options currently available. Features unique to a glovebox or blast room have been noted.

1. Blasting Equipment

- A. Blasting pots should be furnished with a 60 degree slope on the bottom conical section.
- B. Each nozzle should have a separate blast pot with a minimum storage volume of 3 cubic feet. The storage hopper should have a minimum volume of 6 cubic feet.
- C. The storage hopper should be furnished with a level indicator. An optional level indicator in the blasting pot may also be furnished.
- D. The design pressure of the blast pot should not be less than 110 pounds per square inch gage pressure. The pressure vessel should be constructed in accordance with Section VIII of the ASME Boiler and Pressure Vessel Code.
- E. The media refill valve should not leak when the pot is pressurized and should have at least one elastomeric surface to produce a tight seal.
- F. The storage hopper and blast pot combination should operate automatically to fill the blast pot when the blast hose is not in operation. The blasting pot access should be covered with a large mesh screen to prevent entry of foreign material.
- G. For critical applications, a mechanical media feeder should be used to ensure accurate and reproducible media feed rates. Mechanical speeds must be strictly controlled. Feed rates should be variable from 10 to 100 percent of maximum media flow. A feed rate indicator should be furnished.
- H. The media feed mechanism should be able to feed up to 20 pounds of media per minute with a 0.5 inch bore nozzle.
- I. Gravity media feed systems provided for non-critical media flow blasting operations should be furnished with an adjustable valve marked to show its position. The difference between the pot pressure and the air line pressure should also be indicated if this method is used to help deliver media to the transport hose.

- J. Media feed rate and blasting hose air pressure should be easily adjusted by the operator. Controls for adjusting the blasting air pressure and the media flow rate should be easily accessible to the operator if rapid transitions between different substrates are required.
- K. Abrasion resistant blasting hoses should be light weight and electrically grounded. Hose weight should not exceed 0.7 pounds per foot.
- L. Easily replaceable, venturi style nozzles should be employed. Nozzle size and number depends on the application.
- M. The hose should be fitted with an Occupational Safety and Health Administration (OSHA) approved deadman switch.
- N. The hose should be fitted with a twist swivel if the blasting nozzle assembly orientation cannot rotate freely during operation.

2. Floor Recovery Equipment

- A. The solid portions of the concrete blasting room floors should be covered with epoxy, rubber sheeting, or similar material to prevent hard particle contamination of the media from eroded floor material.
- B. Media recovery pits in blasting rooms should have a minimum capacity of about 6 cubic feet. They should not be located near ventilation system exhaust ducts to minimize media losses to the ventilation system.
- C. The slope of media recovery collection troughs or pit bottoms should be a minimum of 60 degrees.
- D. Fall through style floor recovery equipment should be covered with close patterned steel grating strong enough to structurally support anticipated loads. The grating may be covered with wire mesh to minimize large foreign object entry into the recycling system.
- E. Blasting debris transport rates should be at least twice the maximum flow rate of media from blasting nozzles to allow for sufficient storage hopper refill time.
- F. Recovery and transport systems should not destroy reusable media when in operation. There should be adequate clearance between the walls of the screw conveyor tube and conveyor internals.
- G. Pneumatic media transport rates should be between 25 and 75 feet per second.
- H. Mechanical recovery systems should be able to operate in a dusty, abrasive environment. Lubricated, close tolerance equipment should be isolated from the blasting debris.
- I. Partial floor recovery areas should be located away from the walls of the blast room to maximize collection efficiency.
- J. Horizontal surfaces under floor grating should be minimized to avoid a build-up of media.
- K. The media recovery system in the bottom of the glovebox should transport all blasting debris from the blasting chamber.
- L. The working floor of a glovebox should be perforated to allow blasting debris to fall through it while still screening out large foreign objects.

- M. The working floor of a glovebox should be fitted with a turntable for work piece accessibility.

3. Media Recycling Equipment

- A. High efficiency recycling equipment should be used to remove potentially damaging contamination from the recycled media, and should not reject properly sized media from the recycling equipment. The dust collected by the dust collection system should contain less than 5 percent by weight plastic media retained on a 60 mesh screen. The reusable media should contain less than 5 percent material passing through a 60 mesh screen.
- B. The recycling system should first effect a separation using an adequately sized cyclone to remove fine particles from the material stream. An adjustable air wash or air knife arrangement should be used for final dust and fines removal. The size of the particles that the air wash rejects should be manually adjustable based on the blasting operation.
- C. After fine particle removal, the media should be classified by size. A two-tier vibrating screen system should be used for size classification. If an air wash is used, however, a vibrating screen may not be necessary. A stationary 12 mesh screen is still required to prevent damage caused by oversized particles or debris. The screen should be cleaned automatically in a blast room. Manual cleaning is appropriate for a glovebox.
- D. An adequately sized magnetic separator should be used to remove ferrous debris. Commercially available, self cleaning magnetic separators are removing 30 to 40 percent of the magnetic particle contamination by weight per pass of the media through the system, and should be specified whenever possible.
- E. The discarded material collection system should deposit collected dust in a storage bin or hopper that can be emptied with a minimum exposure of personnel to the material.
- F. All access doors should be equipped with rubber gaskets. Access doors should be fitted with interlocks to prevent operation of the blasting equipment when the doors are open.
- G. Electrical equipment located outside of the blasting enclosure should be housed in Class II, Division II, NEMA Type 9 enclosures, unless the operating area requires a more stringent electrical classification.
- H. Use of thin-walled, wire reinforced, flexible ducts for carrying dust laden air streams should be avoided.
- I. Media transportation within the recycling system should be accomplished either mechanically or pneumatically. Mechanical transportation such as bucket elevators, however, may reduce energy consumption and minimize media damage.

4. Ventilation Equipment

- A. The dust collection system (DCS) should be a reverse pulse unit with cartridge style filter elements. The air-to-cloth ratio should not exceed 3.0.
- B. The operation of the DCS reverse pulse mechanism should be automatic. The mechanism should be activated by the differential pressure across the filter element or by a timer with a differential pressure switch override. The timer and the differential pressure switch settings should be adjustable.

- C. Blasting booths should have gravity separation chambers in the ventilation system exhaust ducts that automatically return captured reusable media to the media recycling system.
- D. The average velocity in the ventilation ducts should be about 3000 feet per minute (fpm) to minimize erosion damage and prevent accumulations of dust within the ductwork.
- E. The DCS should deposit collected dust in a storage bin or hopper that can be emptied with a minimum exposure of personnel to the dust. The dust hopper should be furnished with a level indicator to indicate when it is full.
- F. Adequate access hatches should be provided on the DCS to easily replace cartridge filter elements and provide normal maintenance.
- G. Platforms should be provided for all elevated access hatches on the DCS.
- H. The induced draft fan should be located on the clean side of the DCS.

5. Dense Particle Removal Equipment

- A. Good housekeeping and proper enclosure design should be used to help reduce dense particle contamination.
- B. The Air Force recommends that dense particle contamination in recycled media should be no greater than 200 ppm. Dense particle removal equipment suitable for use in a production environment, that can provide media 99.98 percent clean, should be developed.
- C. Dense particle separators should be of the type that will avoid the use of environmentally sensitive chemicals such as freon as the separation liquid.
- D. If a wet-wash system is specified it is essential that the media is thoroughly dried before it is returned to the blasting operation.
- E. Many effective separation techniques that may be applicable to PMB have been perfected by the mining industry. One of these techniques, tabling, appears to be a good candidate to clean plastic media and should be investigated. Fluidized bed techniques that can clean media on a continuously operating as well as a batch basis should also be developed.

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1.0 INTRODUCTION

Plastic media blasting (PMB) is a new technology being implemented as a replacement for wet chemical stripping of painted surfaces. The process utilizes small plastic fragments that are dispersed at high velocity at a painted surface. The plastic media has rough edges which serve as an abrasive to shatter and dislodge surface coatings. The PMB process is similar to conventional abrasive grit blasting, but PMB is much less aggressive and may not damage delicate substrates if properly used.

The use of plastic media for removing coatings from aircraft and aircraft components is increasing. Plastic media blasting effectively removes coatings from aluminum, fiberglass, and composite substrates in a manner that is more cost effective and environmentally acceptable than current chemical stripping methods.

1.1 Objectives

Engineering Management Concepts (EMC) of Camarillo, CA was tasked by the Naval Civil Engineering Laboratory (NCEL) to review current PMB equipment design and to establish minimum performance criteria for the design of blasting equipment. The objectives of this task were to:

- Evaluate the performance of PMB equipment currently used in the military and private industry.
- Develop minimum design requirements for PMB equipment.

The performance evaluation includes design parameters, ease of operation and maintenance, reliability and maintainability, and costs. Operating parameters such as pressure and feed rate accuracy, nozzle selection, and blasting angle were also evaluated.

1.2 Background

PMB operating costs can be reduced by reusing the plastic media until it becomes too small to be effective. PMB equipment manufacturers usually include plastic media recycling equipment as an integral part of the system. The recycling equipment recovers reusable media from the dust created during the blasting operation. Removal of this dust increases visibility in the blast area and eliminates particles in the media that are too small to effectively remove coatings. Dust in the media will displace usable media and cause slower, more erratic paint removal rates. Large particles, such as paint flakes and other debris, are removed to prevent blasting equipment from plugging. Hard and/or magnetic particles are removed because they can damage the delicate substrates being blasted with the plastic media.

Because efficient blasting equipment depends in part on the recycling equipment performance, this report will also review the performance criteria for, and the capabilities of, plastic media recycling equipment.

2.0 PMB EQUIPMENT CLASSIFICATION AND DESCRIPTION

Plastic media blasting equipment can be divided into five functional equipment classifications:

- **BLASTING EQUIPMENT:** Propels the media against the work piece in a controllable manner.
- **FLOOR RECOVERY EQUIPMENT:** Recovers used media from the floor surrounding the blasting area.
- **MEDIA RECYCLING EQUIPMENT:** Cleans and returns reusable plastic media to the blasting equipment.
- **VENTILATION EQUIPMENT:** Removes dust from the blasting area to maintain visibility for operators.
- **DENSE PARTICLE REMOVAL EQUIPMENT:** Cleans reusable media by removing nonmagnetic hard particle contaminants.

A general equipment schematic for a PMB operation is shown in figure 1. The five functional equipment classifications are highlighted. The separate equipment components and performance requirements for the system are discussed below. Media flowing through the blasting equipment is transported by the floor recovery system through the media recycling equipment back to the blasting equipment. The ventilation system cleans the air from the blasting booth and pneumatic transport lines.

Dense particle removal equipment is shown separately from the blasting room equipment. Dense particle removal is a new concept with limited commercial availability. Dense particle removal may either be a part of the continuous media recycling system or may be operated as a separate batch process.

The performance criteria for plastic media blasting equipment presented in this report have been determined by reviewing the performance categories of the equipment and comparing these against the options available with current commercial equipment. Required equipment options, necessary to accomplish the performance criteria, have also been identified. PMB equipment has evolved rapidly over the last few years and new design options are being developed to make PMB equipment more effective and economical. Many of these changes occurred as users have recognized deficiencies in the existing equipment. A new PMB equipment system procured at this time should include the equipment described in the following paragraphs to obtain the best system options available.

New design options will become available as PMB equipment manufacturers continue to improve their equipment. The capabilities of the new options should be compared to the following performance criteria to determine if the additional cost of the design option improves the performance value of the equipment.

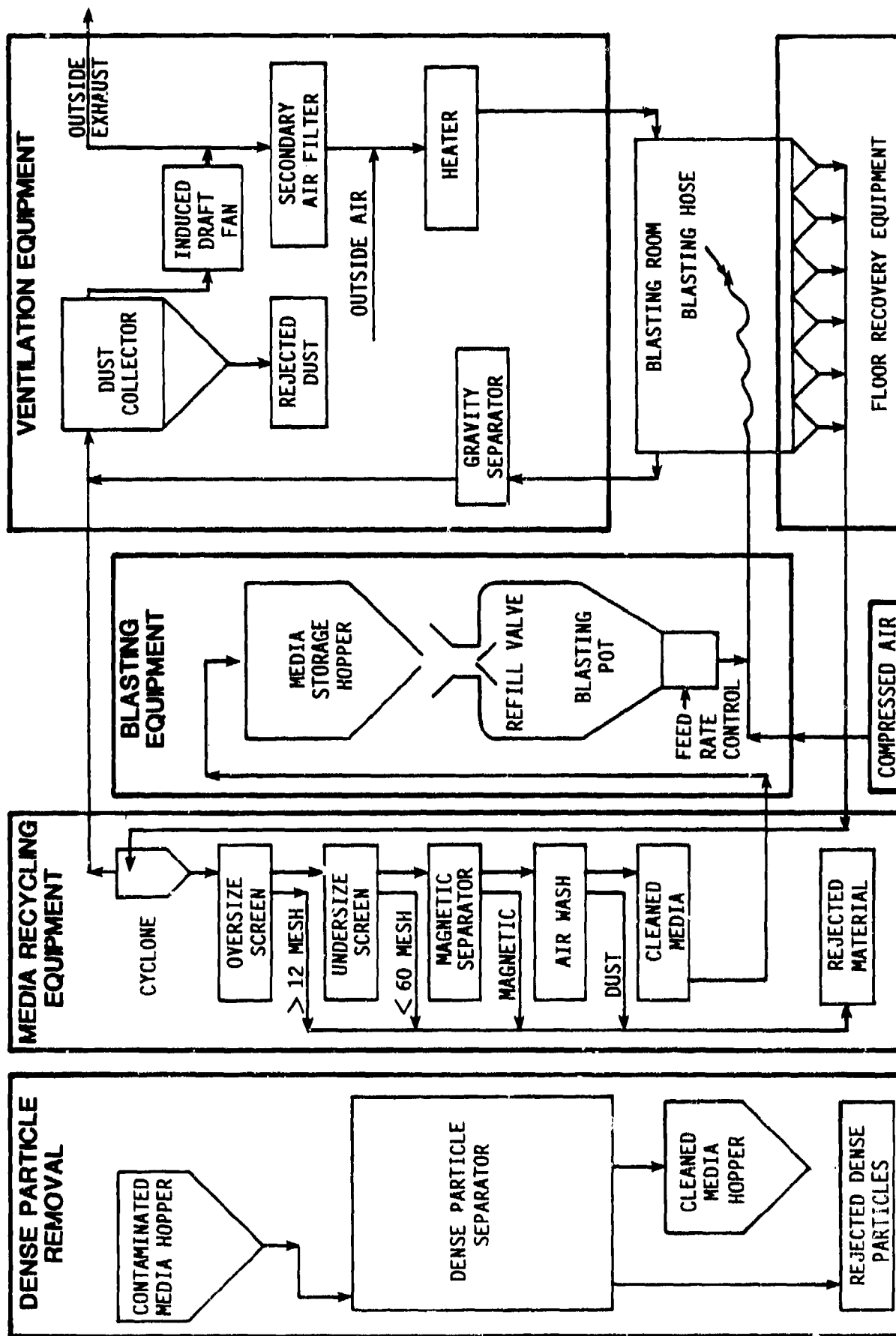


FIGURE 1. PMB EQUIPMENT SCHEMATIC.

3.0 BLASTING EQUIPMENT

Blasting equipment is used to propel the media against the work piece in a controllable manner. The individual performance requirements of the equipment are:

- To store usable media for delivery to the work piece.
- To meter the media into the delivery system.
- To transport the media to the blasting nozzle.
- To propel the media against the work piece.

The usual blasting equipment furnished with a blasting enclosure includes the following components:

- Storage hopper
- Refill valve
- Blasting pot
- Blasting air regulator
- Media flow controller
- Media and air mixing chamber
- Blasting hose
- Deadman switch
- Blasting nozzle

The blasting equipment is used to control the important operating parameters of media particle speed and mass flow. Controlling the blasting operation is important to ensure successful coating removal work without damaging the substrate. Equipment now used to perform these functions has been developed from existing sand blasting equipment. Typical equipment is diagrammed in figure 2.

3.1 Blast Pot and Storage Hopper

A conventional pressurized sand blasting pot is typically used to store the media prior to blasting. The pot design has been altered from a 45 degree to a 60 degree bottom conical slope to ensure media flowing into the bottom of the pot does not bridge over and stop flowing. The chamber is filled with plastic media and compressed air is supplied from an air compressor to provide the force to carry the media through a hose to a blasting nozzle. The pressure is necessary in the blasting pot to equalize the pressure in the blasting hose so that media will gravity flow to the mixing chamber. The media storage hopper holds the plastic media reserves to refill the blasting pot as necessary. The refill valve should operate automatically each time blasting ceases. When the blasting pot is depressurized, the media weight on the cone shaped valve pushes it into the blasting pot, allowing media to fall into it. When the blasting pot is repressurized the air pressure overcomes the weight of the media and seals the blasting pot once again. The refill valve should not leak air when the pot is pressurized and should have at least one elastomeric surface to provide a tight seal. The blasting pot access should be covered with a large mesh screen to prevent entry of foreign material.

The volumes of the storage hopper and the blasting pot should be enough to prevent frequent interruptions in the blasting process for media refills. Ten minutes of uninterrupted blasting is a reasonable minimum time period. The minimum usable volume for the blasting pot should be about 3 cubic feet assuming a plastic media bulk density of 60 pounds per cubic foot and one 0.5 inch blasting nozzle is used with a delivery rate of 20 pounds per minute. There should be a separate blasting pot for each blasting nozzle.

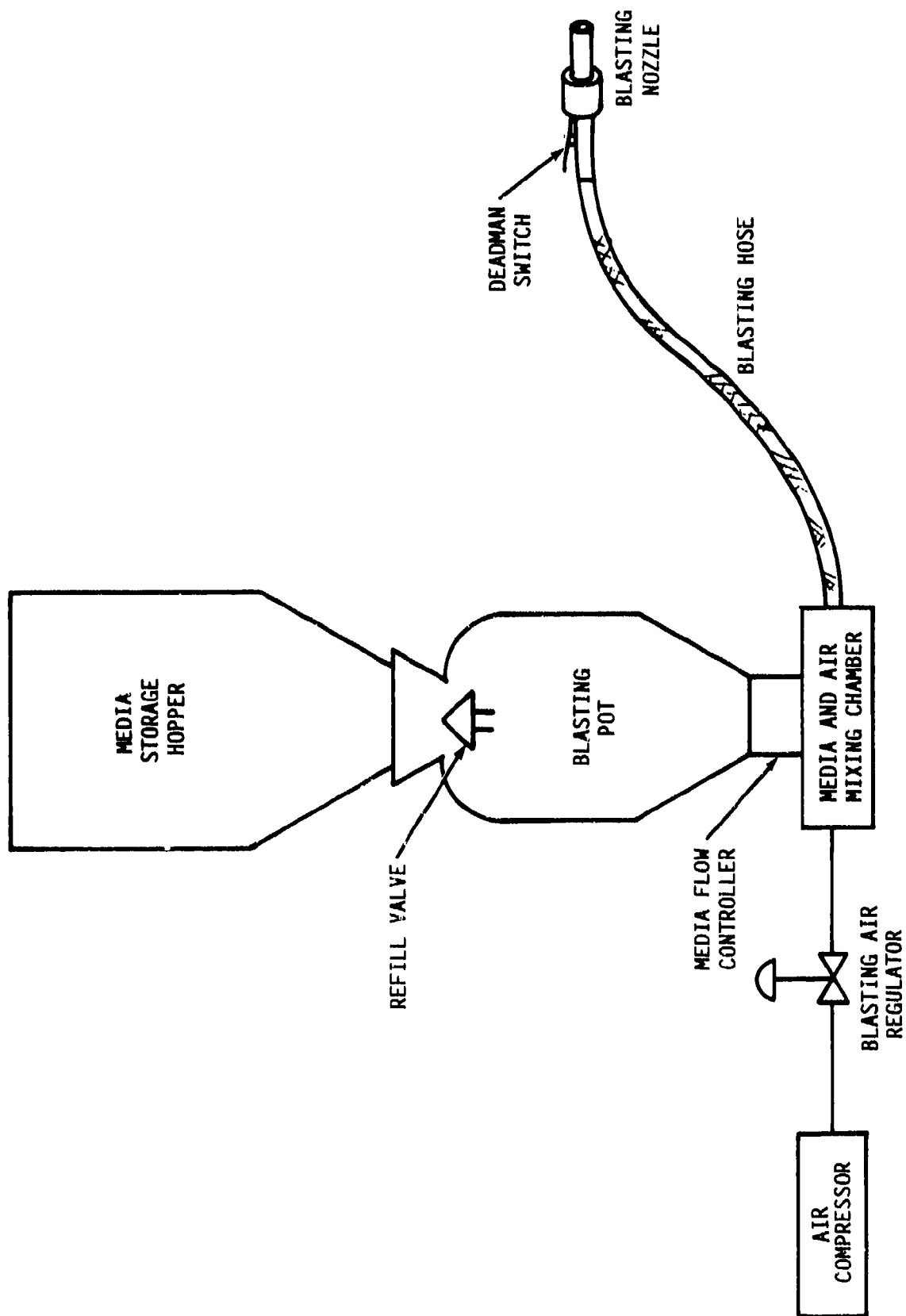


FIGURE 2. BLASTING EQUIPMENT NOMENCLATURE.

The storage hopper should have a minimum volume of 6 cubic feet so that lost media has to be replaced only once per shift. The volume of media losses during one shift are calculated using an assumed media degradation rate of five percent and a media mass flow rate of 7200 pounds for six hours of blasting at 20 pounds per minute. The five percent loss (360 pounds) would occupy about 6 cubic feet.

Media level indicators are available for both the storage hopper and the blasting pot. The level indicator is required for the storage hopper, but is only a convenience on the blasting pot. The design pressure of the blasting pot should be a minimum of 110 pounds per square inch (psig). The pot should be in accordance with the American Society of Mechanical Engineers (ASME), Section VIII, Pressure Vessel Code.

3.2 Media Metering System

Media from the blasting pot is metered into the blasting air stream at the media mixing chamber either by gravity flow through a variable orifice or by a mechanical metering system. The mass flow of media through the delivery system affects the rate that material is removed from the coating. Erratically pulsating media flows can damage sensitive work pieces by unexpectedly changing the mass flow rate. The media metering system should deliver between 0 and not less than 20 pounds of media per minute with a 0.5 inch bore nozzle. The media feed rate should be easily adjusted by the operator. Controls should be readily accessible to the operator if rapid transitions between different substrates are required.

Gravity metering systems use an orifice of varying size to allow different rates of media to fall into the compressed air stream and be transported to the blasting nozzle. At least one manufacturer uses a small valve at the base of the blasting pot to vary the size of the hole so media can fall through into the compressed air stream. The differential pressure between the pot and the airstream can also be varied to alter the media flow. A higher pressure in the blasting pot than in the compressed air stream will cause the media to be blown through the varying size orifice. Gravity feed systems should be furnished with an adjustable feed orifice valve marked to show its various positions. The difference between the pot pressure and the air line pressure should also be indicated if this method is used to help deliver media to the transport hose. Low media flow rates are difficult to reproduce with this equipment due to lack of fine control.

Mechanical media feed systems are designed to provide more consistent media flow rates than pneumatic or gravity media feed mechanisms that are more likely to have erratic media flow pulsations, especially at lower blasting nozzle pressures. Flow rate accuracy can be reliably maintained within ± 1 percent of the media flow rate setting. This kind of mechanical media flow controller is offered by at least one manufacturer in the form of the rotating screw feeder shown in figure 3. A pressure equalizing hose should be furnished to avoid differential pressures across a rotary screw between the blasting pot and the transport hose. Media flow rates can be reliably controlled by varying the rotational speed of the screw. Media discharged from the screw is then transported to the blasting nozzle. Rotary valves are also used to meter media into the blasting air stream. Rotary feeders should be furnished with a variable speed motor and feed rate indicator. Feed rates should be able to be varied from 10 to 100 percent of maximum media flow. The finer feed rate control of a rotating media feeder is important when blasting delicate substrates, especially on a production basis where rates must be accurately repeated.

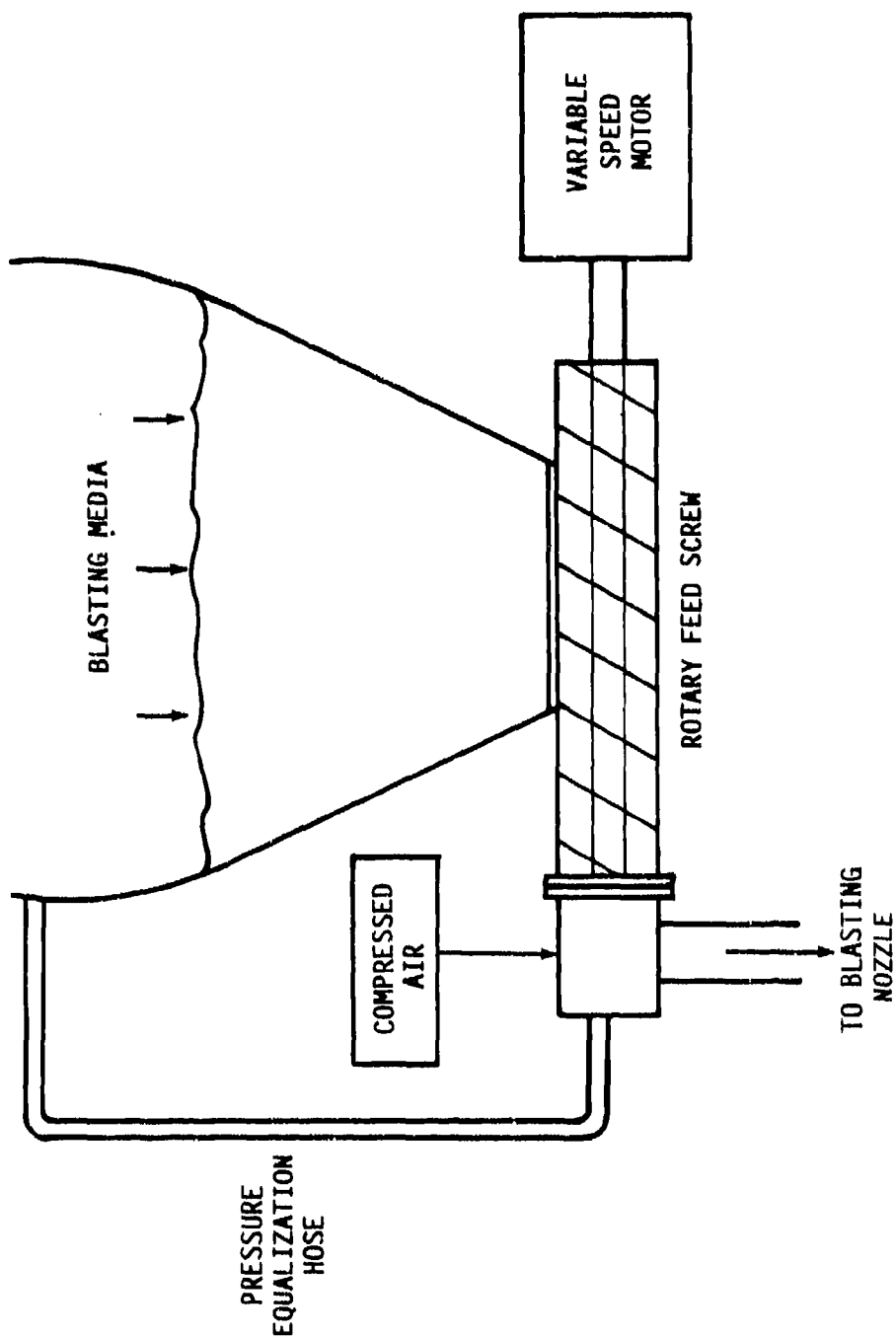


FIGURE 3. MECHANICAL MEDIA FEED SYSTEM.

3.3 Media Delivery System

Ingressed stresses that may be induced in substrates by the blasting process can be minimized by lowering the impact speed of the particle. The lower speeds reduce the "oil canning" effect experienced on some thin substrates. Particle speed is controlled by the differential pressure across the blasting nozzle. Compressed air is used to transport and propel the media through an abrasion resistant hose to the nozzle.

By varying the air pressure used to transport the media, the pressure drop across the nozzle can be varied. The larger the pressure drop, the greater the air speed of the particles exiting the nozzle. An air pressure gauge and regulator for adjusting the transport air and nozzle pressure should be furnished and easily adjusted by the operator. The control should be readily accessible to the operator if rapid transitions between different substrates are required. The range of available air pressure normally extends from about 20 to 100 pounds per square inch (psi), with typical maximum operating pressures of 40 to 50 psi during normal operations.

To attain accelerated particle speeds venturi style sand blasting nozzles are usually used for PMB. Nozzles should be easily replaceable in threaded nozzle holders. The nozzle connection should adapt to nozzles with up to 0.5 inch diameter bores. Smaller diameter bore nozzles should be available for delicate blasting work at low media flow rates and air pressures. The nozzle connection at the end of the hose should be fitted with an OSHA required dead man switch that immediately stops media flow through the nozzle when not held open by the operator.

The blasting hose should be electrically grounded to eliminate static electricity. The hose should also be lightweight, weighing less than 0.7 pounds per foot to minimize operator fatigue. It should be fitted with a swivel if the blasting nozzle cannot rotate freely when being used with special attachments at the nozzle. These attachments can include optional lights or operating controls.

3.4 Wheel Blasting Systems

A completely different type of blasting equipment is based on a high speed rotating wheel to propel media; compressed air is not used. One wheel can output the same amount of media as six to ten blasting nozzles. The wheel uses about 10 percent of the energy that the group of nozzles would use to eject the same amount of media against the work piece. One manufacturer has adapted the process to PMB applications. Figure 4 is a schematic of a wheel blasting system.

Media is gravity fed through a hose to the center of the rotating wheel, travels through a positioning gate and is then propelled by centrifugal force to the outside of the wheel. The angular momentum of the media is increased during this travel until the particles are flung off the wheel's edge. The positioning gate ensures that media is introduced to the center of the wheel. Particles positioned at the center of the wheel must travel an equivalent path across the wheel before being expelled from the edge. Since radial vanes are used to further control the movement of the particles within the wheel, the stream actually exhibits a high speed pulsating flow. The pulsation frequency is high enough to simulate a steady media flow pattern. The velocity of the particles can be varied by adjusting the rotational speed of the wheel. Wheel blast systems should, therefore, be furnished with variable ratio motor to wheel couplings. In order to observe the wheel blast pattern, a section of cardboard was subjected to one pass of the wheel. The outside edges of the pass were lightly blasted. The particles removed increasing amounts of the cardboard toward the center of the blast pattern indicating that the blasting effect is not consistent across the whole of the blast pattern. This pattern should be further investigated to ensure that sensitive substrates are not damaged by the unevenness of the wheel blast pattern.

Blasting wheels are heavy and difficult to control manually. Their higher rates of media flow, however, are useful in large automated blasting systems. An automated system eliminates variations in operating parameters such as dwell time, angle of incidence, stand-off distance, etc. Some automated multiple wheel systems, such as the helicopter blade stripping machine used by Aerospatiale in France, use a series of cameras to determine the degree of paint removal. The cameras provide feedback that controls the operation of the blast wheels. This type of system can maintain adequate coating removal rates at the low media particle speeds required for delicate substrates and is most economically applied to large repetitive blasting projects.

4.0 FLOOR RECOVERY EQUIPMENT

Performance requirements of the equipment recovering material from the floor surrounding the blasting area are:

- To remove blasting debris from the floor in a continuous or semicontinuous manner.
- To structurally support the work piece and personnel in the blasting area.
- To transport the debris/reusable media mixture to the recycling equipment.

The floor recovery equipment may include the following components:

- Floor grating
- Support beams
- Media collection device
- Media transport device
- Media transport ductwork
- Device to prevent damage to the equipment by large foreign objects.

The floor recovery equipment gathers the used media, paint chips, and other material from the blasting room by collecting debris as it falls through steel grating placed across a set of support beams. Mechanical or pneumatic conveying systems are installed under the floor grating to transport material to the recycling equipment. The floor recovery system can either be a full floor recovery system with the entire floor covered by grating or a partial recovery floor with only a fraction of the floor covered by grating.

4.1 Description of Full and Partial Floor Recovery Equipment

The performance requirements of the floor media recovery equipment are simple enough to be accomplished by a variety of commercially available methods. The capital and operating costs of the system are important factors in selecting the appropriate design. Full floor recovery systems are more expensive than partial floor recovery systems but require less operator labor. Recovery pits or pneumatic dust pans require minimal capital investment but have the highest operating costs. Whatever the system selected, it should not destroy reusable media when in operation. The blasting debris recovery and transport rate should be at least twice the maximum flow of media from the blasting nozzles to prevent operating bottlenecks. The systems should be immune to plugging when fully loaded with media.

No investment in floor recovery equipment will require operators to sweep the material from a solid floor and carry it to the media recycling system. Labor inefficiencies caused by personnel working in the bulky protective clothing and breathing air supply hoses required for PMB work causes the cost of labor to perform this recovery work to be high. Floor recovery equipment can be added to minimize these labor costs. The time that operators are sweeping the floor is not only expensive, but it is also time when blasting work cannot be performed. The equipment owner should evaluate the capital and operating costs to determine which of the several system improvements are economically justified. Full floor recovery systems are able to return media to the recycling equipment no matter where it falls. The additional cost of a full floor recovery system in larger PMB enclosures, however, does not appear to be economically justified by the labor cost savings.

A portable pneumatic "dustpan" is available that uses the vacuum produced by an induced draft fan to convey material to the media recycling equipment (see figure 5). The dustpan consists of a slightly raised platform covered by perforated plate attached to a vacuum hose. The perforated plate prevents large foreign material from entering the recovery equipment. The dustpan can be positioned where the heaviest concentration of blasting debris is expected to fall. Material is swept onto the platform and pneumatically transported to the media recovery system. Floor modifications are not required to use the dustpan. This system cannot handle heavy media loading as well as a permanent pit and requires a substantial amount of labor to sweep material onto the dustpan.

The least complex permanent system is a small media collection pit installed in the blasting room as shown in figure 6. Operators sweep or use compressed air to blow blasting debris into the pit. The system is still labor intensive. Pits should have a volume of about 6 cubic feet to match the volume of the media storage hopper. The bottom section of the pit should have smoothly inclined walls with a minimum incline of 60 degrees to prevent media bridging. Mechanical or pneumatic systems are used to transport material to the recycling system. The pit should be covered with close pattern grating strong enough to structurally support anticipated loads. The grating may be covered with wire mesh to prevent large objects from plugging the media transport or recycling equipment. The pit should not be located near blast booth ventilation system exhaust ducts in order to minimize the amount of reusable media inadvertently blown into the ventilation system.

A partial floor recovery system helps to reduce capital costs over a full floor recovery system. This system continuously removes blasting debris from selected portions of the blasting area. The partial floor recovery system requires some manual clean-up, but strategic positioning of the recovery floor sections can minimize this labor requirement. Typical floor arrangements use strips of floor recovery equipment running lengthwise in the blasting room. The strips are equally spaced. A good arrangement for a 45-foot wide booth would have five 3-foot wide recovery strips separated by a 6-foot wide solid strips with two other solid 3-foot wide strips along the edge as shown in figure 7. This arrangement allows the bulk of blasting debris either to fall in or near the floor recovery grating and minimizes sweeping labor. The maximum sweeping distance is an easy 3 feet at any point. Floor recovery strips should not be located at the wall edges of the floor because the blasting debris cannot be pushed into the strip from both sides. Concrete floors adjacent to recovery strips should be sealed with a heavy coat of epoxy or covered with solid rubber sheets to prevent hard particle contamination of the media.

Another partial floor recovery system shown in figure 8 recovers the blasting debris before it hits the floor. Portable shields are positioned so that blasted media rebounds off the blasted surface into the enclosure formed by the shields. The back of the shield enclosure is formed into a dust intake that is connected to a suction system, providing area ventilation as well as blasting debris collection. Reusable media in the ventilation air flow is recovered by an intermediate cyclone. This modular system combines the ventilation and media recovery systems into one unit with a minimum of capital investment.

4.2 Mechanical Floor Recovery Systems

Mechanical systems can convey the material in several ways. Most methods use some type of mechanical conveyance installed under the floor grating. In one method, sweeper arms are dragged down the narrow flat paths between steel floor support beams to the recovery equipment. In another method, the material is directed into a rotating screw or similar mechanical conveyor using sloped troughs between the steel beams. An "inertial floor" uses reciprocating shaker pans to move the media to a collection trough at one end of the active floor.

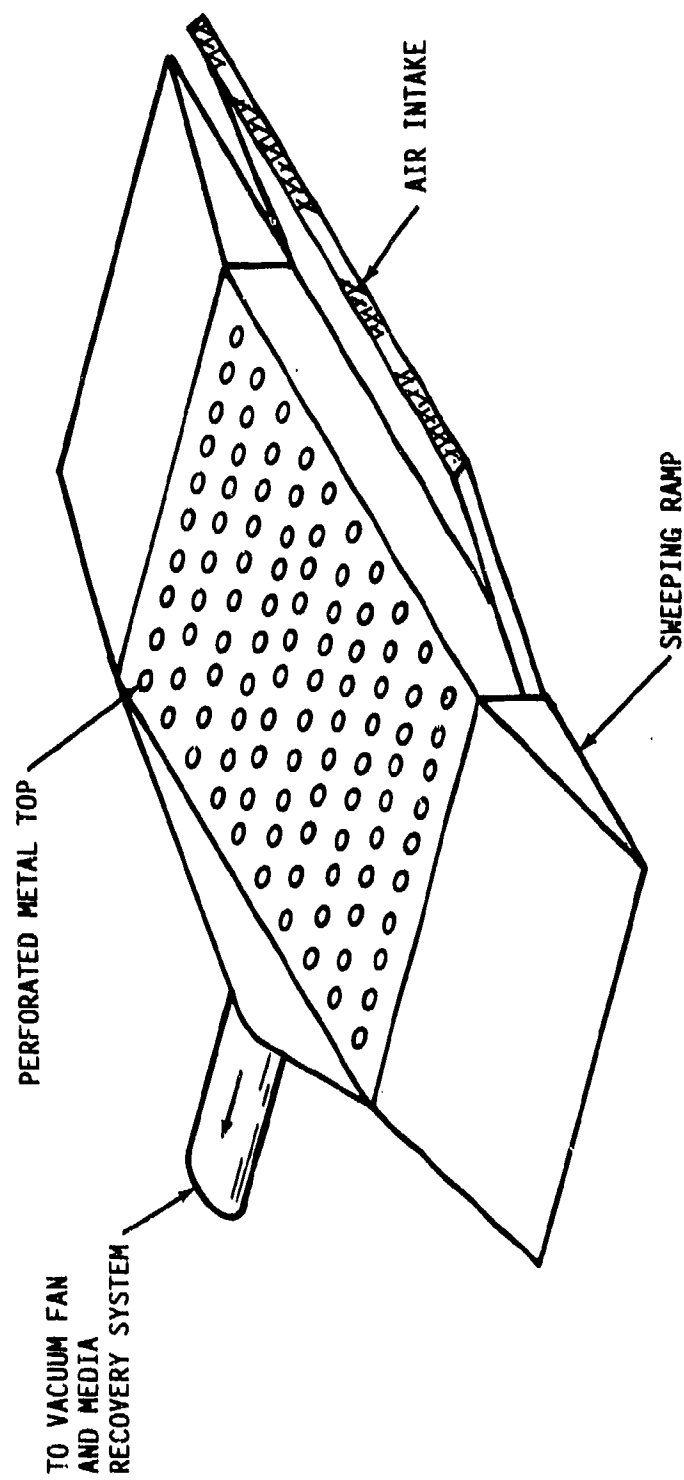


FIGURE 4. PNEUMATIC DUSTPAN.

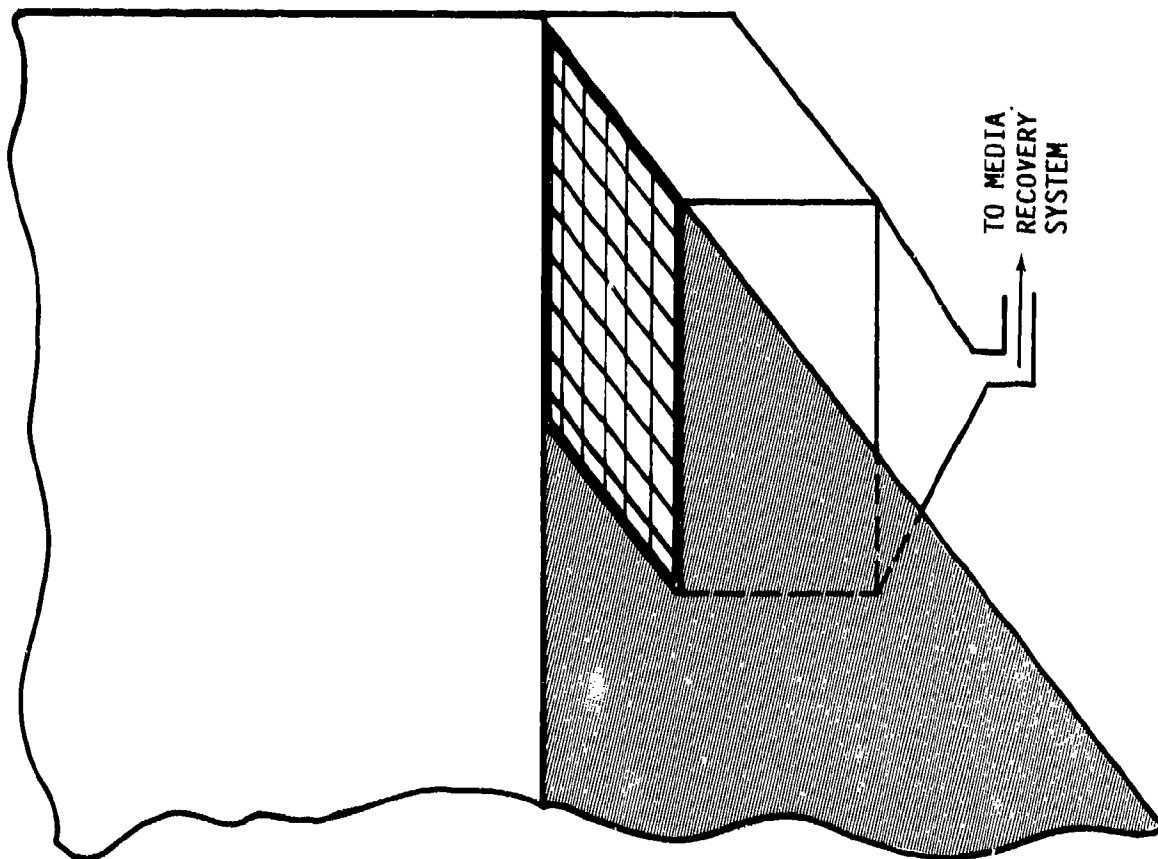


FIGURE 5. MEDIA RECOVERY PIT.

SEALED OR COATED CONCRETE FLOOR SECTIONS ARE 6 FEET WIDE
 CONCRETE END SECTIONS ARE 3 FEET WIDE
 FLOOR RECOVERY SECTIONS WITH GRATING ARE 3 FEET WIDE

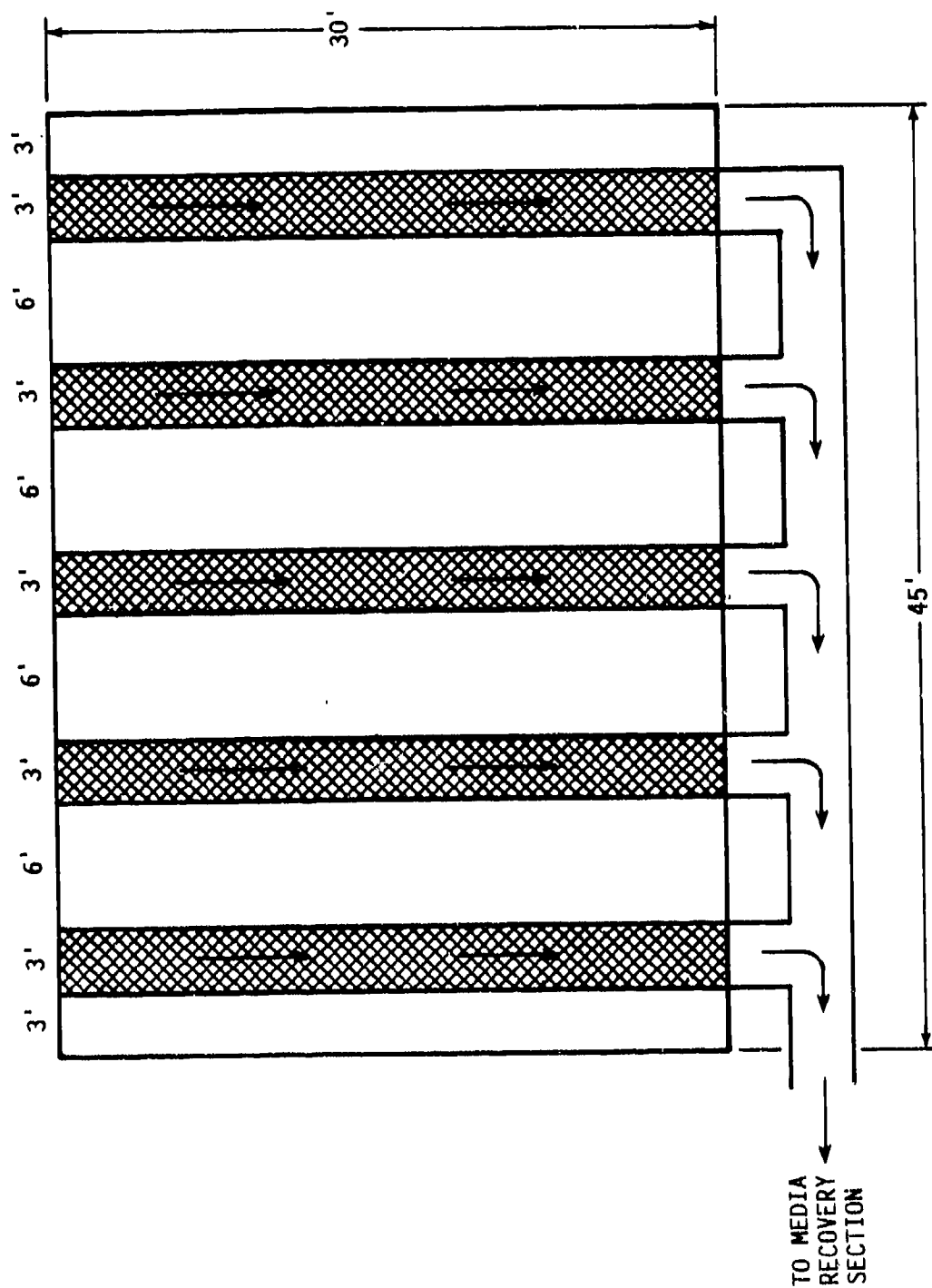


FIGURE 6. TYPICAL PARTIAL FLOOR RECOVERY LAYOUT TO MINIMIZE SWEEPING DISTANCES.

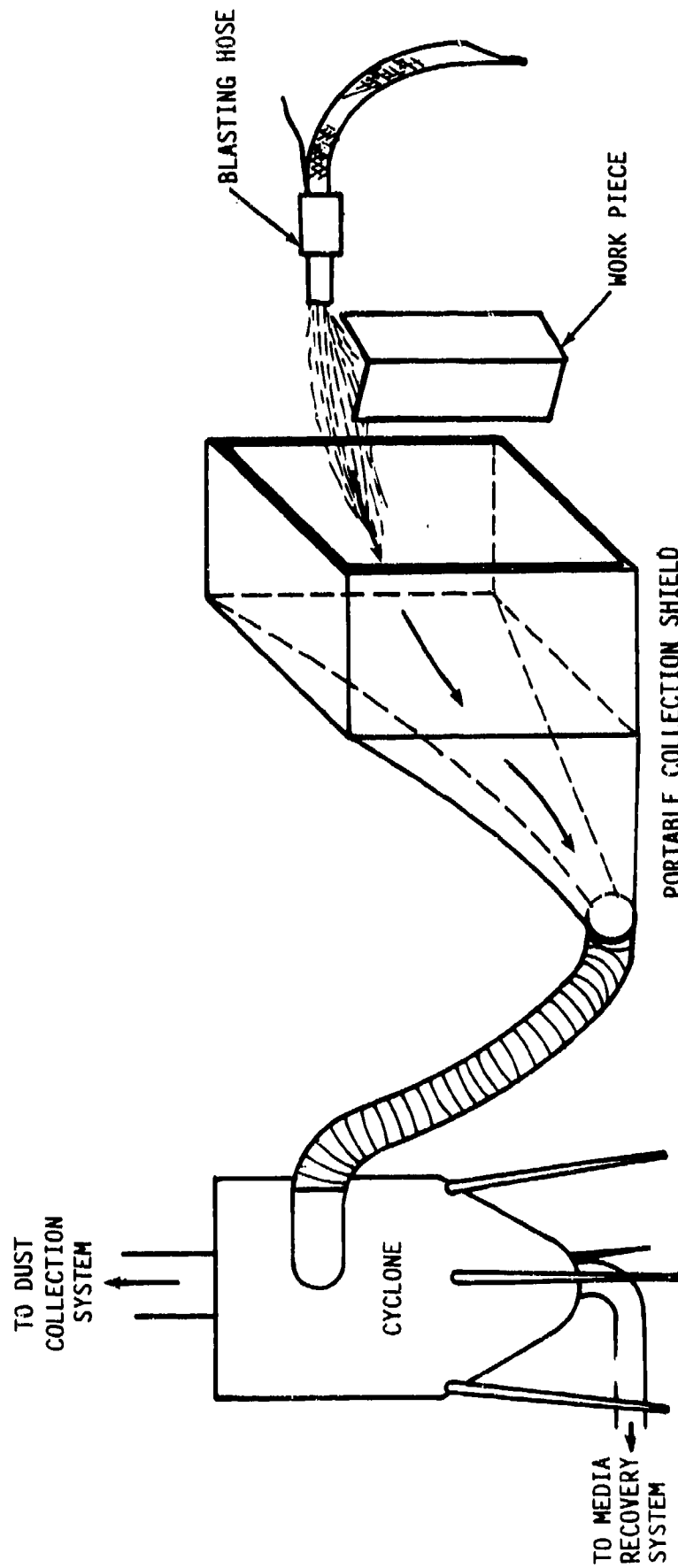


FIGURE 7. PORTABLE COLLECTION SHIELD AND CYCLONE.

The equipment must not be effected by the contamination of its drive mechanisms with media. Bearings, gears, and seals should not be sensitive to the dust and plastic particles present in their operating environment. Lubricated, close tolerance equipment should be isolated from the blasting debris. A mechanical transport system should transfer the material to an air stream for classification by the media recycling system cyclone. A series of mechanical conveyor belts installed beneath the floor grating have been used to convey media to the recycling equipment. Schematics of various mechanical systems are shown in figures 9 through 12. Conveyor belt systems have not proven effective for this application. The belts may not remain aligned on the belt driver and tend to travel and fray. Pulleys wear quickly or shear as the belts travel due to the uneven loading. Down-time and the corresponding maintenance costs tend to be unacceptably high for belt recovery systems.

Screw conveyors must be properly sized to convey large accumulations of media. Adequate clearance between the walls of the conveyor tube and the conveyor internals is necessary to avoid grinding the media. Significant amounts of media are retained in the screw conveyor due to the clearances, therefore, a relatively large amount of media is needed to initially charge a screw conveyor system. The system must be recharged after regularly scheduled cleaning.

4.3 Pneumatic Floor Recovery Systems

Pneumatic systems use the differential pressure developed by induced draft fans. The most common pneumatic systems use a series of 60 degree angle conical trough hoppers to collect the media and gravity feed it into several rows of conveying pipe situated between floor support beams (see figure 13). Media in the pipe is transported pneumatically to the recycling equipment. The outlet of the hopper trough should be not less than 7/8-inch diameter in order to prevent bridging by the media. Pneumatic floor recovery systems should transport media to the first classification stage in the media recycling system without transition equipment. Pneumatic transport systems should not damage reusable media when in operation. Pneumatic systems should convey material at between 25 and 75 feet per second (fps). Velocities greater than 75 fps will cause higher erosion rates in the duct work and increase media degradation. Media flow tends to plug at velocities less than 25 fps. The systems have used negative draft from either the ventilation system draft fans or a separate fan. Attempts to combine the ventilation system air movement requirements with a pneumatic floor recovery system have not been successful.

Pneumatic requirements can be reduced significantly by sequencing the operation of the individual rows of conveying pipes. The sequencing only operates a fraction of the total rows at any one time, and by alternating between them cleans the entire floor with each complete cycle. The duct size downstream of the floor and the size of subsequent recycling equipment is also reduced.

One innovative system now available utilizes a mechanically operated travelling vacuum head to remove debris from the flat surface between the support beams. This system is shown in figure 14. This system can be less expensive to install because the required clearance underneath the floor grating to fit in the floor recovery system is reduced. Plugging problems caused by overloading that are typical of other pneumatic systems, are avoided using the mechanical drive system. The drive system meters the amount of media flow into the pneumatic transport system by controlling the speed of the vacuum head. This control ensures adequate air flow rates in the pneumatic duct will be able to continuously move the measured flow of media in the ducts. The vacuum head is moved with a cable drive system that is not sensitive to dust and grit.

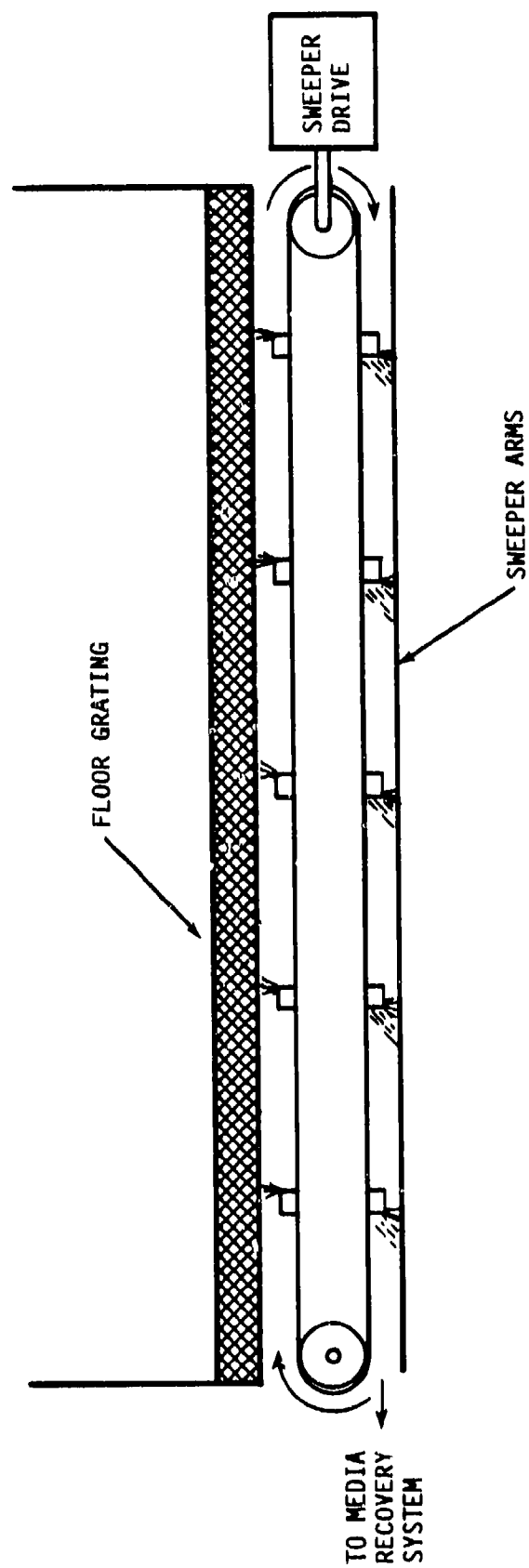


FIGURE 8. TRAVELING SWEEPER ARMS FLOOR RECOVERY SYSTEM.

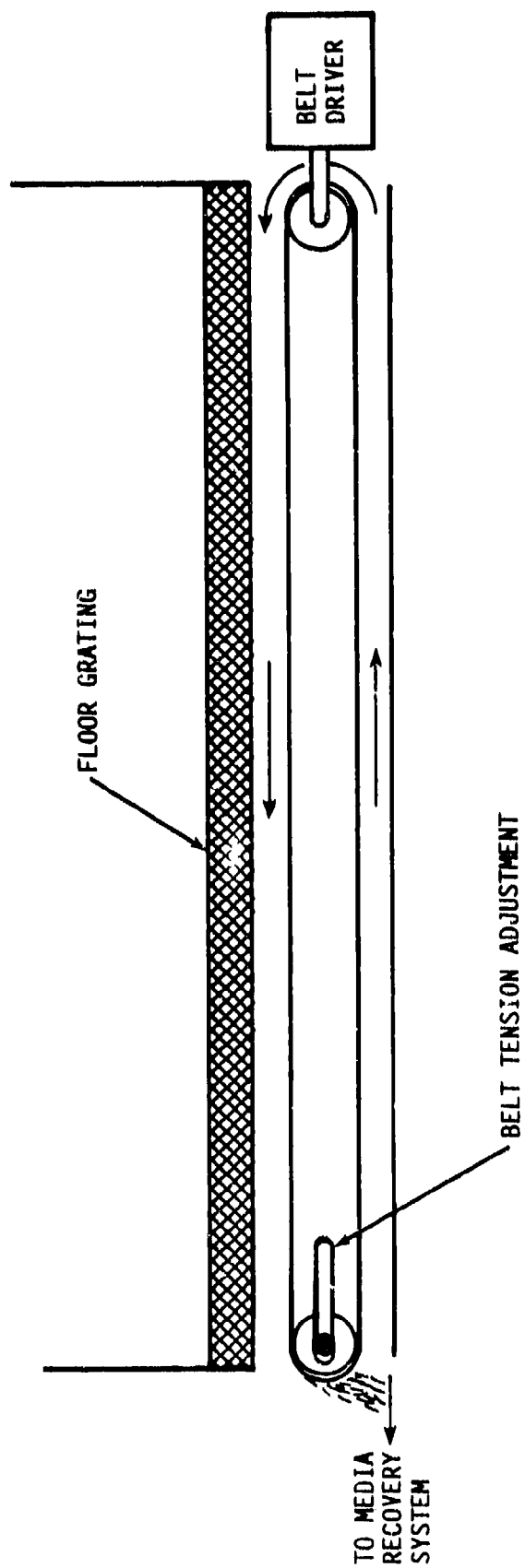


FIGURE 9. CONVEYOR BELT FLOOR RECOVERY SYSTEM.

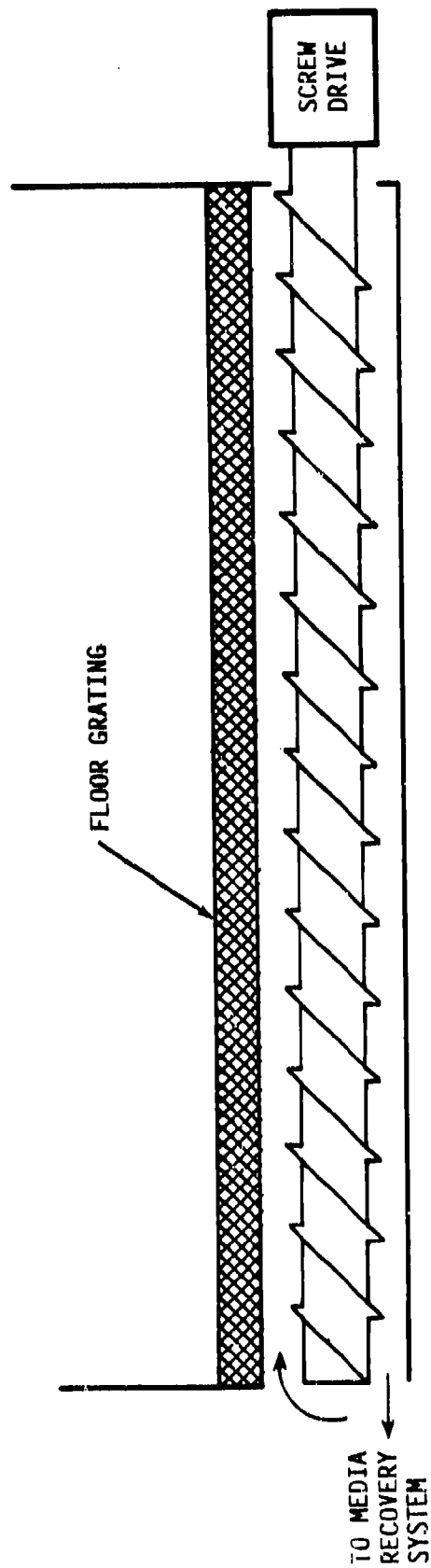


FIGURE 10. SCREW CONVEYOR FLOOR RECOVERY SYSTEM.

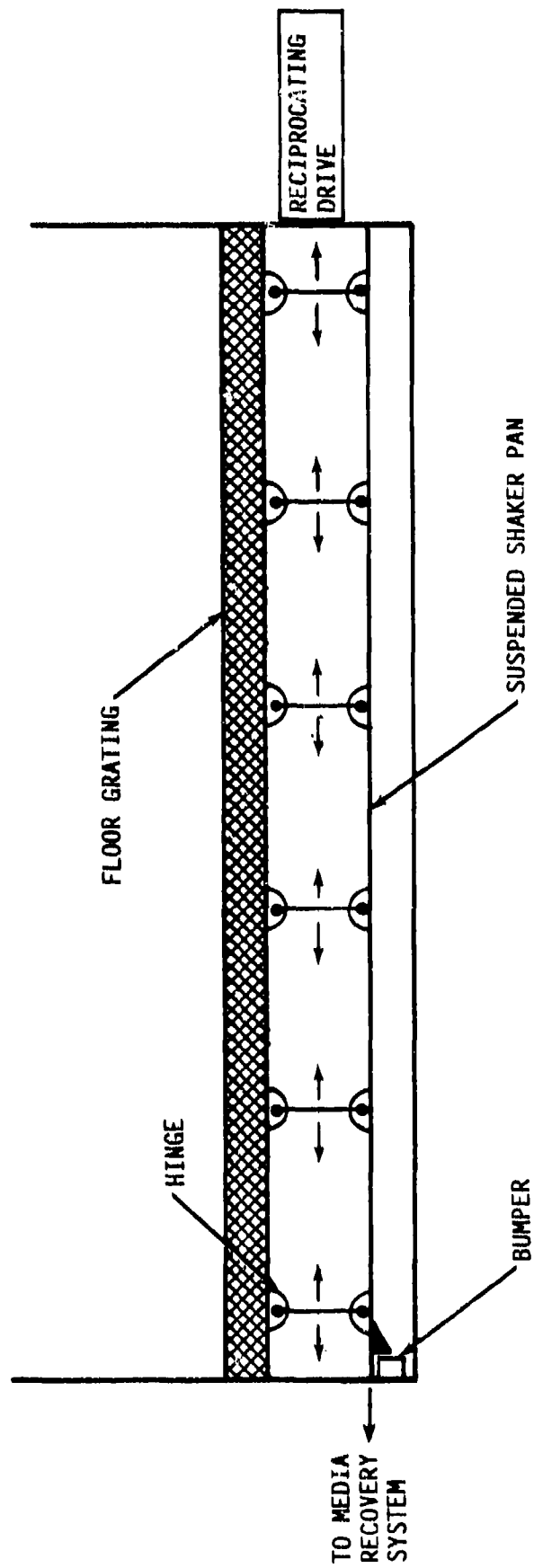


FIGURE 11. RECIPROCATING SHAKER PAN FLOOR RECOVERY SYSTEM.

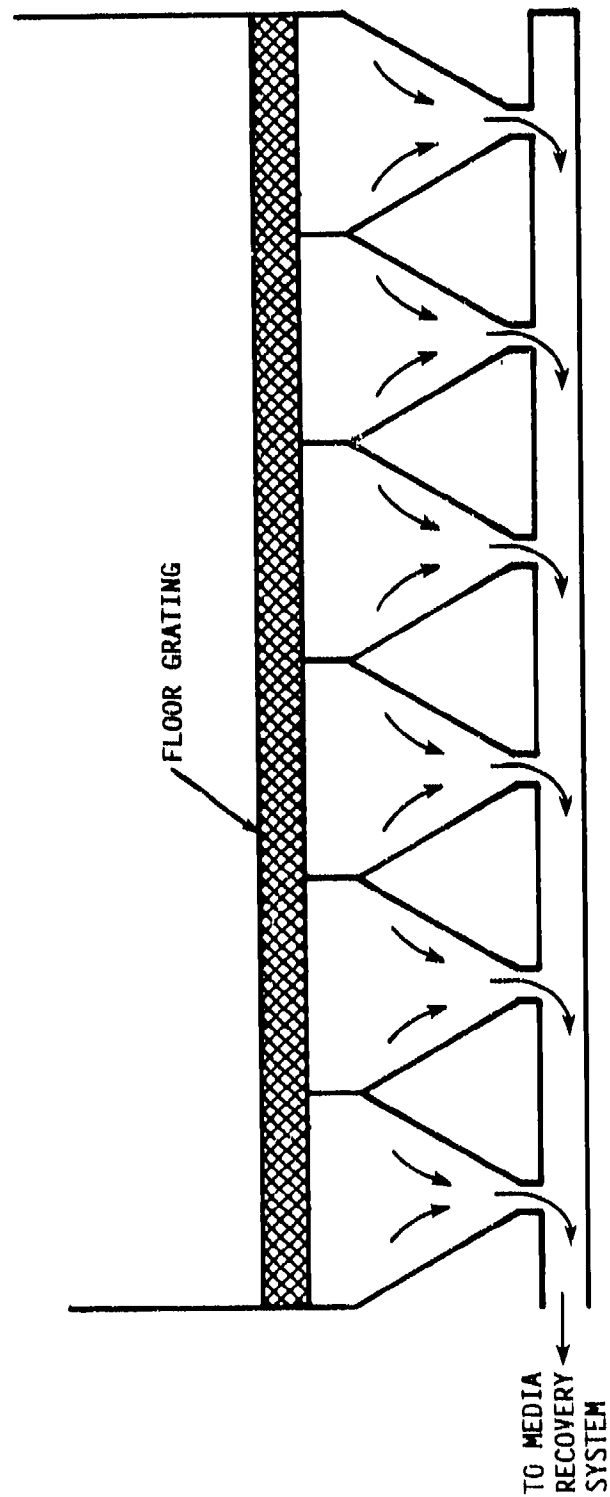


FIGURE 12. PNEUMATIC FLOOR RECOVERY SYSTEM.

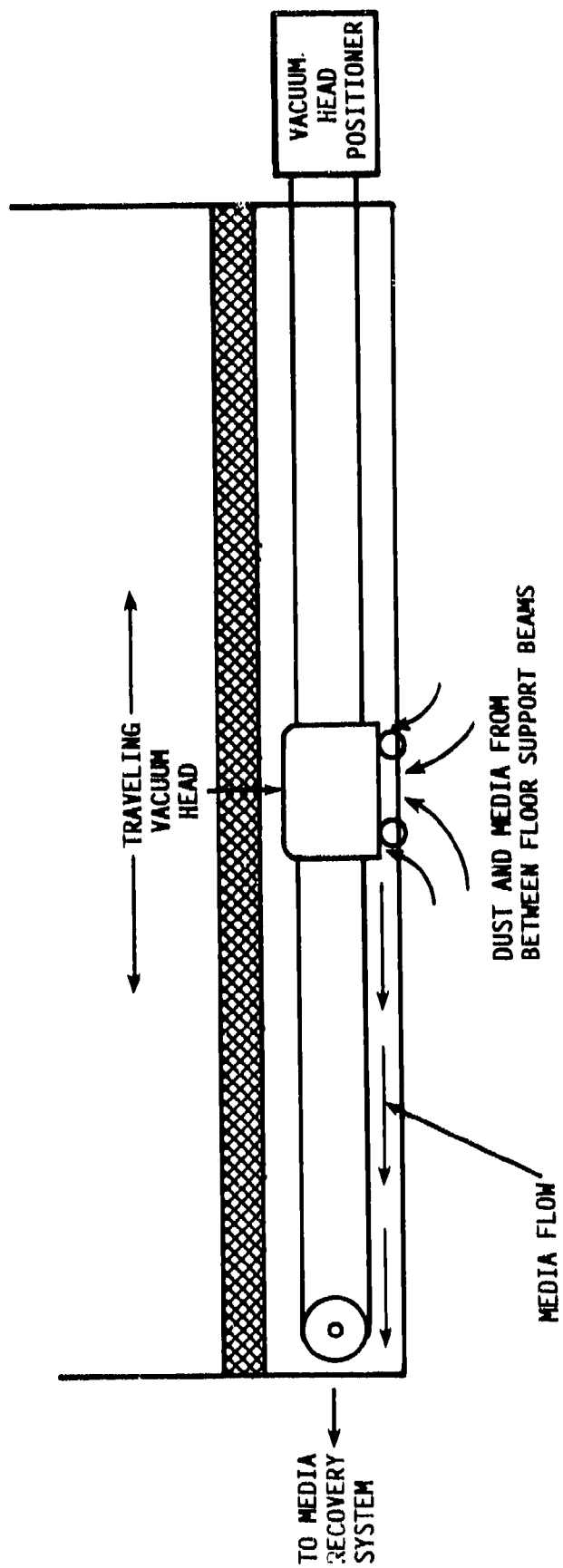


FIGURE 13. TRAVELING VACUUM HEAD FLOOR RECOVERY SYSTEM.

5.0 MEDIA RECYCLING EQUIPMENT

Media recycling equipment cleans and returns reusable plastic media to the blasting equipment. The performance requirements of the equipment are:

- To accept the material being transported from the floor recovery system.
- To collect the material being transported from the ventilation system large particle separator.
- To remove particles greater than 10 mesh (Tyler equivalent scale) from the reusable media stream.
- To remove particles less than 60 mesh (Tyler equivalent scale) from the reusable media stream.
- To remove magnetic particles from the reusable media stream.
- To transport properly classified reusable media to the blasting equipment storage hopper.
- To collect the non-reusable portion of the blasting debris for disposal.

An efficient media recycling system is the key element in a cost effective blasting operation. Media must be cleaned to prevent substrate damage and maintain efficient operation. However, properly sized reusable media should not be discarded in the cleaning process. The annual operating expense for replacing lost media at \$1.60 per pound can easily be greater than the capital cost of the separation equipment. A recycling system for a single 0.5 inch nozzle (20 pounds per minute) operating six hours per day, five days per week, with three percent recoverable media loss per cycle (over and above the typical 5 percent degradation loss) will require almost \$90,000 annually for media replacement costs.

The media recycling equipment may include the following components:

- Cyclone separator(s).
- Collection hopper for returned media.
- Rotary valve.
- Vibrating or stationary screens.
- Magnetic separator.
- Air wash.
- Mechanical elevators.
- Pneumatic transport systems.
- Rejected debris collection trays, bins or bags.

To minimize media replacement costs, the particles discarded by the entire recycling equipment including cyclones, vibrating screens, air washes, and magnetic separators should contain less than 5 percent by weight reusable plastic media large enough to be retained on a 60 mesh screen. The recycling equipment should effectively clean the media. Reusable media should contain less than 5 percent by weight particles small enough to pass through a 60 mesh screen.

5.1 Cyclone Separators and Rotary Valves

The initial media recycling step, usually accomplished by a cyclone separation, is to remove dust from the material collected from the blasting area. The dust from the cyclone is transported to a baghouse. Initial removal of the dust helps to prevent plugging later in the recycling process. The cyclone is also useful in agitating and removing dust adhering to reusable media. Manufacturers have tended to undersize this cyclone resulting in reusable media being lost to the baghouse. An adequately sized cyclone separator should be used to remove fine particles from the material stream.

A recently marketed cyclone design combines a partial cyclone for classification with a particle air wash. After media enters the cyclone, air is introduced in a narrow stream flowing at high velocity perpendicular to the direction of the media particle flow. This effect helps remove any dust that might be entrained with the reusable media and transports it to the baghouse. This classification system has proven to be highly efficient in meeting media recycling requirements in the newer PMB equipment. The rate of air passing through the air wash should be adjustable to provide optimum results.

Rotary valves can be used to provide an airlock during transfer of media between recycling system components operating at different pressures. A typical rotary valve location is at the bottom of the cyclone collection hopper. Rotary valves can also be used to meter a constant flow of plastic media to the recycling equipment.

5.2 Vibrating Screens

The material recovered in the cyclone is then classified to isolate the particles between 12 and 60 mesh. A variety of equipment can be used for this purpose. A secondary cyclone, or a vibrating or rotating screen, are currently the preferred secondary classification equipment.

A two-tier vibrating screen is frequently selected to classify the material. A 12 mesh top screen collects the oversize material while a 60 mesh bottom screen separates the undersize material. These undersize fractions are then rejected to a collector. The 12 to 60 mesh fraction collected on the bottom 60 mesh screen is then routed to the media storage hopper. The vibrating screen capacity should be sized to avoid plugging or overloading the screens. The screen should preferentially be cleaned automatically in a blast room. An oversized screen should be manually cleaned in a glovebox.

5.3 Magnetic Separator

An adequately sized magnetic separator should be positioned in the media flow stream to remove tramp metal from the classified media. Magnetic material can enter the recycle stream as a result of new media contamination, poor housekeeping, substrate erosion, or erosion of steel portions of the plastic media recovery/recycling system. The harder metal particles circulating through the system can damage the substrates during blasting.

A variety of magnetic separators are available from manufacturers and may incorporate either automatically-cleaned electromagnets or manually-cleaned permanent magnets. One PMB system uses a magnet approximately one square inch in size located in the throat of the blasting pot. Other manufacturers install larger permanent magnetic separators, which still require manual effort to clean. The magnetic separator should be automatically self-cleaning to ensure its effectiveness. Manually cleaned separators (permanent magnets) tend to be ignored and, thus, lose their effectiveness over time as their magnetic particle retention capacity is exceeded.

One manufacturer has produced a satisfactory automatic, continuously-cleaned magnetic separator by using a partially magnetized rotating drum. The drum is magnetized where the media contacts it. Magnetic material is retained on the drum and rotates away from the media path. As the drum rotates, the magnetic field is deenergized and the magnetic material falls into a separate hopper for disposal. Commercially available, self cleaning magnetic separators remove greater than 35 weight percent per pass of the magnetic particle contamination in the media (see paragraph 9.1.2). Other design options should be explored to improve this efficiency.

5.4 Miscellaneous Equipment

The cyclone, vibrating screen, and magnetic separator should discard the rejected material into a storage bin or hopper that can be emptied with a minimum exposure of personnel to the material.

All access doors to the ventilation equipment should be fitted with rubber gaskets to prevent dust leaks into the room where unprotected personnel may be working. The access doors should be equipped with interlocks to prevent operation of the blasting equipment when the doors are open.

- Electrical equipment located outside of the blasting enclosure should be housed in Class II, Division II, NEMA type 9 enclosures, unless the operating area requires a more stringent electrical classification.

- Both mechanical and pneumatic methods are acceptable to convey media through the recycling system. Mechanical transport devices, such as bucket elevators, may reduce energy consumption and minimize media damage as compared to pneumatic systems. Pneumatic transport systems should not use thin-walled, wire-reinforced flexible ducts due to their rapid failure under normal operating conditions from media erosion.

6.0 VENTILATION EQUIPMENT

The ventilation equipment removes dust from the blasting area to allow work piece visibility. The performance requirements of the equipment are:

- To minimize personnel exposure to toxic materials and minimize explosion hazards.
- To remove dust from the work piece area during blasting in a manner ensuring good visibility.
- To capture dust entrained in the ventilation air stream for disposal.
- To return reusable media entrained in the ventilation air back to the system for recycling.
- Condition air for personnel safety and comfort.

The usual equipment included in a ventilation system may include the following components:

- Ductwork to/from blasting room and recovery equipment.
- Gravity separation chamber.
- Baghouse.
- Induced draft fan.
- Ventilation control dampers.
- Exhaust ductwork.
- Dust collection hopper.

6.1 General Description of Ventilation Systems

Ventilation equipment designs have been progressing to a relatively constant configuration. Air flows into the blasting booth from one side, traverses the blasting chamber, and exits at the other side into a cyclone system. Fines from the recycling system then travel to a baghouse. An induced draft fan located downstream of the baghouse moves the air through the system and discharges it to a vent stack. The basic system is shown in figure 15.

The Naval Energy and Environmental Support Activity (NEESA) has developed ventilation system design guidance for PMB installations. NEESA indicates that based on ANSI Z9.4-1985, 29CFR 1910.94 (OSHA), and MIL-HDBK 1003/17 (Industrial Ventilation Systems), PMB enclosures using a crossdraft flow pattern must have air velocities of 100 feet per minute (FPM) since coatings containing lead and chromates are being removed. Operational tests have indicated that velocities of approximately 60 fpm in large booths have maintained good visibility. Operators are always equipped with OSHA/MSHA approved blasting hoods with supplied breathing air and are not exposed to hazardous concentrations of toxic materials.

The air flow rate also varies across the cross section of the blasting room. Air speeds are much greater in the center of the room where the blasting work is likely to be performed. The nominal cross section air flow calculation also does not account for the effect of air flow obstructions by the work piece and personnel in the booth. The obstructions would decrease the cross sectional area and increase local velocities at the work place. The obstructions also create turbulence making laminar air flow difficult to maintain.

The exit ductwork from the blasting area should be designed to minimize the amount of reusable media entrained in the air stream. Several manufacturers have installed baffles on the ductwork inlets to deflect media back to the blasting floor. The average velocity in the ventilation ducts should be about 3000 feet per minute (fpm) to minimize erosion damage and prevent accumulations of dust within the ductwork. A seldom used, but effective design, places a gravity separation chamber in the exit ductwork to remove media from the air stream. A slanted pipe equipped with a flapper valve is used to return media to the blasting area from the gravity separation chamber.

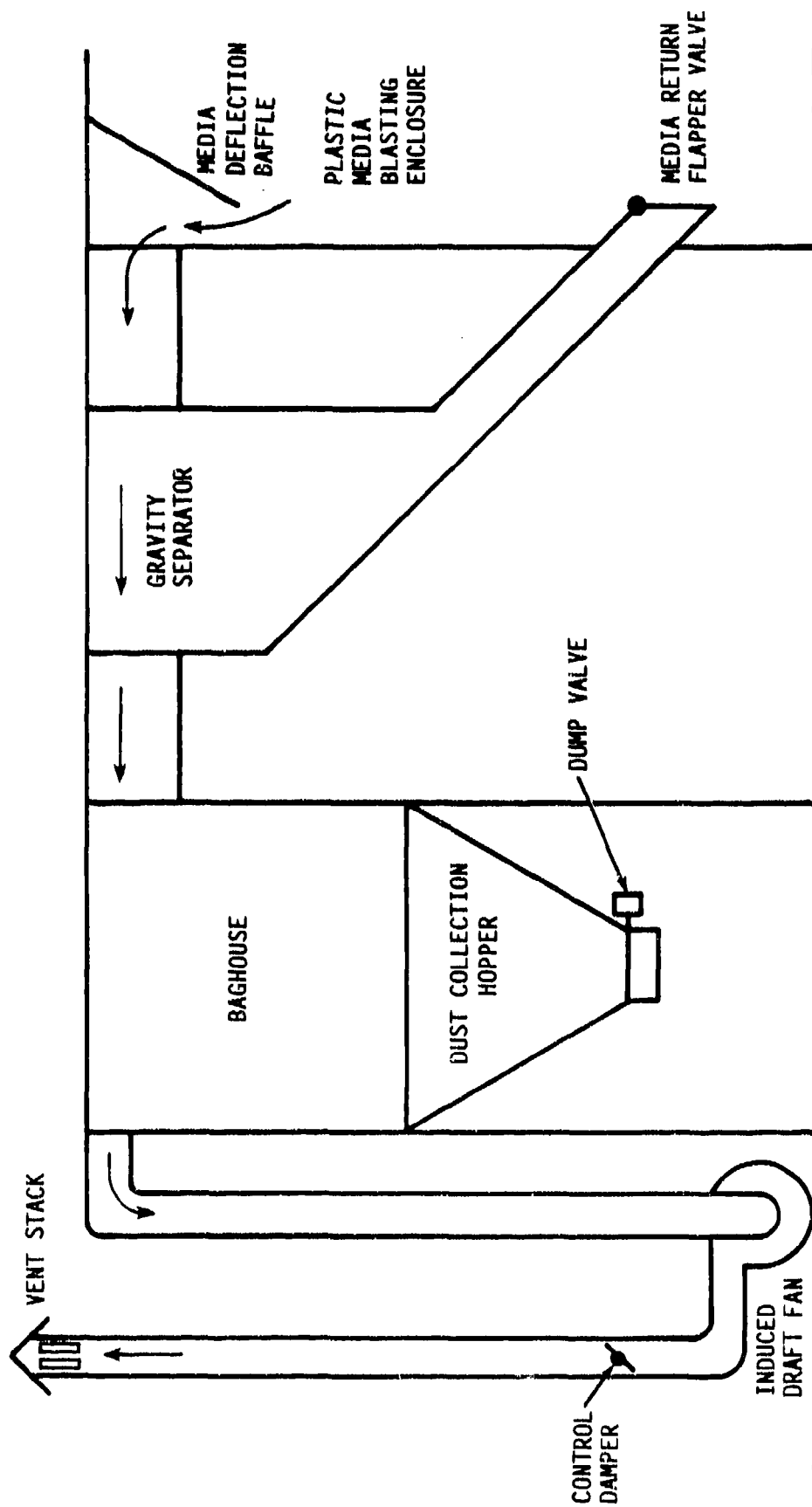


FIGURE 14. VENTILATION SYSTEM NOMENCLATURE.

Cyclones separators may also be used to remove media from the ventilation air before it is trapped in and discarded by the baghouse. Dust laden air gathered from other cyclones in the system is routed to the baghouse.

The baghouses selected to remove dust should be of the reverse pulse style using either cartridge or bag filter elements. The reverse pulse units use bursts of compressed air to dislodge contaminants on the filter elements. The operation of the reverse pulse mechanism should be automatic. The mechanism should be activated by the differential pressure across the filter element or by a timer with a differential pressure switch override. The timer and the differential pressure switch settings should be adjustable. The dust then falls to the bottom of the baghouse for collection and disposal. Filter velocity is defined as the ratio of the airflow rate to the available filter area. Baghouses should use filter velocities with an air-to-cloth ratio of less than 3.0.

Cartridge filter elements are usually the economical choice for small installations. Adequate access hatches should be provided to easily replace cartridge filter elements and provide normal maintenance. Platforms should be provided for all elevated access hatches.

The dust collection hopper for the baghouse should be designed to minimize exposure of personnel to the dust during removal operations. The hopper should be furnished with an isolation valve and a dust collection system that will work in the slight vacuum caused by the draft fan. The dust hopper should be furnished with a level indicator to indicate when it is full.

The induced draft fans tend to be adequately designed and sized for the commercially available equipment. The fan should be located downstream of the dust collector. Sufficient draft should be induced to provide the required air velocities in the blasting area. The air discharged from the fan should usually be routed outside the building enclosing the PMB booth and equipment especially if unprotected personnel may be exposed.

Ventilation air will usually require conditioning to avoid problems caused by the ambient temperature and humidity. Low temperatures may increase the brittleness of the substrates being blasted and also reduce media life. High temperatures may increase operator fatigue and decrease productivity. High humidity may cause media agglomeration leading to problems in the media recovery and recycling equipment. The design of the HVAC equipment should minimize the energy costs associated with heating or cooling the ventilation air.

7.0 DENSE PARTICLE REMOVAL EQUIPMENT

The purpose of dense particle removal equipment is to remove particles more dense than the plastic media that are of the same size as the plastic media and able to pass through the media classification system. The dense, hard particles may cause damage to sensitive substrates if allowed to remain in the plastic media. The individual performance requirements of this equipment are:

- To remove particles of significantly higher specific gravity that are in the same size range as the reusable plastic media.
- To dry or otherwise reverse the effects of the separation process on the reusable plastic media.
- To collect the denser particles for disposal.

The dense particle removal equipment can include the following components for a flotation-style cleaning system: (Manufacturers may not supply all of the components listed or may supply alternates.)

- Media storage hopper
- Media delivery system
- Tiered flotation tank
- Circulation pump
- Media collection screen
- Media dryer
- Cleaned media storage hopper
- Fluid cleaning system

The hard particles, although denser than plastic, still fall in the size classification range between 12 and 60 mesh. For example, a 20 mesh plastic media particle has about the same weight as a 24 mesh sand particle or a 32 mesh stainless steel particle. The almost 300 to 1 volume ratio between 12 and 60 mesh particles easily masks the relative density ratios of 6 to 1 between metal particles and plastic media. The cyclone, sieving, and air wash recycling operations are not discriminating enough to remove the hard particle contaminants. The Air Force recommends not greater than 200 ppm by weight concentration of hard particle contamination in recycled media. Dense particle removal equipment is still being developed and is only marginally available on a commercial basis.

7.1 General Description of Dense Particle Removal Equipment

The performance criteria for dense particle separation equipment is to provide dry media free from dense particles for use in subsequent blasting operation. The media should be dry to prevent caking or plugging of the blasting system. The concentration of dense particles remaining in the media should be not greater than 200 ppm weight percent of the cleaned media.

One possible media cleaning system uses a flotation system where the dense particles sink away from the floating plastic media particles. The media to be cleaned is placed in the media storage hopper and metered into the flotation tank. Freon has been used as a possible flotation fluid because its specific gravity is between that of the plastic media and the hard particles. The flotation fluid is circulated to help carry the media across weirs while sand and other particles sink to the bottom of the individual chambers. Fluid reaching one end of the tank is screened to remove impurities and returned to the tank. The plastic media floats onto a separation screen and falls into a heated screw conveyor to be dried and transported to the cleaned media storage hopper.

Although effective, the environmental sensitivity of freon will probably prevent its use as a commercial flotation agent. Freon, along with other chlorofluorocarbons (CFC) have been implicated in the degradation of atmospheric ozone. The liquid is also expensive and will have significant operational losses due to high evaporation rates. Alternate methods such as water washing techniques are currently being developed. It is also possible that substitute flotation agents may be identified.

Tabling is one equipment option now used in the mining industry for density separations. A media and water slurry is poured over a moving riffled tabletop. The heavier particles tend to remain in the riffles and travel along them to a side of the table, while the lighter plastic particles travel over the riffles across the table. The plastic media is then dried and transported to a storage hopper. The effectiveness of this process depends mainly on the difference in specific gravity between the contaminants and the plastic media.

Dense particle separation equipment installations are an economic choice of the equipment owner. The equipment owner must balance the replacement costs of reusable media discarded due to hard particle contamination against the capital and operating costs of a dense particle removal system. An additional factor is the cost of damaged parts due to unanticipated hard particle contamination.

8.0 PLASTIC MEDIA BLASTING GLOVEBOX

Plastic media blasting in a glovebox is simpler than full scale blast booths due to the reduced scale of operation. Four of the five functional equipment classifications are highlighted. The dense particle removal equipment is not shown, as it is similar to what would be used to clean media from a blasting room. The individual equipment components for the system are discussed below. Figure 16 is a schematic of a glovebox.

8.1 Blasting Equipment

The blasting equipment for a glovebox is similar to the equipment used in a blasting room. The blasting pot and media storage hopper are, however, usually smaller. The glovebox is equipped with latex gloves and working surface. A turntable should be furnished to improve accessibility to the workpiece. The blasting hose may be suspended from an internal roof track for easier handling.

8.2 Floor Recovery Equipment

The media recovery equipment for a glovebox typically consists only of a work area of perforated metal. Blasting debris fall through the perforations to a conical section with a vacuum intake at the bottom of the cone. Suction is provided by the baghouse induced draft fan. The blasting debris is then conveyed to a cyclone separator.

8.3 Media Recycling Equipment

A small cyclone separator is usually provided and can be equipped with an efficient air wash at its outlet to fully remove dust from the reusable media without a vibrating screen. A stationary, manually cleaned perforated metal screen at the cyclone outlet can collect oversized material as reusable media falls across it into a storage hopper. Gloveboxes are also furnished with small media recycling systems equipped with vibrating screens. The magnetic separator design is similar to those used in larger systems. Performance requirements for gloveboxes are similar to blasting rooms.

8.4 Ventilation Equipment

A single draft fan pulls all the air through the media return duct and baghouse. The baghouse is usually a pair of cartridge style filter elements. The dust is collected in a single hopper or bin. Exhaust air is typically vented outside.

Ventilation rates do not have to be greater than 100 fpm in a glovebox because personnel are not exposed to airborne dust. Sufficient air velocity must be maintained to maintain visibility and prevent dust concentrations from reaching explosive concentrations in the glovebox.

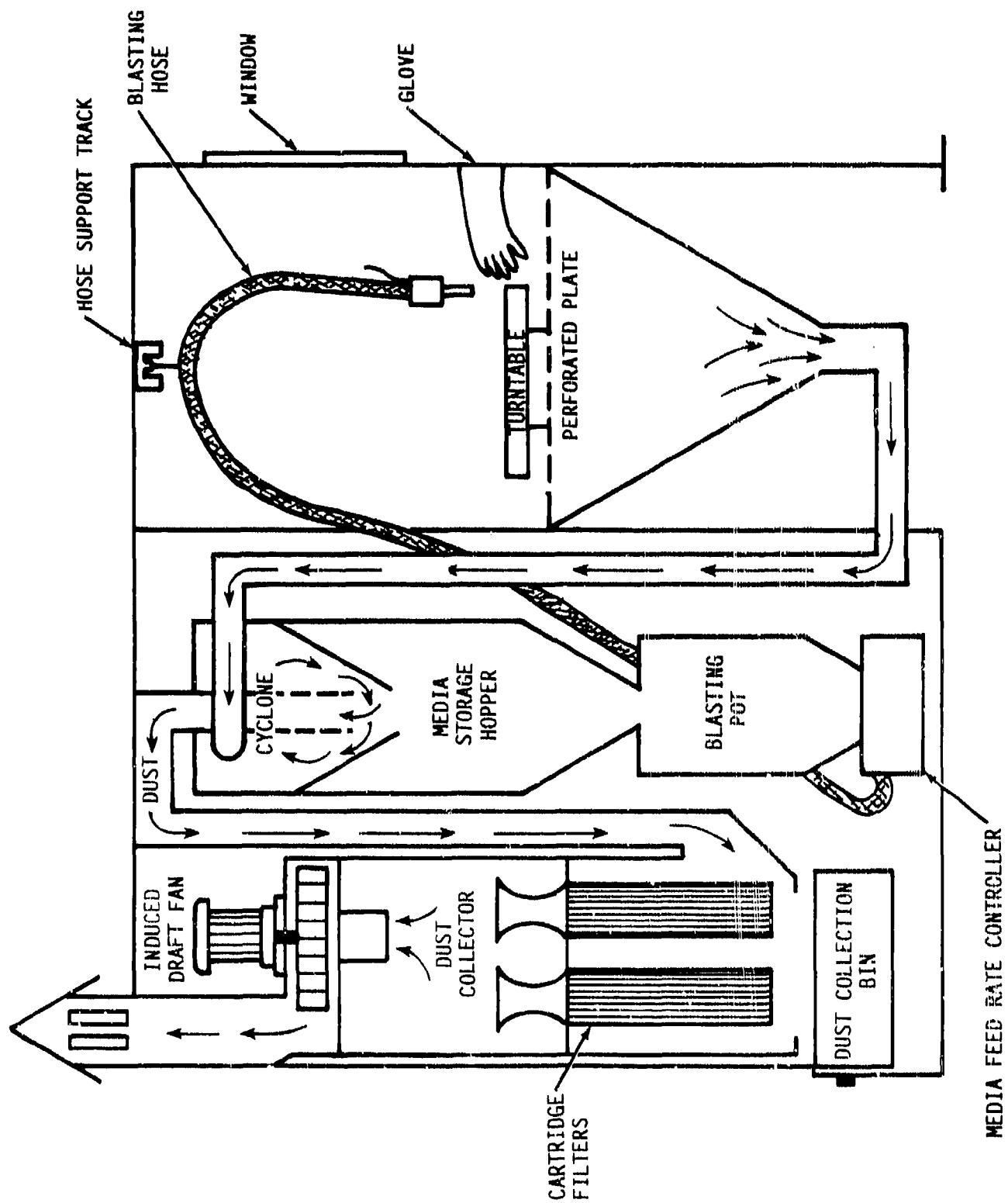


FIGURE 15. GLOVEBOX NOMENCLATURE.

9.0 EQUIPMENT TEST DATA

Tests were performed to evaluate the effectiveness of PMB equipment manufactured by Schlick, Incorporated of Metelen, West Germany. Media flow rate accuracy and magnetic particle removal efficiency were analyzed. Painted fiberglass and carbon epoxy composite test panels were provided by Mr. J. J. Bauer of Bell Helicopter Textron. These test panels were blasted under varying conditions. Stripping effectiveness and surface effects were then noted.

9.1 Glovebox Blasting Tests

The nozzle blasting tests were conducted using a Schlick glove box, model DSS-BC 1500 Electronic. The self contained glove box design uses a combination cyclone/wind sifter and stationary oversize screen to clean the media without a vibrating screen. An electromagnet is used to remove magnetic particles from the recycled media. The blasting pot is equipped with a rotary screw conveyor and level detector. Dust collection is performed using a reverse pulse style baghouse with cartridge filter elements.

9.1.1 Media Flow Rate Test

The glovebox was equipped with electronic media flow and air pressure controllers with a digital display panel located at the front of the glovebox. The controllers were effective in maintaining flow and pressure at various set levels. Tests to determine the accuracy of the displayed media flow rate at various pressure and flow rate combinations were performed. Media was discharged from the nozzle into a covered container for one minute and then the contents of the container were weighed. A minimum of three samples were collected at each pressure and flow combination. The data collected showed that test weights repeatable within 10 percent of the stated flow rate were obtainable, which is within the error of the test method.

Regular pulsations of media flow on the order of 200 pulses per minute were observed at low media flow rates and low pressures. The amplitude of these flow rate changes were estimated visually at about 20 percent of the average media flow. These pulsations were explained as being caused by an oversized nozzle for these blasting conditions. The excessive air flow swept media off of the end of the rotating screw. The transport air, depending on the relative orientation of the screw to the direction of the transport air, would blow media off of the screw surface before it could fall off the screw into the transport air flow stream. The frequency of the periodic pulsations were primarily determined by the speed of the rotating screw. A smaller nozzle helped to diminish the amplitude of the pulsations.

9.1.2 Magnetic Separator Test

A test was performed to determine the effectiveness of the Schlick glovebox electromagnet for magnetic particle removal. 25 pounds of new media contaminated with 0.1 pounds (4000 ppm) of small steel shot with diameters ranging from 1/64th to 1/16th inch was added to the glovebox media supply.

The contaminated media was then cycled through five complete blasting and recovery cycles. The amount of steel shot captured by the magnetic separator was weighed after each cycle. Table 1 shows the amount of shot removed after each cycle.

Table 1. Shot Removed by Electromagnet

Cycle	Shot In System (grams)	Shot In System (ppm)	Shot Removal (grams)	Shot Removed per cycle (%)
Initial Charge	45.48	4000	-	-
1	23.35	2000	22.13	48.6
2	14.90	1300	8.45	36.2
3	9.56	800	5.34	35.8
4	5.86	500	3.70	38.7
5	3.34	300	2.52	43.0

The magnetic separator reduced the original shot contamination from 4000 ppm to less than 300 ppm after the five cycles (see figure 17). The removal rate was relatively constant throughout the test, even though the actual amount of contamination rapidly decreased. The magnet was able to remove about 40 percent of the remaining contamination with each cycle. The consistent nature of contaminant reduction is shown in figure 18. The straight line formed when the logarithm of the remaining shot weight is plotted per cycle suggests that the limitation on the magnet was not particle retention capacity but rather related to how the particles flowed through the magnetic field.

9.2 Nozzle Blasting Tests

Nozzle blasting parameters and their effects on substrates were also evaluated in the Schlick glove box. The tests were conducted using Dupont Type L media in the 30 to 40 mesh size range. The standoff distance in all cases was about 12 inches. Media flow rate, blasting pressure and angle of incidence were varied during the test. A piece of fiberglass and aluminum wing was coated with one coat of epoxy polyamide primer and two coats of polyurethane top coat. The wing was then divided into 12 sections for individual blasting tests (see figure 19). Results are presented in table 2.

Section D of the panel was blasted at varying rates and pressures to identify the range of variables that would be effective during the test. Media flow rates were varied between 50 and 100 percent of the maximum rate of about 18 pounds per minute. The blasting pressure was varied between about 15 and 45 psig. The angle of incidence was varied between 25 and 45 degrees. Flaking of the coating observed. This was attributed to insufficient cure time. The section did allow a good comparison between some of the operating variables.

Comparing the coating removal rate between section L and section G indicates that the removal rate is directly proportional to the media flow rate. Constant conditions of 29 psig blasting pressure, 45 degree angle of incidence, and 12 inches of standoff distance were used. The approximate removal rate for section L was 14.8 square inches per minute at about 18 pounds of media per minute versus 6.7 square inches per minute at about 9 pounds of media per minute for section G. The 50 percent drop in media flow rate caused a 55 percent reduction in stripping rate. The error in test measurement was about 20 percent.

WEIGHT OF SHOT FOR EACH CYCLE

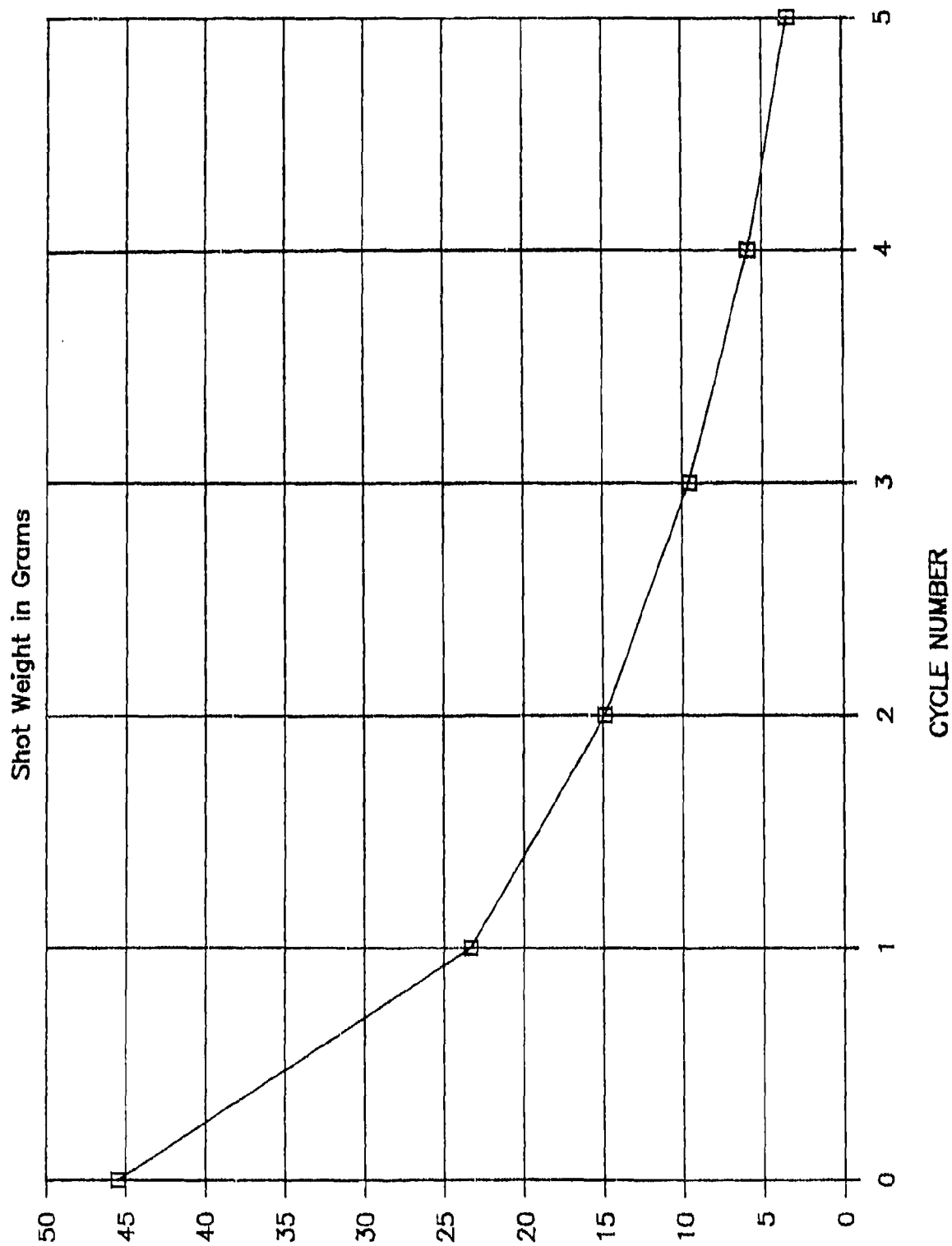


Figure 16. Weight of Shot Removed

WEIGHT OF SHOT IN GRAMS

LOG WEIGHT OF SHOT FOR EACH CYCLE

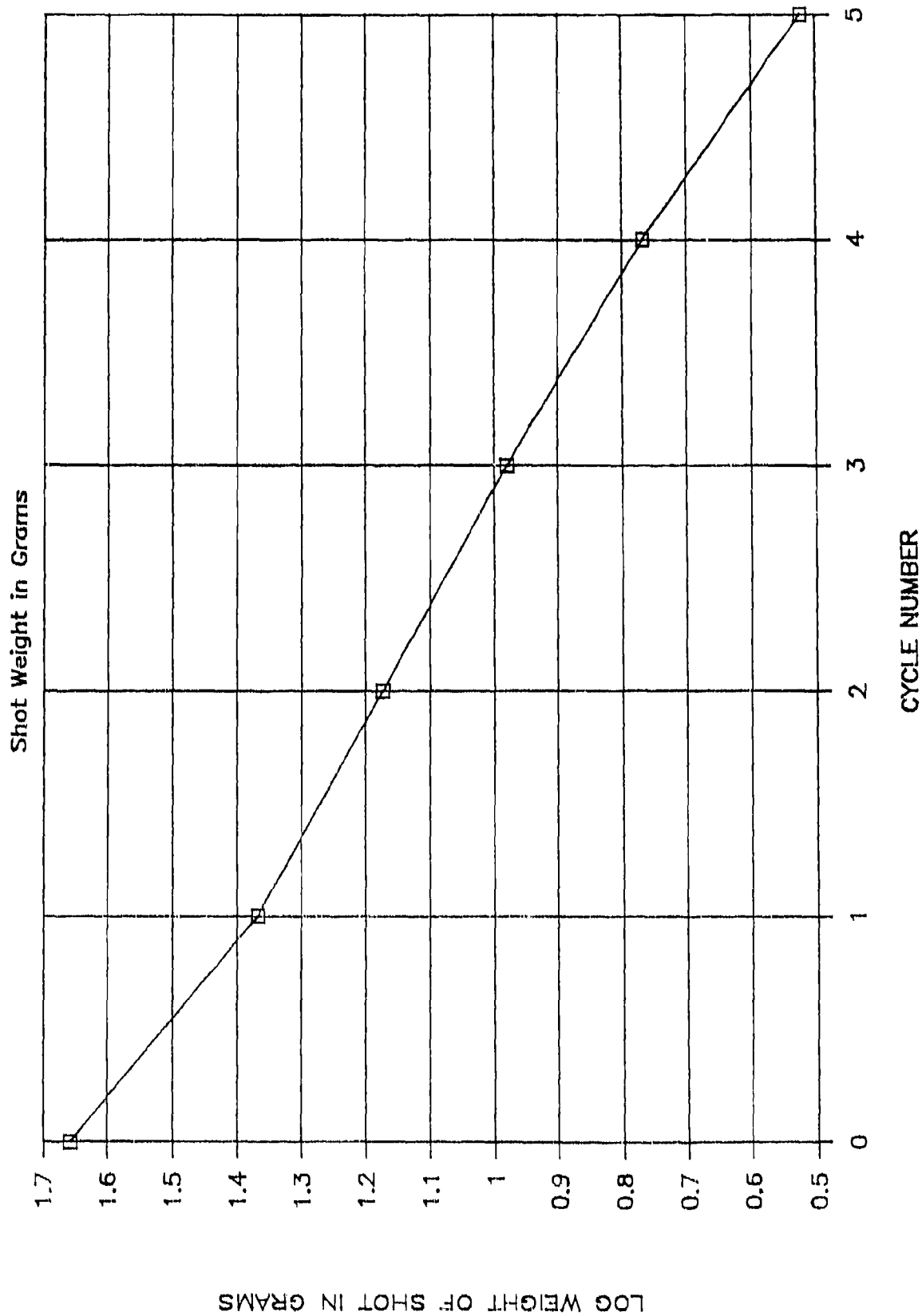


Figure 17. Log Weight of Shot Removed

Panel Schematic

A	B	C	D
E	F	G	H
I	J	K	L

Figure 18. Panel Sections For Nozzle Blasting Tests

Table 2. Nozzle Blasting Tests

SECTION	PRESSURE (bar)	MEDIA FLOW	ANGLE	DISTANCE	COMMENTS	REMOVAL RATE (sq in per minute)
D	1.5	50%	45°	12"		
D	2.5	80%	45°	12"	Faster than at 50%.	
D	3.0	100%	45°	12"	Starts to look like change.	
H	1.5	100%	45°	12"	Takes off in flakes-not a peeling like before.	
L	2.0	100%	45°	12"	Some damage occurring 1:52 duration to remove 3.75" x 6" area.	14.8
K	1	50%	45°	12"	Two minutes-barely removing paint, no breakthrough to substrate yet.	
G	2	50%	45°	12"	Flaking off. Took 3:20 to take off 5.75" x 3.75".	6.7
C	3	80%	25°	12"	Flaking, peeling off metal easily, flaking is on fibreglass.	
I	3	80%	25°	12"	Cleaned faster.	
A	2	100%	25°	12"	Flaking off, high damage. Took 3:26 to remove 6.5" x 4".	8.0

Coating removal rates also appear to be directly proportional to the sine of the angle of incidence. The sine of the angle of incidence is a relative measure of the media flow stream force component that is perpendicular to the plane of the workpiece (see figure 20). Thus, the perpendicular component of the blasting media force vector expectedly appears to perform the coating removal work. Constant conditions of 29 psig blasting pressure, 18 pounds of media per minute and 12 inches of standoff distance were used. The approximate removal rate for section L was 14.8 square inches per minute at a 45 degree angle of incidence versus 8.0 square inches per minute at a 25 degree angle of incidence for section A. The 46 percent drop in stripping rate is about equal to the 40 percent reduction in the value of the sine of the angle of incidence. The error in test measurement was about 20 percent.

9.3 Wheel Blasting Tests

The blasting effectiveness of the wheel blasting device produced by Schlick was also tested. Various test panels of carbon epoxy construction were blasted under varying wheel blasting parameters. The test parameters were the rotational speed of the wheel, the stand off distance of the wheel, and the amount of time the panel was blasted.

The results of this testing are compiled in Appendix A. The tests were conducted primarily to determine if the wheel blasting method was effective in removing coatings from carbon epoxy materials without damaging the substrate. This was successfully accomplished with the correct blasting parameter selection.

The choice of media size was also important. Much better blasting results were obtained with a media consisting of about half 30-40 mesh and half 20-30 mesh size than with all 20-30 mesh size.

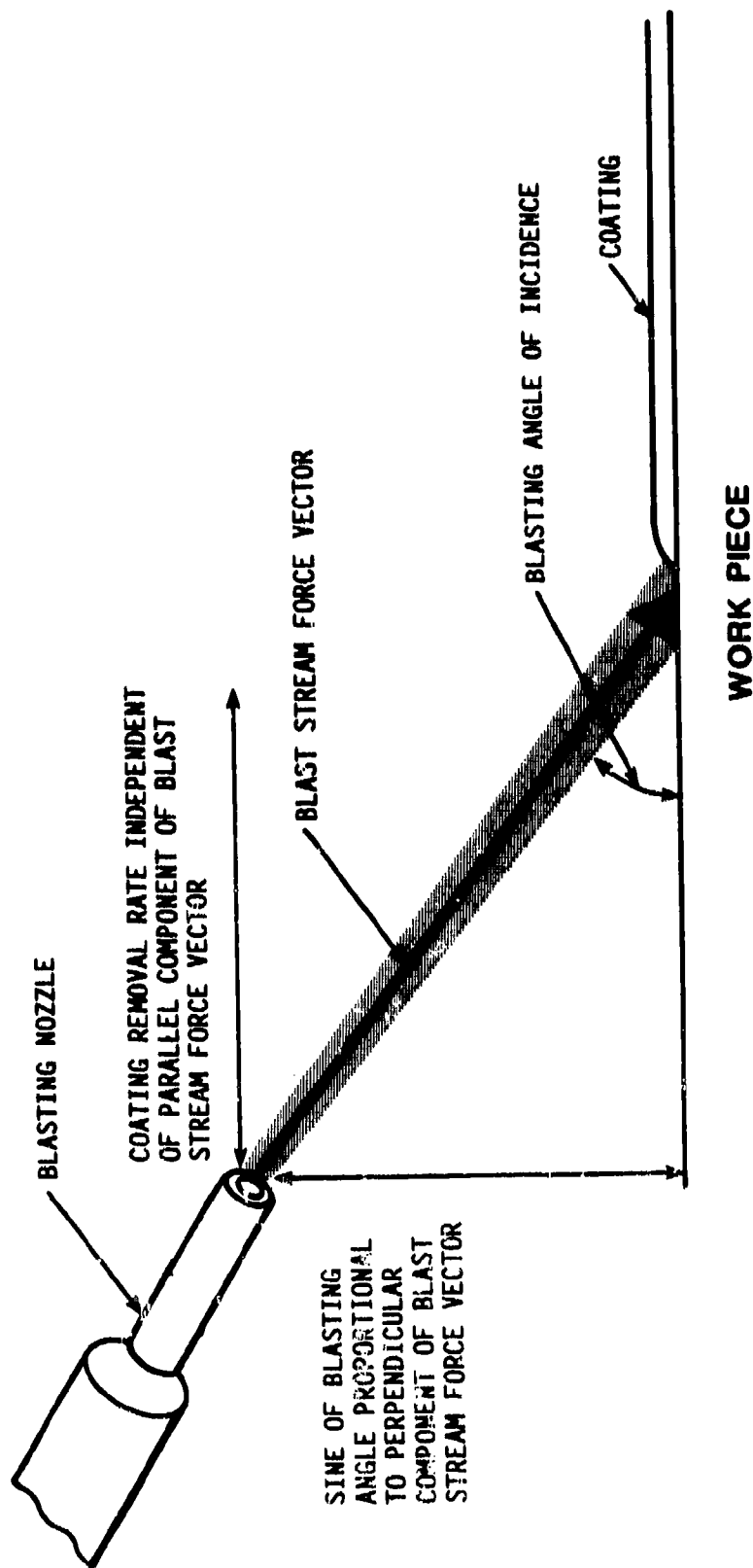


FIGURE 19. COATING REMOVAL RATE PROPORTIONAL TO SINE OF BLASTING ANGLE OF INCIDENCE.

APPENDIX A

WHEEL BLASTING TESTS

SECTION NUMBER	SECTION DESCRIPTION	RCM	SPEED (M/MIN)	NO. OF PASSES	DISTANCE (mm)	LABORATORY COMMENTS
13A	- UNIDIRECTIONAL CARBON/ EPOXY TAPE (V-22 WING)	3600 3600	2.5	2	350	- INCOMPLETE PAINT REMOVAL: NO DAMAGE OF EXPOSED SURFACES.
13B	- UNIDIRECTIONAL CARBON/ EPOXY TAPE (V-22 WING SKIN)	3600	2.5	4	350	- DID NOT REMOVE ALL OF THE PAINT. BUT BETTER THAN 13A: ISOLATED AREAS AROUND REMAINING PAINT "SPOTS" WHERE RESIN HAS BEEN REMOVED TO EXPOSE BARE FIBERS OF THE TAPE: ALSO ISOLATED "FLECKS" WHERE PAINT AND RESIN HAVE BEEN REMOVED AND FIBERS ARE EXPOSED: NO FIBER BREAKAGE.
13C	- UNIDIRECTIONAL CARBON/ EPOXY TAPE (V-22 WING)	3600	2.5	3	350	- ALMOST ALL OF THE PAINT HAS BEEN REMOVED BUT STILL ISOLATED AREAS OF BARE FIBERS SHOWING AND ALSO A "FLECK" PATTERN OVER THE ENTIRE AREA SHOWING VERY SMALL PATCHES OF EXPOSED FIBER: NO FIBER BREAKAGE.
11 SECTION 2	- UNIDIRECTIONAL CARBON/ EPOXY TAPE (V-22 WING SKIN)	3900	2.5	2	460	- GOOD PAINT REMOVAL: PEEL PLY PATTERN LEFT IN THE RESIN DURING CURE HAS BEEN "FLATTENED" OUT OR PARTIALLY REMOVED ACROSS THE ENTIRE SURFACE INDICATING MINOR RESIN REMOVAL: ISOLATED SPOTS OF EXPOSED FIBERS BUT NO FIBER BREAKAGE.
12A	- UNIDIRECTIONAL CARBON/ EPOXY TAPE (V-22 WING SKIN)	3900	5.5	2	490	- GOOD PAINT REMOVAL WITH MINIMAL RESIN REMOVAL: PEEL PLY IMPRESSION CLEARLY VISIBLE ON SURFACE: NO EVIDENCE OF EXPOSED FIBERS.
12C	- UNIDIRECTIONAL CARBON/ EPOXY TAPE (V-22 WING SKIN)	3900	5.5	2	490	- GOOD PAINT REMOVAL WITH MINIMAL RESIN REMOVAL: PEEL PLY IMPRESSION CLEARLY VISIBLE ON SURFACE: NO EVIDENCE OF EXPOSED FIBERS.
9A	- FIBERGLASS/EPOXY MAIN ROTOR BLADE SKIN	3900	2.5	4	350	- RESIN REMOVED DOWN TO THE GLASS FIBERS OVER THE ENTIRE BLADE SURFACE: EVIDENCE OF FIBER BREAKAGE.
9B	- FIBERGLASS/EPOXY MAIN ROTOR BLADE SKIN	3600	2.5	4	350	- RESIN REMOVED DOWN TO THE GLASS FIBERS OVER THE ENTIRE BLADE SURFACE: EVIDENCE OF FIBER BREAKAGE.

SECTION NUMBER	SECTION DESCRIPTION	RPM	SPEED (M/MIN)	NO. OF PASSES	DISTANCE (mm)	LABORATORY COMMENTS
19A	- CARBON/EPOXY PLAIN WEAVE FABRIC W/EMBEDDED WIRE (V-22 MACELLE PANEL)	3600	6	6	?	- GOOD PAINT REMOVAL EXCEPT FROM RESIN STARVED AREAS: RESIN REMOVED AT POINTS OF SURFACE POROSITY AND AT INTERSECTION OF CROSSEWERS (OVERLAP) OF FIBERS IN WEAVE PATTERN OF FABRIC: SOME FIBERS EXPOSED BUT NO FIBER BREAKAGE.
19B	- CARBON/EPOXY PLAIN WEAVE FABRIC W/EMBEDDED WIRE (V-22 MACELLE PANEL)	3600	4	10	?	- GOOD PAINT REMOVAL EXCEPT FROM RESIN STARVED AREAS: RESIN REMOVED AT POINTS OF SURFACE POROSITY AND AT INTERSECTION OF CROSSEWERS (OVERLAP) OF FIBERS IN WEAVE PATTERN OF FABRIC: SOME FIBERS EXPOSED BUT NO FIBER BREAKAGE.
20A	- UNIDIRECTIONAL CARBON/ EPOXY TAPE OVER PLAIN WEAVE C/EP FABRIC (V-22 MACELLE DOOR)	3600	4	6	350	- GOOD PAINT REMOVAL WITH MINIMAL RESIN REMOVAL: PEEL PLY IMPRESSION CLEARLY VISIBLE ON SURFACE: NO EVIDENCE OF EXPOSED FIBERS.
20B	- UNIDIRECTIONAL CARBON/ EPOXY TAPE OVER PLAIN WEAVE C/EP FABRIC (V-22 MACELLE DOOR)	3600	2	6	380	- GOOD PAINT REMOVAL WITH MINIMAL RESIN REMOVAL: PEEL PLY IMPRESSION CLEARLY VISIBLE ON SURFACE: NO EVIDENCE OF EXPOSED FIBERS.
10A	- FILAMENT WOUND CARBON/ EPOXY ROVING (V-22 DRIVESHAFT)	3900	?	?	490	- POOR PAINT REMOVAL: NO DAMAGE TO EXPOSED SURFACES.
10B	- FILAMENT WOUND CARBON/ EPOXY ROVING (V-22 DRIVESHAFT)	3900	?	?	490	- GOOD PAINT REMOVAL: MINOR RESIN REMOVAL BUT NO EXPOSED FIBERS.
10B	- FILAMENT WOUND CARBON/ EPOXY ROVING (V-22 DRIVESHAFT)	3900	?	?	490	- GOOD PAINT REMOVAL: MINOR RESIN REMOVAL BUT NO EXPOSED FIBERS.
10C	- FILAMENT WOUND CARBON/ EPOXY ROVING (V-22 DRIVESHAFT)	3900	?	?	380	- GOOD PAINT REMOVAL: MODERATE RESIN REMOVAL AND ISOLATED EXPOSED FIBERS: NO FIBER BREAKAGE.

SECTION NUMBER	SECTION DESCRIPTION	RPM	SPEED (M/MIN)	NO. OF PASSES	DISTANCE (mm)	LABORATORY COMMENTS
9A	- FILAMENT WOUND CARBON/ EPOXY ROVING (V-22 DRIVESHAFT)	3900	-	NOZZLE AT 2.0 BAR & 80%		- GOOD PAINT REMOVAL: NO EVIDENCE OF RESIN REMOVAL.
9B	- FILAMENT WOUND CARBON/ EPOXY ROVING (V-22 DRIVESHAFT)	3900	-	NOZZLE AT 2.0 BAR & 80%		- GOOD PAINT REMOVAL: NO EVIDENCE OF RESIN REMOVAL.
9C	- FILAMENT WOUND CARBON/ EPOXY ROVING (V-22 DRIVESHAFT)	3900	-	NOZZLE AT 2.0 BAR & 80%		- GOOD PAINT REMOVAL: MINOR RESIN REMOVAL BUT NO EXPOSED FIBERS.
9D	- FILAMENT WOUND CARBON/ EPOXY ROVING (V-22 DRIVESHAFT)	3600	5	2	?	- GOOD PAINT REMOVAL: UNIFORM MODERATE RESIN REMOVAL OVER ENTIRE SURFACE: SOME FIBER EXPOSURE BUT NO FIBER BREAKAGE.
9E	- FILAMENT WOUND CARBON/ EPOXY ROVING (V-22 DRIVESHAFT)	3600	5	1	?	- GOOD PAINT REMOVAL: UNIFORM MODERATE RESIN REMOVAL OVER ENTIRE SURFACE: SOME FIBER EXPOSURE BUT NO FIBER BREAKAGE.
4A	- FILAMENT WOUND CARBON/ EPOXY ROVING (V-22 DRIVESHAFT)	3600	2.5	2	350	- GOOD PAINT REMOVAL: MODERATE RESIN REMOVAL OVER ENTIRE SURFACE.
4B	- FILAMENT WOUND CARBON/ EPOXY ROVING (V-22 DRIVESHAFT)	3600	2.5	2	350	- GOOD PAINT REMOVAL: MODERATE RESIN REMOVAL OVER ENTIRE SURFACE WITH SOME EVIDENCE OF "PITTING": NO EXPOSED FIBERS.

NOTES: 1) ALL PAINT REMOVAL (EXCEPT FOR SECTION NOS. 12A & 12C) WAS PERFORMED USING A 50/50 MIX OF POLYPLUS (3.4 MOH) 30-40 MESH AND POLYPLUS (3.5 MOH) 20-30 MESH PLASTIC MEDIA. PAINT REMOVAL FROM SECTIONS NOS. 12A & 12C WAS PERFORMED USING DUPONT TYPE L 30-40 MESH PLASTIC MEDIA.

2) ALL PARTS WERE PREVIOUSLY PAINTED WITH ONE COAT OF MIL-P-23377 EPOXY POLYAMIDE PRIMER AND TWO COATS OF MIL-C-83286 POLYURETHANE TOPCOAT.

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 NAVORDSTA Code 0922B1, Indian Head, MD; PWO, Louisville, KY
 NAVPETRES Director, Washington DC
 NAVPGSCOL Code 61WL (O. Wilson), Monterey, CA; E. Thornton, Monterey, CA
 NAVPHIBASE PWO, Norfolk, VA; SCE, San Diego, CA
 NAVSCOLCECOFF Code C35, Port Hueneme, CA
 NAVSEASYSKOM Code PMS296L22 (J Rekas), Washington, DC
 NAVSECGRU Code G43, Washington, DC
 NAVSECGRUACT PWO (Code 40), Edzell, Scotland; PWO, Adak, AK; PWO, Sabana Seca, PR
 NAVSECSTA Code 60, Washington, DC; Code N70, Washington, DC
 NAVSHIPREPFFAC SCE, Subic Bay, RP; SCE, Yokosuka, Japan
 NAVSHIPYD Code 202.5 (Library), Bremerton, WA; Code 420, Long Beach, CA; Code 443, Bremerton, WA; Library, Portsmouth, NH; Mare Island, PWO, Vallejo, CA; Norfolk, Code 380, Portsmouth, VA; Norfolk, Code 411, Portsmouth, VA; Norfolk, Code 440, Portsmouth, VA; Norfolk, Code 450-HD, Portsmouth, VA; Norfolk, Code 457L, Portsmouth, VA; PWO (Code 400), Long Beach, CA; PWO, Bremerton, WA; PWO, Charleston, SC
 NAVSTA A. Sugihara, Pearl Harbor, HI; CO, Brooklyn, NY; CO, Long Beach, CA; CO, Roosevelt Roads, PR; Code 4216, Mayport, FL; Code 423, FPBO Guantanamo Bay; Dir, Engr Div, PWD, Guantanamo Bay, Cuba; Engrg Dir, PWD, Rota, Spain; PWO, Mayport, FL; SCE, San Diego, CA
 NAVSUPPACT PWO, Holy Loch, UK; PWO, Naples, Italy
 NAVSUPPFAC Contract Admin Tech Library, Diego Garcia
 NAVSUPPO Sec Offr, La Maddalena, Italy
 NAVSUPSYSCOM Code 0622, Washington, DC
 NAVSWC Code E211 (Miller), Dahlgren, VA; Code W42 (GD Haga), Dahlgren, VA; DET, White Oak Lab, Code W50 (Okonski) Silver Spring, MD; PWO, Dahlgren, VA
 NAVTECHTRACEN SCE, Pensacola FL
 NAVUSEAWARENGSTA Code 073, Keyport, WA
 NAVWARCOL Code 24, Newport, RI
 NAVWPNCEN AROICC, China Lake, CA; Code 24, China Lake, CA; Code 2637, China Lake, CA; PWO (Code 266), China Lake, CA
 NAVWPNSTA Code 093, Yorktown, VA; Dir, Maint Control, PWD, Concord, CA; Earle, Code 092, Colts Neck, NJ; Earle, PWO (Code 09B), Colts Neck, NJ; PWO, Charleston, SC; PWO, Seal Beach, CA; PWO, Yorktown, VA
 NAVWPNSUPPCEN PWO, Crane, IN
 NETC Code 42, Newport, RI; PWO, Newport, RI
 NCR 20, CO
 NMCB 3, Ops Offr; 40, CO; 5, Ops Dept; 62, Engrg Offr
 NOAA Dir, Pac Marine Cen, Seattle, WA; Library, Rockville, MD
 NORDA Code 410, Bay St. Louis, MS
 NRL Code 2530.1, Washington, DC
 NSC Cheatham Annex, PWO, Williamsburg, VA; Code 02, Pearl Harbor, HI; Code 43, Oakland, CA; Code 54.1, Norfolk, VA; Code 700, Norfolk, VA; SCE, Charleston, SC; SCE, Norfolk, VA
 NSD SCE, Subic Bay, RP
 OCNR NRL (Prout), Alexandria, VA
 OFFICE OF SECRETARY OF DEFENSE OASD, (P&L)E (Wm H. Parker), Washington, DC; ODDR&E, Environ & Life Sci, Washington, DC
 PACMISRANFAC HI Area, PWO, Kekaha, HI
 PHIBCB 1, CO, San Diego, CA; 1, P&E, San Diego, CA; 2, CO, Norfolk, VA
 PMTC Code 5041, Point Mugu, CA

PWC ACE Office, Norfolk, VA; Code 10, Great Lakes, IL; Code 10, Oakland, CA; Code 101 (Library),
 Oakland, CA; Code 1011, Pearl Harbor, HI; Code 1013, Oakland, CA; Code 102, Oakland, CA; Code
 123-C, San Diego, CA; Code 30, Norfolk, VA; Code 30V, Norfolk, VA; Code 400, Great Lakes, IL; Code
 400, Guam, Mariana Islands; Code 400, Pearl Harbor, HI; Code 400, San Diego, CA; Code 412, San Diego,
 CA; Code 420, Great Lakes, IL; Code 420, Oakland, CA; Code 420B (Waid), Subic Bay, RP; Code 421
 (Kayu), Pearl Harbor, HI; Code 421 (Quin), San Diego, CA; Code 421 (Reynolds), San Diego, CA; Code
 422, San Diego, CA; Code 423, San Diego, CA; Code 424, Norfolk, VA; Code 430 (Kyi), Pearl Harbor, HI
 PWC Code 430 (Kyi), Pearl Harbor, HI
 PWC Code 50, Pensacola, FL; Code 500, Great Lakes, IL; Code 500, Norfolk, VA; Code 500, Oakland, CA;
 Code 590, San Diego, CA; Code 600, Great Lakes, IL; Code 612, Pearl Harbor, HI; Code 614, San Diego,
 CA; Code 615, Guam, Mariana Islands; Code 700, Great Lakes, IL; Code 700, Norfolk, VA; Code 700, San
 Diego, CA; Library (Code 134), Pearl Harbor, HI; Library, Guam, Mariana Islands; Library, Norfolk, VA;
 Library, Pensacola, FL; Library, Yokosuka, Japan; Tech Library, Subic Bay, RP; Util Dept (R Pascua),
 Pearl Harbor, HI
 SUPSHIP Tech Library, Newport News, VA
 UCT TWO, CO, Port Hueneme, CA
 US DEPT OF INTERIOR BLM, Engrg Div (730), Washington, DC; Natl Park Svc, RMR/PC, Denver, CO
 US GEOLOGICAL SURVEY J Bales, Raleigh, NC
 USCINCPAC Code J44, Camp HM Smith, HI
 USDA Ext Serv (T Maher), Washington, DC; For Svc Reg 8, (Bowers), Atlanta, GA; For Svc, Equip Dev
 Cen, San Dimas, CA; For Svc, Tech Engrs, Washington, DC
 USNA Mech Engrg Dept (Power), Annapolis, MD; PWO, Annapolis, MD; Sys Engrg (Tuttle), Annapolis, MD
 USS USS JASON, Rpr Offr
 ARIZONA STATE UNIVERSITY Design Sci (Kroelinger), Tempe, AZ
 BROOKHAVEN NATL LAB M. Steinberg, Upton, NY
 CALIFORNIA Nav & Ocean Dev (Armstrong), Sacramento, CA
 CITY OF LIVERMORE Duckins, PE, Livermore, CA
 CLEMSON UNIVERSITY Arch Col (Egan), Clemson, SC
 CLEVELAND STATE UNIVERSITY CE Dept (Akinmusuru), Cleveland, OH
 CORNELL UNIVERSITY Library, Ithaca, NY
 DAMES & MOORE Library, Los Angeles, CA
 FLORIDA INST OF TECH CE Dept (Kalajian), Melbourne, FL
 FOREST INST FOR OCEAN & MT Library, Carson City, NV
 INSTITUTE OF MARINE SCIENCES Library, Port Aransas, TX
 IOWA STATE UNIVERSITY Arch Dept (McKrown), Ames, IA; CE Dept (Hundy), Ames, IA
 KEENE STATE COLLEGE Sci Dept (Cunningham), Keene, NH
 LAWRENCE LIVERMORE NATL LAB FJ Tokurz, Livermore, CA; Plant Engrg Lib (L-654), Livermore, CA
 LEHIGH UNIVERSITY Linderman Library, Bethlehem, PA
 LONG BEACH PORT Engrg Dir (Allen), Long Beach, CA
 LOS ANGELES COUNTY PW Dept (J Vicelja), Alhambra, CA
 MICHIGAN TECH UNIVERSITY CE Dept (Haus), Houghton, MI
 MISSOURI Nat Res Dept, Energy Div, Jefferson City, MO
 MIT Engrg Lib, Cambridge, MA; Lib, Tech Reports, Cambridge, MA; RV Whitman, Cambridge, MA
 NATL ACADEMY OF SCIENCES NRC, Dr. Chung, Washington, DC; NRC, Naval Studies Bd, Washington,
 DC
 NEW MEXICO SOLAR ENERGY INST Dr. Zwibel, Las Cruces, NM
 NEW YORK Energy Office, Lib, Albany, NY
 NEW YORK STATE MARITIME COLLEGE Longobardi, Bronx, NY
 NY CITY COMMUNITY COLLEGE Library, Brooklyn, NY
 OREGON STATE UNIVERSITY CE Dept (Hicks), Corvallis, OR
 PENNSYLVANIA STATE UNIVERSITY Applied Rsch Lab, State College, PA
 PURDUE UNIVERSITY Engrg Lib, W. Lafayette, IN
 SEATTLE PORT W Ritchie, Seattle, WA
 SOUTHWEST RSCH INST Energetic Sys Dept (Esparza), San Antonio, TX; M. Polcyn, San Antonio, TX
 STATE UNIVERSITY OF NEW YORK CE Dept (Reinhorn), Buffalo, NY; CE Dept, Buffalo, NY
 TECH UTILIZATION K Willinger, Washington, DC
 TEXAS A&I UNIVERSITY Civil & Mech Engr Dept (Parate), Kingsville, TX
 TEXAS A&M UNIVERSITY CE Dept (Machemehl), College Station, TX
 UNIV OF TENNESSEE CE Dept (Kane), Knoxville, TN
 UNIVERSITY OF ALABAMA Dir Fac Mgmt (Baker), Birmingham, AL
 UNIVERSITY OF CALIFORNIA CE Dept (Mitchell), Berkeley, CA
 UNIVERSITY OF HARTFORD CE Dept (Keshawar), West Hartford, CT
 UNIVERSITY OF HAWAII Manoa, Library, Honolulu, HI
 UNIVERSITY OF ILLINOIS Library, Urbana, IL; Metz Ref Rm, Urbana, IL
 UNIVERSITY OF MICHIGAN CE Dept (Richart), Ann Arbor, MI
 UNIVERSITY OF NEBRASKA Polar Ice Coring Office, Lincoln, NE

UNIVERSITY OF NEW MEXICO NMRI (Falk), Albuquerque, NM; NMRI (Leigh), Albuquerque, NM;
 NMRI (Tapscott), Albuquerque, NM
 UNIVERSITY OF TEXAS CE Dept (Thompson), Austin, TX; Construction Industry Inst. Austin, TX
 UNIVERSITY OF WASHINGTON Engrg Col (Carlson), Seattle, WA; RL Terrel, Edmonds, WA
 UNIVERSITY OF WISCONSIN Great Lakes Studies Cen, Milwaukee, WI
 VENTURA COUNTY Deputy PW Dir, Ventura, CA; PWA (Brownie), Ventura, CA
 WORCESTER POLYTECH INST Mech Engrg Dept (Sullivan), Worcester, MA
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 APPLIED SYSTEMS R. Smith, Agana, Guam
 ARCAIR CO D. Young, Lancaster, OH
 ARVID GRANT & ASSOC Olympia, WA
 BATTELLE New Eng Marine Rsch Lab, Lib, Duxbury, MA
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 DURLACH, O'NEAL, JENKINS & ASSOC Columbia, SC
 DYNAMAC CORP HMTC-C, Rockville, MD
 GARD INC LB Holmes, Niles, IL
 GDM & ASSOC, INC Fairbanks, AK
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 PRESNELL ASSOC, INC DG Presnell, Jr, Louisville, KY
 SANDIA LABS Library, Livermore, CA
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 TREMCO, INC M Raymond, Cleveland, OH
 TRW INC Crawford, Redondo Beach, CA; Engr Library, Cleveland, OH; Rodgers, Redondo Beach, CA
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 WISS, JANNEY, ELSTNER, & ASSOC DW Pfelfer, Northbrook, IL
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 NEASE, A.D., JR Panama City, FL
 PADILLA, LM Oxnard, CA
 PAULI, DC Silver Spring, MD
 PETERSEN, CAPT N.W. Pleasanton, CA
 PODELL, H.I. New Rochelle, NY
 QUIRK, J Panama City, FL
 SPIELVOGEL, L Wyncote, PA
 STEVENS, TW Dayton, OH
 TAMPA PORT AUTHORITY Engrg Dept (Schrader), Tampa, FL
 ULASZEWSKI, CDR T.J. Honolulu, HI
 VAN ALLEN, B Kingston, NY