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# THE CONTAINER MATERIAL STUDY: A TREATISE ON THE EVOLUTION AND CONTINUED PROGRESSION OF CONTAINERIZATION

ARMY MOBILITY EQUIPMENT RESEARCH AND DEVELOPMENT CENTER

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by

J. A. Zwolinski



March 1973





U. S. ARMY MOBILITY EQUIPMENT RESEARCH AND DEVELOPMENT CENTER
FORT BELVOIR, VIRGINIA

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# THE CONTAINER MATERIAL STUDY: A TREATISE ON THE EVOLUTION AND CONTINUED PROGRESSION OF CONTAINERIZATION

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March 1973

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The Commander
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## SUMMARY

This report has been prepared to fulfill the requirements and directives of HqUSAMC letter dated 26 May 1969 which requested an investigation into new and different materials of construction used in containerization. To accomplish this task, numerous contractual efforts have been initiated and performed such that a short treatise can be offered at this time highlighting the significant accomplishments under the general program, "Container Material Study."

A brief description of the plan of attack has been presented such that the reader may fully understand and appreciate the numerous efforts undertaken. The current day state-of-the-art has been addressed, and additional work has been performed to investigate the dynamic loadings which containers experience in the commercial environment. The list of varied materials of construction is lengthy, but the various construction techniques can be lumped easily such that categories of construction arise.

Conclusions are offered as appropriate. It is interesting to note that the majority of conclusions appear to be valid only through FY77; thus, some forecasting and directionality is presented for years beyond the target applicability goal.

A major accomplishment of this effort is a comparative analysis matrix formulated to give the biased or objective reader a tool which, when used properly, will provide guidance in selecting a particular material design concept for a given set of criteria. The matrix is fully discussed and materials are presented with their design relationships. The military environment is presented providing further insight into containerization.

Noteworthy areas of additional interest are the extensive comparisons of three major, current-day, sidewall panels: corrugated steel, aluminum sheet and post, and Fiber-glass Reinforced Plastic (FRP)/Plywood as related to each other. Other materials also addressed are: popular sandwich constructions, new or different configurations for aluminum, and the end product of a rotationally molded container.

It is established that containers as currently constructed lack a basic design philosophy. True intermodal containers should be designed on a rational basis noting in particular the sidewall materials and their relationship with the framing arrangement. Thus, the report primarily addresses materials of construction for the sidewalls.

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13. ABSTRACT


In this report, a large variety of materials of construction for containerization has been presented in order to establish preferred sidewall materials and appropriate overall construction techniques for dry-freight shipping containers. An elaborate comparative analysis matrix, which is user orientated, is presented to allow the avid reader to utilize the raw data presented. Eighteen attributes can be comparatively ranked such that an optimum material can then be determined.

The evolution and continued progression of containerization including applicable interfacing systems are fully presented. Critical conclusions and remarks address future procurement practices as related to the latest Military Specification MIL-C-52661(ME) entitled, Container, Cargo. The entire military environment is presented.

It is established that containers as currently constructed lack a basic design philosophy. Further, a rational basis noting in particular the sidewall materials and their relationship with the framing arrangement is offered for refrigerated, ammunition, and secondary usage type containers along with shelter concepts.


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| State-of-the-Art | | | | | | |
| Ammunition | | | | | | |
| Shelters | | | | | | |
| Refrigeration | | | | | | |

# FOREWORD

The present study was performed between 26 May 1969 and 31 December 1971 while the author was associated as a project engineer with the Materials Handling Equipment Development Branch, Mechanical Technology Department, United States Army Mobility Equipment Research and Development Center (USAMERDC), Fort Belvoir, Virginia. The study was conducted under Project 1G664717DH14, Task 05.

This report summarizes innumerable personal contacts, contractual efforts, assimilation of data from the open literature, and the author's professional analysis and judgment in presenting the information.

The author acknowledges the gainful efforts of all the contractors who participated in this task. In particular, special acknowledgment is offered to my fellow associates for their helpful and constant encouragement in accomplishing this task in a timely and effective manner.

Particular and special thanks is given to J. K. Knaell, Chief, Materials Handling Equipment Development Branch, for the opportunity offered the author to conduct this study using manners and methods which many times appeared unorthodox. Also, my personal thanks is offered to Mr. Sidney Berger for his unrelinquishing quest in solving the innumerable problems presented and his continued encouragement in supporting many of the decisions I was required to make.

Acknowledgment is further offered to Mr. Arthur J. Rutherford, Chief, Mechanical Equipment Division, and Mr. Mark H. Henderson, Chief, Mechanical Technology Department, my direct line supervisory chain of command, who have allowed me to pursue until a meaningful answer has been gained.

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# THE CONTAINER MATERIAL STUDY: A TREATISE ON THE EVOLUTION AND CONTINUED PROGRESS OF CONTAINERIZATION

## I. INTRODUCTION

1. **Objective and Scope.** The objective of this investigation is to address the following two statements as presented in the initial directive:

a. Determine the advisability of substituting aluminum or other lightweight materials for steel skins on 8- by 8- by 20-ft military containers.

b. Determine the advisability of substituting aluminum or other lightweight materials for steel throughout the 8- by 8- by 20-ft military container.

Supplementing the directive was the underlying supposition that the investigations were to be conducted on the basis of total logistic impact to include engineering, testing, application to production base, maintenance, transportability and cost effectiveness.

To shorten the learning curve, it was deemed necessary that the evolution of design and construction practice be documented such that the rationale behind currently preferred types of containers could be related to operational needs. Within the overall objective, there was a constant need to resolve material selection problems on an interim basis in order to facilitate additional study when and where it was warranted.

The scope of the investigation was sufficiently comprehensive to determine the total logistical impact due to changes or advances in the technical characteristics of the containers. This included engineering, testing, production, maintenance, transportability, cost effectiveness, review of all International Standards Organization (ISO) regulations plus Military Specification MIL-C-52661(ME), and a thorough dynamic analysis as related to the ever popular and quite simple static analysis. Thus, noting the above, problems of material selection were considered in relation to design and fabrication approaches and to the operational environment which is suited to each particular material.

The containers of interest to this investigation were primarily of the reusable, demountable variety which consolidate and unitize cargo shipments generally as specified in the American National Standard MH 5.4 and Military Specification MIL-C-52661 (ME). Containers which deviated from the above specifications in a dimensional or other nonfunctional way were also considered. Containers of major concern were, however, those with the following common denominator, i.e., transportability by rail, container vessel, or tractor trailer. Limited air transport was considered since selected designs do address this mode of transport.

**2. Containerization–Background and Evolution.** Containerization is one of the means of forming unit loads which has been steadily coming into wider use so that today containerization appears to be the best way of transporting goods over land or sea. Goods going into maritime trade have been the main area of container application because the traditional cargo-handling approach of break-bulk, i.e., stowing one case at a time, has been a cost burden to the ship-line operator bearing more than half his total cost. Economic necessity since World War II has been the driving force behind containerization. Container Express (CONEX) boxes measuring 6 ft. 10 in. high by 8 ft. 6 in. long by 6 ft. 3 in. wide with a tare weight of 1800 pounds and a gross weight of 10,500 pounds are typical of the period of the early 1950's in the commercial and military environment. Several advantages of CONEX were realized. As compared to palletization, which in itself reduces handling costs in a drastic way, reusable containers have a characteristic of greater flexibility in carrying goods of nonuniform size and shape, of carrying bulk solids and liquid commodities, and of protecting the goods against damage and pilferage when containers are properly packed. In the early phases, no special-handling equipment was available or required. Neither was any modification necessary on common commercial carriers. However, the economic benefits from these first steps in containerization were of low level, and acceptance of the concept by shippers and transportation operators was limited.

During the 1950's, a great deal of effort went into determining what should be the near optimum cargo-handling approach. Concurrent consideration of the problems in transportation by several modes was a primary factor in leading to the present series of large containers. Large containers which would move into ships' cellular holds with only vertical motion and which could be quickly mounted on over-the-road carriers appeared to be the successful solution to the problem. The railroads had been working in the direction of carrying highway trailers on flat cars for the long haul. However, due to tunnel height limitations on several systems, demountable containers have come into rail use also. Several independent efforts toward large-scale containerization, unfortunately, resulted in size and handling fitting differences. Container lengths have varied in the range of 17 to 40 feet with even longer containers being built for specialized uses. An 8 ft by 8 ft cross section is widely used. On the longer containers, a width of 8 feet is still predominant, but the height will vary from the ever popular 8 ft. 6 in. to 9 ft. 6 in.

The lack of standardization has been an impediment to full success of the containerization concept because it restricts intermodal transfer–probably the most important asset. The American Standards Association (ASA), under sponsorship from the American Society of Mechanical Engineers (ASME) and the American Materials Handling Society (AMHS), adopted conventions for standard sizes in 1961 and for container strength and fitting configurations in 1962. This inauspicious beginning has led to a complete set of standards for various shipping containers. The International Organization for Standardization (ISO) and the Society of Automotive Engineers (SAE) are the primary technical standards producing bodies as related to land and sea and land, sea, and air respectively.

At the time the initial standards were adopted, the various types of containers and associated equipments did not inter-relate adequately. Most of the above containers and equipments continued in use without modification. These are in highly integrated proprietary systems where change would have been difficult. In the past few years, however, numerous shipping concerns have noted the modern berths and have begun to address the problem of nonuniform size. Mainly, most all of those organizations subsequently entering container operations have abided by the standards.

3. **Operational Usage.** Many of the characteristics of containers have come about through the pressures of operational employment. The requirement that containers be suitable to all modes of transportation has influenced nearly all aspects of design. Presumably the 40 ft maximum length, of the first-issued standard, is derived from the then maximum limit on length of highway trailers prevailing in a majority of states. The subdivisions were selected so that smaller units could be coupled for handling and still conform to the 40 ft maximum. For example, the nominal 20 ft length of the subunit is actually stated in the standard to be 19 ft, 10½ in.

The emphasis on lightweight construction is due more to over-the-road limitations than to ship transport considerations. Road vehicles must conform to limitations on axleloads, and unnecessary tare weight detracts directly from revenue-producing loads. (Of course, the foregoing statement is addressing a fully ladened container.) Ship transport puts less demand on weight saving since cargo liners tend to be volume limited. However, many containers are carried on the weather deck of ships in stacks up to and including four high. The vessel's stability in roll, sway, and yaw is affected by this topside weight, so there is still some benefit to lightweight construction. Added weight on the weather deck does not affect heave, pitch, and surge in the same fashion as roll, sway, and yaw; thus, these motions are considered extraneous when stability (center of buoyancy and center of flotation) is considered. The tolerable weight penalty aboard ship is greater than for truck transport.

Each of the transport modes contributes something to strength requirements. Stacking loads which are critical on frame construction occur in ship holds. Ship transport on open decks leads to the need for substantial construction of panels since spray, salt water, and severe racking loads are frequently encountered. Handling by shipboard and shoreside cranes induces bending loads on the containers transverse to their long axis. The inevitable humping of rail cars, regardless of whether or not they are placarded, leads to the dominating longitudinal strength requirement.

Functional variation in containers is also due to the type of cargo service appropriate to each design. The widely used box types are intended for dry, general cargo. Refrigerated containers with wall construction designed for high insulation are also in wide use. Some dry-cargo containers are insulated and shipped with an inert atmosphere present to refrigerate and preserve the contents. Tank types in which a frame is built around a cylindrical tank are used for various liquids and granular-type goods. Various bulk commodities are carried in shallow, open-top containers with fabric covers. Numerous other configurations can be readily seen in specialized shipment of odd-shaped goods. This report addresses, specifically, the materials of construction for dry-freight-cargo containers.

## II. OVERALL APPROACH

4. **Efforts Essential to the Program.** In order to be generally responsive to the directive as posed, a systematic approach was proposed. The following subparagraphs categorically identify the efforts believed to be essential to the program.

a. The initial phase of the investigation concentrated on the determination of the state-of-the-art in containerization practice within commercial and maritime trade. Heavy emphasis was placed on the cause and effect relationships which have been self generating in the latest design technology. It was the author's intent that, by understanding the rationale behind current design practice and materials selection, it would be possible to provide technical guidance for future procurement of containers for U. S. Army usage.

b. Two lines of attack were pursued. Industry was surveyed and interviewed to determine the nature of problems which have been encountered and the design solutions which have been effective. Concurrently, analysis of designs was performed to relate loading conditions, environmental resistance, maintenance burdens, costs, and the like to the physical characteristics of the containers. The industry survey provided a vast amount of input data which was analyzed closely to determine significant patterns and rates of occurrence as related to the above.

c. Contacts with industry in a sufficient degree to provide assurance that cooperation was forthcoming was of paramount importance. The trade associations, particularly in aluminum and plywood, have a great amount of data which substantiates the use of their materials. They collect and publish data on service experience, independent testing, and purchases and forward this data to potential buyers. It was found that several large suppliers of raw materials are performing design and evaluation studies of current container construction in order to promote their product and assist the fabrication sector of the industry. The fabrication sector does little, if any, research and development in the containerization area due to the very low profit margin. Questionnaires, telephone communications, letters, and visits to numerous companies proved to be most useful.

d. Noting that the above addressed the defining of the state-of-the-art and that results were not immediately available, various materials of construction were either procured or donated by industry for test and evaluation by USAMERDC's Materials Research Support Division (MRSD). The materials were tested at various temperatures with the following representing the major areas of interest:

(1) Saltwater spray
(2) Impact loading
(3) Electrolytic behavior
(4) Repairability
(5) Biological deterioration

e. Certain materials began to appear favorable especially in resistance to impact which appeared to be the most serious area of concern as determined by the usage profile established for the commercial and maritime environment. Thus, containers using various construction techniques and different sidewall materials were examined. (By this time, the state-of-the-art results indicated that the majority of damage to a container was in its sidewalls.) To examine sidewall materials adequately, the following types of containers were procured:

(1) Honeycomb sandwich panels in a steel and aluminum frame (Fig. 1)

(2) Styrofoam sandwich panels in a steel frame (Fig. 2)

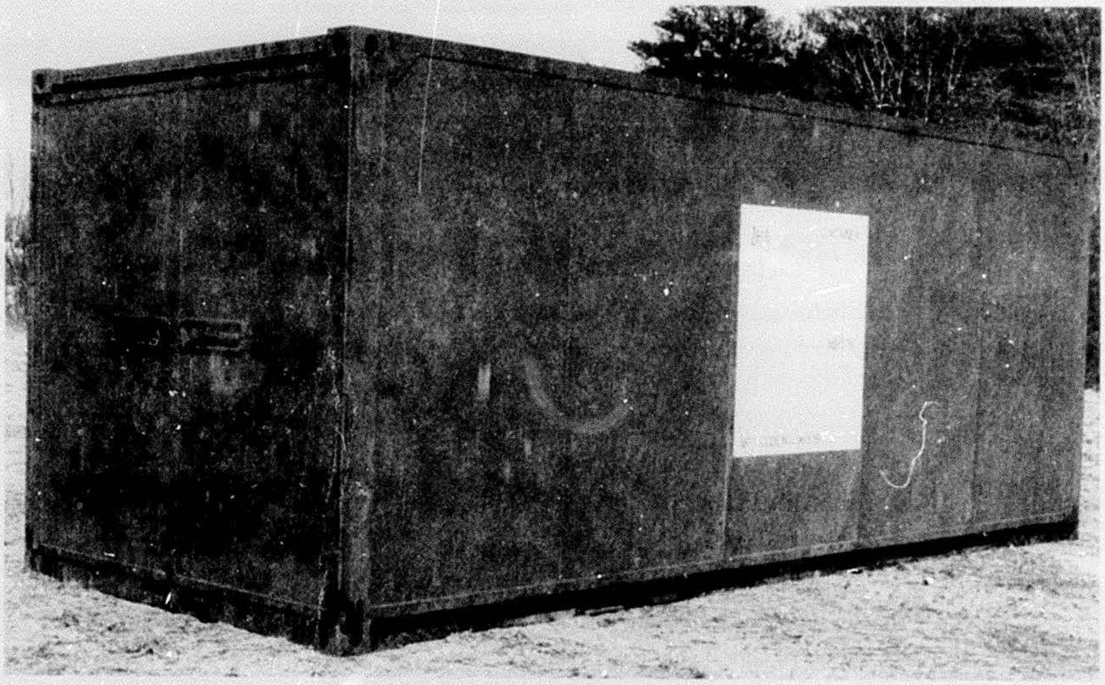
(3) Fiber-glass Reinforced Plastic (FRP)/Plywood in a steel frame (Fig. 3)

(4) The all-steel MILVAN (Figs. 4 and 5)

The study of new and different materials and construction techniques is still continuing. Changes in design philosophy in the last 3 years has been significant with the following varieties of containers having been examined but not fully evaluated:

(1) Rotationally molded using plastic and expandable metals (Fig. 6).

(2) Monolithic-type approach using all fiber-glass inner and outer square cross section cylinders filled with foam (filament winding).



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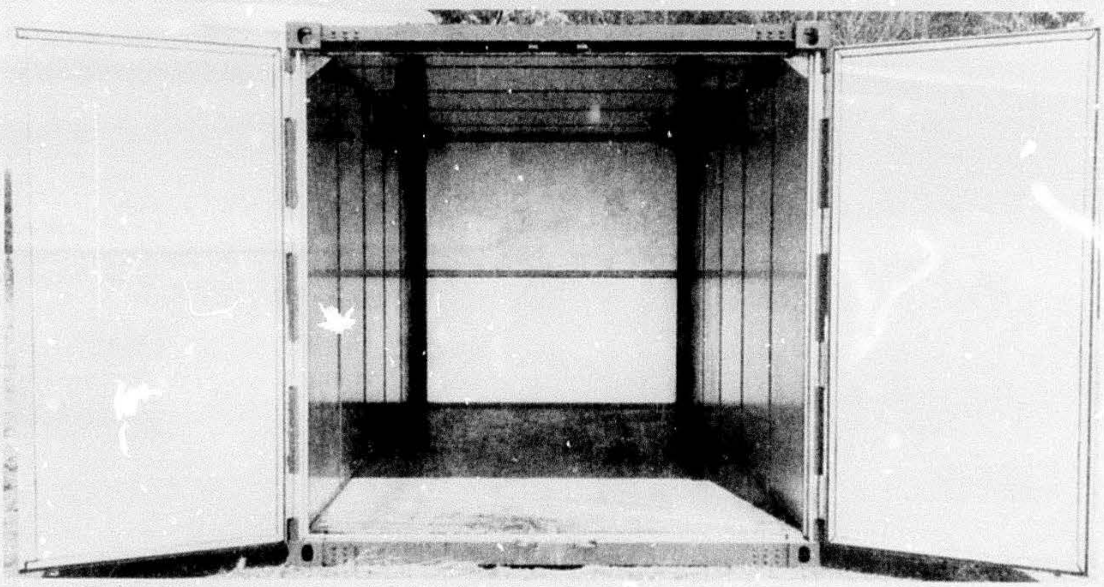

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Fig. 1. Two views of a honeycomb sandwich container consisting of paper honeycomb core material and aluminum face sheets. Note the "H" members connecting the 4 by 8 ft panels in place on each wall.

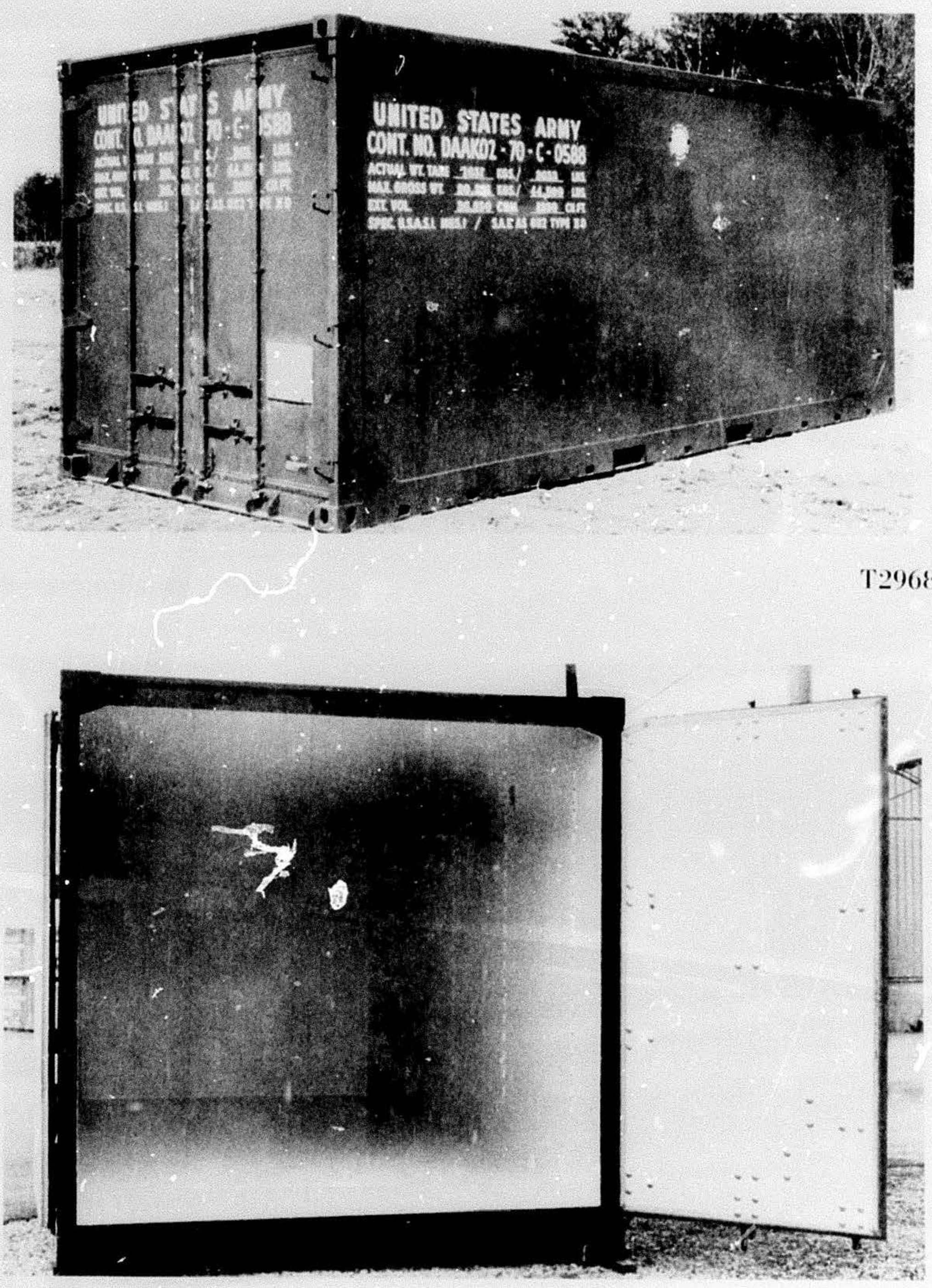


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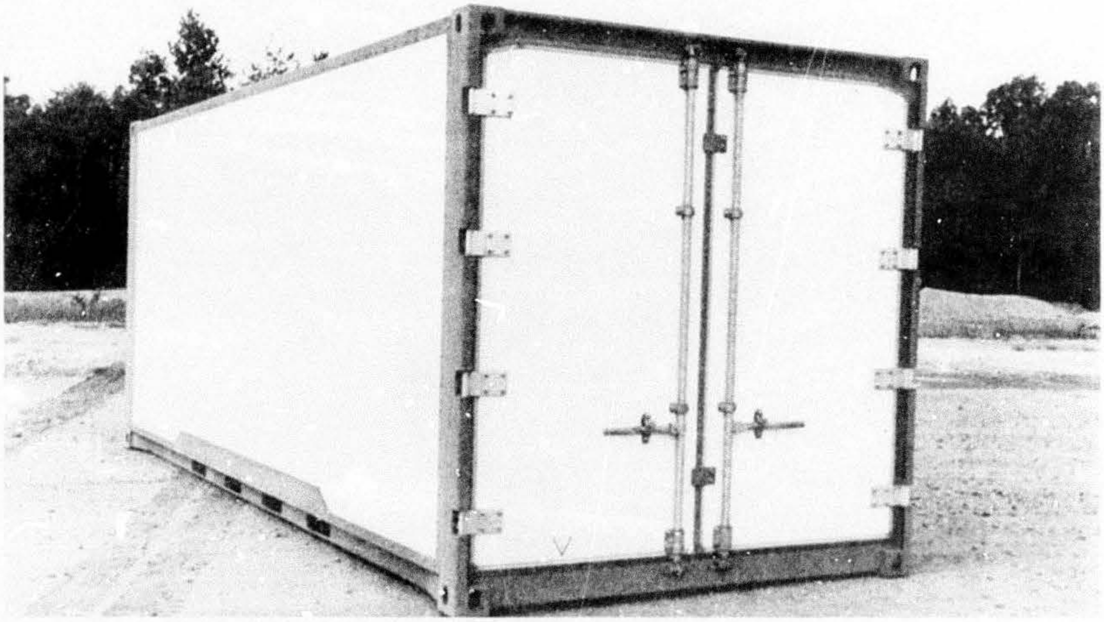
Fig. 2. Two views of a foam sandwich container consisting of aluminum face sheets and a high-density polystyrene core. Note the restraining rails, the first known attempt by the military to investigate the feasibility of mechanical restraints.



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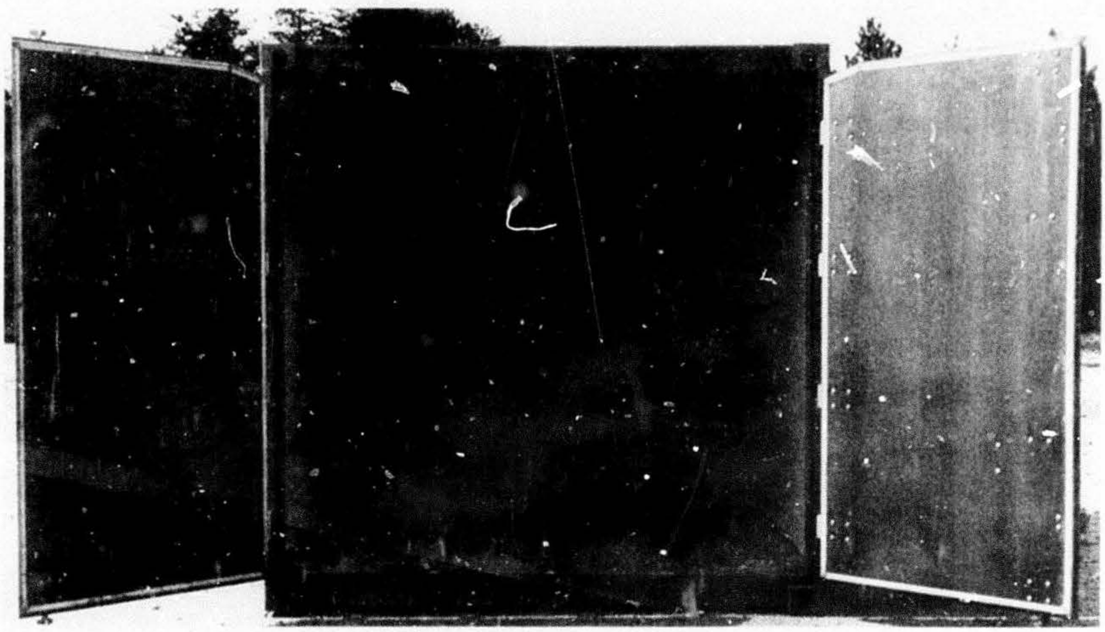

T1442

Fig. 3. Two views of a fiber-glass reinforced plastic/plywood container. Note the smooth walls and reinforcing material about the tineways. The frame is all steel.


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Fig. 4. An 8- by 8- by 20-ft steel MILVAN container.

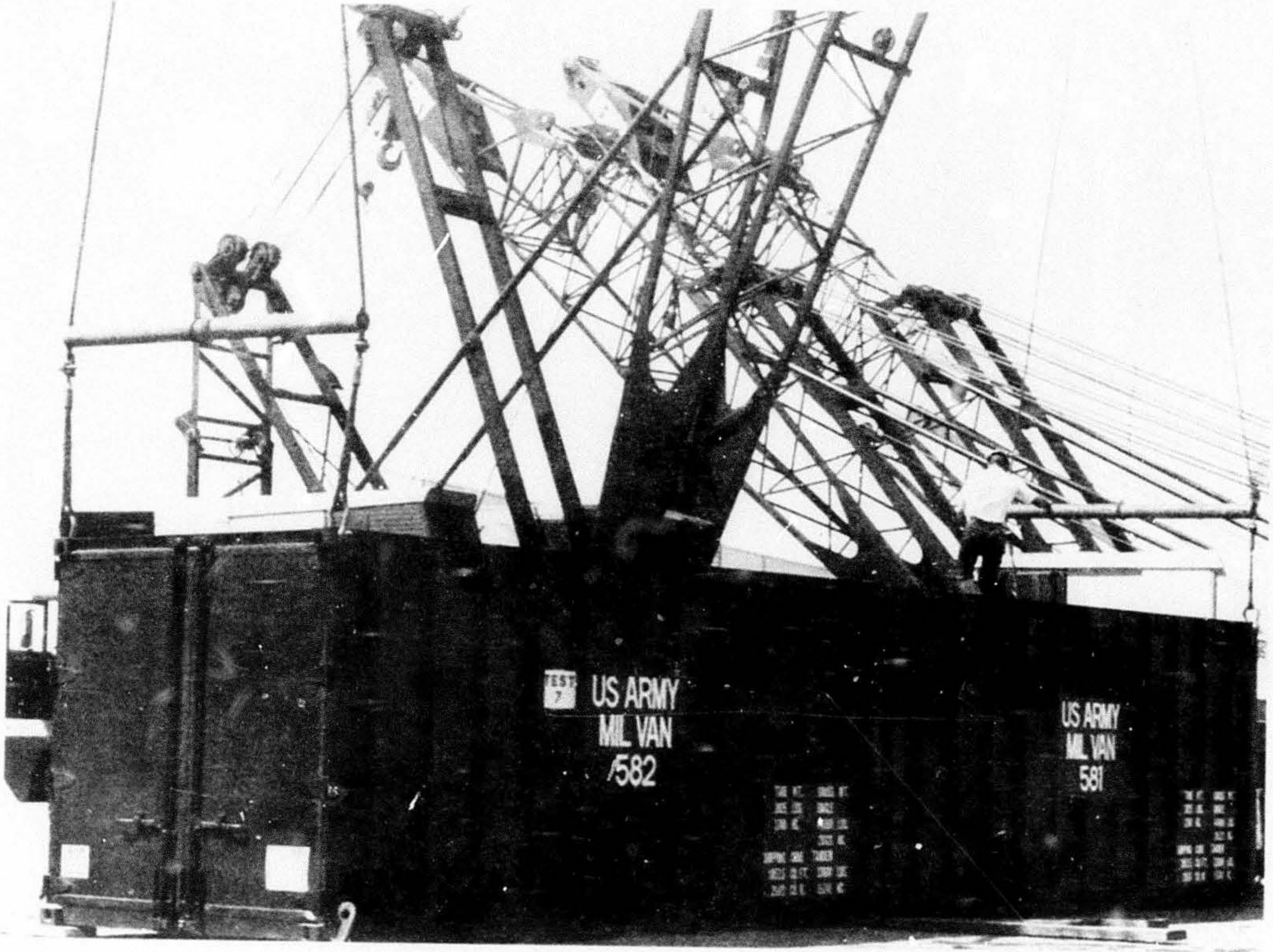



Fig. 5. Two MILVAN containers coupled to form a 40-foot configuration. The coupling feature is apparently unique to the military.

Fig. 6. Metal frame of a rotationally molded container showing the back wall of expanded wire mesh and the punched plate right-hand side. (Note: This container will be placed in a mold with a plastic which when sealed and then heated will flow in and around the container walls. The final result is a very low modulus material on the outside of the panel with the wire in the center having a high modulus.)

(3) All aluminum sheet containers using aluminum corner fittings.

The above innovations are certainly making their mark on the ever-expanding field of containerization.

f. With the significance of impact loadings on the container being realized, the program continued with an investigation leading to improved resistance by the container to the dynamic environment.

The objectives were established such that it was necessary to pursue a complete understanding of the behavior of the panels under service conditions. At the same time, it seemed most reasonable to present recommendations which would move development of containerization forward in a practical way. The actual severity of the environment was questioned to determine whether existing standards for container qualification are adequate. It is felt that this objective should be carried to an extent that, if a discrepancy is found between qualification standards and the actual environment, measures must be found to bring the two into alignment. Contained in the above is the most urgent objective: the application of the findings to obtain the best direction toward optimum design for containers as related to the military's application along with the determination of the qualification criteria.

The study on impacting damage was planned such that the dynamic load environment could be related to the static testing criteria established in the majority of the standards. The simplification of describing loads and environments generally in terms of load factors or uniformly distributed static loads is only a small step toward the understanding of valid design criteria. The most damaging loads are concentrated and impulsively applied. Thus, a crucial effort was the determination of panel response to dynamic loads.

## III. PRELIMINARY RESULTS

Three general categories of interest are presented: Materials of Construction, Design Characteristics, and Design and Material Interrelationships. The initial work effort addresses a comprehensive list of materials plus design considerations which must be acknowledged.

5. **Materials of Construction.** Examination of the state-of-the-art shows that present construction materials include many positive properties which tend to justify their current usage. Aluminum dominates at present. However, there are many container designs which use a mix of aluminum panels on a steel frame and are considered by the trade to be aluminum units. There are composite materials such as aluminum- or

steel-clad plywood found frequently in door construction. An entire list of candidate materials would be never ending; however, the following list does present materials of construction considered to some extent (see also the E.aluation Matrix in Section IV):

(1) FRP/Plywood Sandwich
(2) FRP/Styrofoam Sandwich
(3) FRP/Reinforced Plastic imbedded in Styrofoam Sandwich
(4) FRP/Honeycomb Sandwich
(5) Al/Honeycomb Sandwich
(6) Al/Styrofoam Sandwich
(7) Al/Plywood Sandwich
(8) Various Al Sheet Sandwiches
(9) Steel/Plywood Sandwich
(10) St/Styrofoam Sandwic.a
(11) Steel sheets
(12) FRP/Urethane Foam Sandwich
(13) Al/Urethane Foam Sandwich
(14) Expanded metals/plastic

The above list addresses numerous materials; and, if depth of section or thickness of a component is varied, one can readily see the large number of combinations which could be derived. The properties of all materials found to be of some significance were tabulated in various subsidiary reports. Areas of major concern were:

(1) strength-to-weight ratio
(2) modulus of elasticity
(3) ductility and brittleness
(4) thermal expansion
(5) dimensional stability
(6) moisture absorption
(7) corrosion resistance (include rot for nonmetallics)

Measures or indices of efficiency must be used to determine the merit of each type. For example, there is wide reference in the trade to the obvious characteristics such as: steel is used for high strength; or aluminum is used for light weight. Comparisons on the basis of strength-to-weight ratio are useful in resolving merit and show in fact that for widely used grades the two metals are quite close. Similar indices were devised to include additional material properties in the listing above. Materials not in wide use were included in the overall evaluation. Probably the most important factor is cost, and this figure over the "long haul" will be critical.

Of course, great time and detail went into the three predominant materials of construction for sidewalls. Prior to this discussion, if must be realized that primarily two types of frames were used when either riveting or welding panels ranging in size from 30 in. by 96 in. approximately to 8 by 20 ft. It is important to note that most container sidewalls are sheets welded or riveted together to form a 20-foot sidewall. This is especially true for steel and aluminum.

By far, the most impressive results to date are found in the sandwich-material family. It has been found that, upon impact, the thickness of the section is important in resisting puncture. For example, a piece of aluminum, 0.040 in. thick, will fail upon impact, i.e., tear or rip. It is interesting to note that a sheet of aluminum 0.020 in. thick will withstand the current day static test of .6g's on the sidewall. Relating the above example to a sandwich material, it was found that the puncture would not propagate through the entire panel and that for most materials the sandwich material itself did not allow water migration. Thus, repair would not be required immediately. The trade-off for the above case is simply a matter of economics. The sandwich is approximately five times more expensive. One must then address life-cycle costing in order to attain relevant results. In this approach, one can readily see in the open literature that steels and aluminums suffer a great amount of degradation due to the environment. This was not the case with the more expensive Fiber-glass Reinforced Plastic (FRP) Plywood or other materials which faired equally as well as FRP/Plywood such as stainless steel or expanded metal encapsulated by a polystyrene material.

Thus, as time went by, the author could readily see trends being established. The most severe was the fact that a procurement on a least-cost basis, primarily, seems unreasonable because additional expenditures will certainly improve life-cycle performance and overall effectiveness. From all indications, the cost of the FRP/Plywood type container is essentially fixed because it definitely appears that this type, for the time being, is the best material design combination. However, it should be noted that if aluminum were offered in corrugations similar to the steel sheets on the present MILVANs the sidewalls would have an improved resistance to puncture due to an increase in the moment of inertia and depth of section along with appropriate change in Modulus of Elasticity. With steel, the changes appear to be less significant. The environment is by far the most damaging to this material, and additional chrome and nickel should prove to be a substantial enough addition to combat the problem of corrosion. Several firms are currently producing a low-grade stainless steel which does more than the common steels used today. For an entire container, however, the additional cost is less than 100 dollars, and it appears the life will be substantially increased especially if the 0.047 in. thick wall is increased to 0.062 in., for example.

Past efforts have shown that a container having a tare weight of 4000 to 6000 pounds is actually insignificant to the overall systems approach to containerization.

Thus, changes which reflect an increase in weight are for the most part nondisparaging except for the rare case where air transport is anticipated. In this case, the logical end to the total logistical problem appears to be modular containerization rather than the standard 8- by 8- by 20-ft configuration.

All factors being equal, the following is presented. The military's current MILVAN fleet of all-steel containers is not the optimum. However, it would certainly appear realistic to address an all-steel container with minor modifications such that its response to a dynamic load is improved and its corrosion resistance is increased. The relatively new concept of an all-aluminum container also warrants consideration because this container does have a very worthwhile scrap value. This is to say that from a cost standpoint alone the steel would be less on the initial buy; however, the demurrage is so great that the steel container is essentially worthless in 2 to 2½ years while its competitor, aluminum, will always have a scrap value depending upon the location of the container when totally damaged. This cost appears to offset the initial gain of steel in a least-cost initial procurement. Noting the above, FRP/Plywood cannot be ignored because this container, while costing more, appears to constantly exhibit high availability statistics. It can absorb impact that the others cannot. It is a rugged container. It will always be ready to be stuffed and shipped with the shipper realizing that his goods have the best chance of reaching the far shore in an acceptable condition.

**6. Design Characteristics.** This topic examines the approaches by which the materials are employed to produce useful product designs. Of major concern was the determination of weight distribution as presently practiced between frame and panels and whether this has been optimized on a rational basis. Any attempt to lighten panel structures can only be made with a full consideration of what strength contribution is provided by the panels to the composite structure when the panels are acting as girders under transverse bending or as a structure under torque. It was also necessary to investigate the distribution of material in fabricated panels as between skin and stiffeners. Among the designs in wide use, the stiffness-to-weight parameter was established as a function of the stiffener section properties and spacing. Resistance to localized impact and tearing was evaluated for various panel designs. For composites, e.g., FRP/Plywood, similar investigations were performed for variations in face and core thicknesses. The results are most interesting and relate directly to the preceding topic on materials. The overall strength and stiffness of designs were analyzed with the container being considered as a single structural unit.

Results in this category were not significant other than to note that a container was not found with an all-aluminum frame which could pass the requirements of a cargo container specification. It is common practice to reinforce these frames with steel. This is especially true of corner posts and fork tineways if the container has the latter. Also, the undercarriage does receive abuse if the container is skidded over the terrain. Steel reinforcing members appear to be the logical solution because the vast majority of longitudinal rails are steel. All types of sections are employed. It is significant that most designers strive for a large cross sectional area and a moment of inertia which is as large as possible. This relates directly to the six-high stacking requirement and the severe racking loads experienced in transit. A racking load by definition in the requirements document is approximately 35,000 pounds and is applied at one of the upper corner fittings in the transverse direction with the base fixed. The requirement stems from the desire of the maritime people to stack containers up to four high on the deck of the ship. The 35,000 pounds, a testing requirement found in most standards, does appear to be worthwhile and one of the most formidable tests to pass.

Most panels pass the basic test requirements as related to static loads. Recall that it has been found, in fact, that sheet aluminum, less than .020 in. in thickness, will pass the static-load requirement. Thus, in actuality, from a testing point of view, almost any material of very thin cross section can support the static load leading one to question the validity of static loads on sidewalls. The more logical solution to an apparent ambiguity is to dynamically critique the sidewall. In real life, this is the situation because all container sidewalls can support far more than .6g's on the sidewall. In fact, impact damage is considered, thus giving rise to the materials in use today.

Aluminum sheet and post is most impractical. The posts are easily ripped from the sidewall. The sheet is less than .100 in. thick and is subject to easy penetration by a foreign object either from the outside or the inside. Numerous case histories exist wherein the internal dunnaging has failed and the load has penetrated the sidewall. The posts are spaced 12, 18, and 24 inches on center with the latter case being unusual. The sheet aluminum varies in width. The width is dependent upon availability from the material supplier, and in many cases numerous widths exist.

Steel sidewalls are normally not flat sheets as in the aluminum case. The steel is corrugated and is not reinforced by posts. It is welded to the frame whereas aluminum and FRP/Plywood, in general, are riveted. The corrugations increase the moment of inertia for the panel and thereby enhance its general performance when impacted. Also, its Modulus of Elasticity is three times as great. This appears to aid in stiffness, a quality which in the container business *does not* seemingly add to the performance of the material. Steel and aluminum containers are normally lined with ¼-inch plywood sheet. This offers insulating qualities and provides a smooth interior wall to skid pallets against when dunnaging.

FRP/Plywood is the third popular container sidewall material. From an impact point of view, it unquestionably rates superior to its counterparts. It is heavier on a per-square-foot basis. However, if a steel or aluminum corrugated panel were increased in weight to approximately 3 pounds per square foot, neither would behave as well as the FRP/Plywood. In design, one must realize that this panel has a great deal of resiliency: and a deflection of 6 inches on a sidewall measuring 8 by 20 ft is not uncommon. With steel or aluminum, a permanent set would take place with the yield strength of both having been surpassed. A liner is not required when this material is used. This material when repaired after damage decreases in efficiency while the others remain fairly constant.

7. **Design and Material Interrelationships.** Many extraneous factors enter into design analysis when materials and design configurations are jointly considered. For example, inherent properties of materials may show qualities which cannot be carried over into finished-product designs for any number of reasons. High-strength tensile steels have excellent strength-to-weight ratios, but minimum gauge and flange crippling may result in less than an advantageous design. Design of difficult joints sometimes offsets advantages of a material or design approach. Areas studied included comparisons of total weight when high-strength material is used, when variations are made in the frame and panel weight distribution, when panel stiffeners are limited in dimension to avoid loss of interior cube, and when structural criteria are varied. All of the above become most evident when the interrelationship considered between design and materials addresses the dynamic loading environment rather than the static. The subject of the general environment to be encountered is significant. Many oceangoing vessels take a great deal of water, which is an extremely corrosive agent to most metals, over the deck. The merit of existing designs and the evaluation of certain designs reconfigured with different materials have been examined. Included in this topic were the following three major areas of concern:

a. productivity
b. maintenance requirements
c. costs

Interesting compromises arose immediately once the author took materials of a nature previously described and designed new container configurations. Of course, impulsively applied loadings were of major concern because the majority of damage to a container occurred in this situation. One can immediately detect that the panels with greatest depth of section would seemingly rate highest. In many cases, this is not the true picture because the material when affixed to a rigid framework is not allowed to behave in its natural mode. For example, FRP/Plywood in a very rigid frame cannot exhibit its resiliency properties because there is no give or relaxation in the frame; thus, the rivets will pop. However, to go one step farther, the designer has purposely taken the strength away from the upper rails such that these upper rails freely rotate as the FRP/Plywood wall is deflected. This is a case of matching, properly, a material property with a design characteristic. Lighter upper rails for steel and aluminum would not add to the performance of the panel. Intuition tells one that, especially in the case of aluminum, the lightweight rail would deform from a static load. Steel would behave similarly because neither material can offer strength along its longitudinal axis. FRP/Plywood tends to behave in a light steel frame much like a monolithic structure because the entire container is always working and accepting the jostling and general handling environment as a routine happening. In the case of steel in a strong frame, one can detect a shear ruggedness which is unrelenting in fighting the environment rather than tending to flow with the normal occurrences. Aluminum is in the middle. The sheet and post configuration tends to offer a protective covering for the goods in the sheet form, while the posts add vertical and some transverse strength. It appears that, as the Modulus of Elasticity drops, the materials become more workable and thus are capable of encountering a blow which will prove to be less damaging to the entire container. For example, a steel with a yield strength of 175,000 psi will fracture readily while plywood with a yield strength of approximately 1200 psi will absorb a great deal of punishment and will not fail. Granted that the material thicknesses are different, the fact remains that the lower yield strength materials tend to offer this nebulus factor called resiliency. Another way to look at this situation is to consider the behavior of the sidewalls to be as springs, each with a given spring constant. The steel has a high constant; thus, the material will try to resist movement much more so than wood. The resistance to movement is the trouble spot. A certain amount of give or yield or bend is fine as long as contents are not damaged or containers located adjacent to each other do not contribute to their own destruction. Such destruction could occur in the sea mode of transportation.

Considering all factors in the material design relationship, the dynamic environment appears to be, without question, the predominant area of concern. It definitely appears that the benefit of a low value of Modulus of Elasticity stands out as a dictating factor. This seems to contribute to an understanding of the superior performance of FRP/Plywood panels in the container service environment. It had previously been supposed that the performance advantage of FRP/Plywood was due mostly to the additional material in the panel; FRP/Plywood panels are approximately 3.0 pounds/sq ft as compared to 1.5 pounds/sq ft for aluminum and 1.8 pounds/sq ft for steel. Intuition and a numerical analysis of impact on a modeled container sidewall enable the author to state unequivocally that corrugations are decidedly superior to the common stiffened sheet-post type of construction in efficiently dispersing material to resist loads. Of course, this particular design advantage would be even more pronounced for static-load comparisons. An interesting result of the study is that the gain in design efficiency of corrugations over stiffened sheets will overcome a material advantage and that conventional steel panels are more resistant to impact than conventional aluminum panels.

New panel configurations can always be obtained; however, a significant change of materials represents a higher risk in panel improvement versus that of present day materials which can be readily reoriented into new configurations such that they are used more efficiently. For example, a higher risk developmental effort would relate to bonded sandwich constructions, especially those involving materials which have no service record in harsh structural applications. Nevertheless, it still appears to be possible and most probable that by the above approach one can best tailor panel properties for high-impact resistance and incorporate numerous other features such as maintenance procedures, productivity, corrosion resistance, and the like.

An optimum metal panel interfacing with a container framework of steel has not been established. An all-aluminum configuration using thick aluminum sheets as sidewalls and an aluminum framework including forged corner fittings does not appear to offer the ultimate in design. It appears to be more of an expedient to allow the aluminum industry to offer something new and different to stem the tide from FRP/Plywood containers in the commercial and maritime environment. The above is truly an advance in the state-of-the-art and certainly surpasses the case of stiffeners applied to one side of a sheet. The aluminum sheet and post design is clearly the lowest ranking panel regardless of the intrinsic merits of the metal. Corrugation patterns have evolved empirically and offer possibilities for further refinement. A refinement that requires additional attention is sectional inertia and whether it can be increased by fewer webs, i.e., whether the pattern can have greater spacing across the span for a given depth of section. Results to date tend to indicate a minimum of effect for variations in section depth and unit weight. The depth of section should be held to lower thicknesses than presently used in order to restore some of the lost cube taken up by overly deep sections. A panel thickness in the range of 0.75 to 1.0 inch (similar to that of FRP/Plywood) would seem to be a logical objective. It must be realized that the vast majority of 8- by 8- by 20-ft containers are cube limited rather than weight limited.

It is easy to address the existing configurations and critically evaluate their performance capabilities. The true problem arises when new panels are considered. An example is foam with an aluminum skin in a steel frame. The 8- by 20-ft panel is made in pieces as with aluminum and steel. Will this sandwich panel perform as well as the FRP/Plywood which is one piece, 8 by 20 ft? The answer is not readily apparent. One must first attack the panel and determine if it is of high quality, i.e., is the bond of foam to aluminum acceptable? In the problem formulation, a simple beam with free ends and a concentrated, applied load was considered. The stresses calculated were all within acceptable limits indicating a good match of materials. Thus, the core and face sheets are working harmoniously. A definite mismatch would be steel on foam. In this case, the transmitted stress would be quite low; thus, the foam is not working to its ultimate potential. It must be realized that in the above discussion a simple bending load was considered. For panels such as those above, the shear stresses should be examined to detect skin core delamination. Again in shear (which is really the dictating design factor), the loadings are reasonable. Experimental results substantiate this.

From the above and numerous other sources of information, a simple deduction is presented, i.e., double-walled panels appear attractive in the dynamic analysis. However, there are some practical difficulties which accompany inherent advantages. The problem of matching core and face material properties disappears when only one material is used. However, the fabrication of double-walled constructions has not been solved by a price competitive process let alone the integration of this panel into a frame. Additionally, as was mentioned earlier, there is the problem of failure in tearing. With double-wall construction, the material is inevitably thinner than in a corrugation of comparable unit weight. Resistance to tearing types of failure should be less for double walls. However, it is obvious that if the thickness of the face sheets is in the neighborhood of .075 in. there should be a significant improvement in tear resistance as compared to conventional, stiffened-sheet panels. Furthermore, double-wall constructions have flat surfaces on both sides which will deflect many of the glancing impacts which presently lead to damaged stiffeners, i.e., riveted "hat" section posts. With the sheet thickness as cited and section depths in the range of 0.75 to 1.25 in., the upper limit of unit weight will be approximately the same as the all-aluminum configuration previously discussed.

## IV. DISCUSSION

The report, to this point, has presented numerous arguments for various materials and their interrelationship with a container. This section has been prepared to acquaint the reader with the many nebulus areas within containerization. Also, the discussion on new and different design material techniques currently being employed or planned for the near future will portray to the reader the art as it currently exists. An Evaluation Matrix has been prepared. The author has utilized this specific matrix in justifying numerous conclusions contained in this report.

8. **Initial Panel Testing.** Work has been directed toward obtaining materials combinations which will sustain a given impact. For example, the concept of fiber glass as a sheet material bonded to an aluminum or steel honeycomb core has been examined. In this case, one would of course find that the ratios of moduli of elasticity will be reversed from the argument made earlier in addressing the aluminum on foam honeycomb or wood configuration. Preliminary efforts have shown the material to be an absorber of shock loadings; however, these panels were, as were numerous others, approximately 2 inches thick. All sandwiches seemingly behave quite well in the dynamic environment as related to the nonexistence of puncture through the inner skin. Tests performed in our laboratory showed that paper honeycomb with any material facing identified tended to delaminate much more readily than any other core material. Stainless steel faired extremely well; however, our specimen was a plate 0.1875 in. thick.

The sandwich configurations of all types displayed excellent flexural strength characteristics. Impact resistance was a relative factor. In the laboratory tests, the very thick stainless steel faired best of all; however, a material this thick is impractical. Thus, in relating standard configurations such as the .047 in. thick steel sidewall of the MILVAN against FRP/Plywood or other sandwich panels, the latter consistently rated superior. Included within the testing program for the various panels was exposure to the elements, general repairability, and, of course, the all-important impact testing. Panels were placed in special test cells to determine the biological deterioration of the foams, honeycombs, and woods. Results indicate that the majority of panels considered were not vigorously attacked when the edges of the specimens were sealed. Panels were placed on site at Albrook Air Force Base, Panama Canal Zone, and at Fort Belvoir, Virginia, while the arctic-type testing was simulated. Results again show little degradation in panel performance after exposure for nearly 2 years. These results are based upon the premise that the panel is protected at its edges. If sealing had not been done, the wood and paper honeycomb would have eventually deteriorated.

Impact testing is a very interesting subject. At a time when dynamic loadings are so very important, decisions are still being made based on static analysis only. It is the author's opinion that this is due to a lack of knowledge in this particular field and a complete breakdown of inter-agency coordination. The Department of Transportation has been doing excellent work in the area of impulsively applied loadings. To standardize on a number of fixed tests and essentially eliminate the static tests would certainly upgrade the engineer's capability to either accept or reject a given item. In our tests, we originally used a 12-inch-square section and impacted this with a typical fork tine. It was a simple drop test. Knowing the mass of the falling object and its height prior to drop immediately gives one the energy imparted into or absorbed by the panel. It was found that the section originally affixed on all four sides did not exhibit behavior traits found in larger sheets of like material. The panels being fixed tightly could not behave as originally intended. The framework was actually working with the panel; thus, the panel was truly not being tested. To improve on these relative testing results, a larger panel—18 inches square—was used. The results improved. However, the author still believes that the test apparatus was inadequate. A better mathematical approach would have found this to be true in the beginning; however, at that time there was little, if any, feel for how the materials would behave. Thus, the specimen size did not become critical until after the samples were exhausted and no further funding was available to continue the testing.

The testing proved to be most fruitful because the vast amount of raw data has provided a great deal of insight into the relationship between materials and their behavior while in a specific configuration. Highlights, of course, include the wealth of information obtained as related to sandwich construction, corrosion resistance, repairability, maintainability, biological deterioration, structural shapes, electrolysis, and the like.

These data have been used throughout this report in a qualitative fashion and have definitely influenced the overall program as related to objectives such as meeting and coping with the military environment rather than the commercial. Flame resistance was considered because a situation could readily occur where the exhaust from a motor vehicle could impinge the container sidewall and perhaps provide the heat required to initiate a fire. It was found that the foams tend to melt, the FRP/Plywood will not support sustained combustion, and the metals simply lose strength.

9. **Military Environment.** The military environment is significantly different than the commercial environment. However, the differences are not found in the shipping mode, i.e., rail, truck, or sea. Rather, the notable changes are found in the areas of dunnaging, terminal and port handling, transfer, storage, maintenance, and availability. Most areas listed above are conceptually different than the procedures commonly used within the normal industrial complex.

Dunnaging is drastically different in the military environment as compared with the commercial. As an average, industry requires approximately 1 hour to stuff, block, and brace; to tie down; and to prepare the manifesto for shipping. On the other hand, the military requires approximately 6 hours to accomplish the same tasks. The military containers for which this figure is presented are of two types. One has an eight-rail-per-side dunnage restraint system, and the other is the standard, flat-wall-type container typically found in industry today. (Expensive restraint systems such as found in the present-day MILVAN container have not been readily accepted by industry because of two main contributing factors: initial cost, and additional cost in time and manpower to use the restraint bars which are easily lost or stolen.) The private entrepreneur, in his quest to save excessive expenditures, will establish a quota of containers which have to move in 8 hours. Incentives are then provided to the workers such that corners are cut, the workmanship becomes shoddy, and the cargos are in a state which could precipitate damage. It is a fact that men associated with containerization know from experience what they can "get away with." Thus, I have found this group of men most forward and direct in readily establishing the idea that, if a container experiences internal damage, the insurance company will cover the loss. The supervisor realizes this and readily agrees with the method of doing anything to get a job done. It is a very competitive world to these people, and they realize that ships will not wait for them to stuff a container. Thus, to make or save a dollar, depending upon your viewpoint, is a most desirous goal. The military certainly does not compete in shipping goods; thus, expedited deliveries appear to mean little. The objective to date by the military has been to follow a course much like that feeling found in numerous offices, i.e., don't do anything which would tend to throw containerization into disfavor with the superiors.

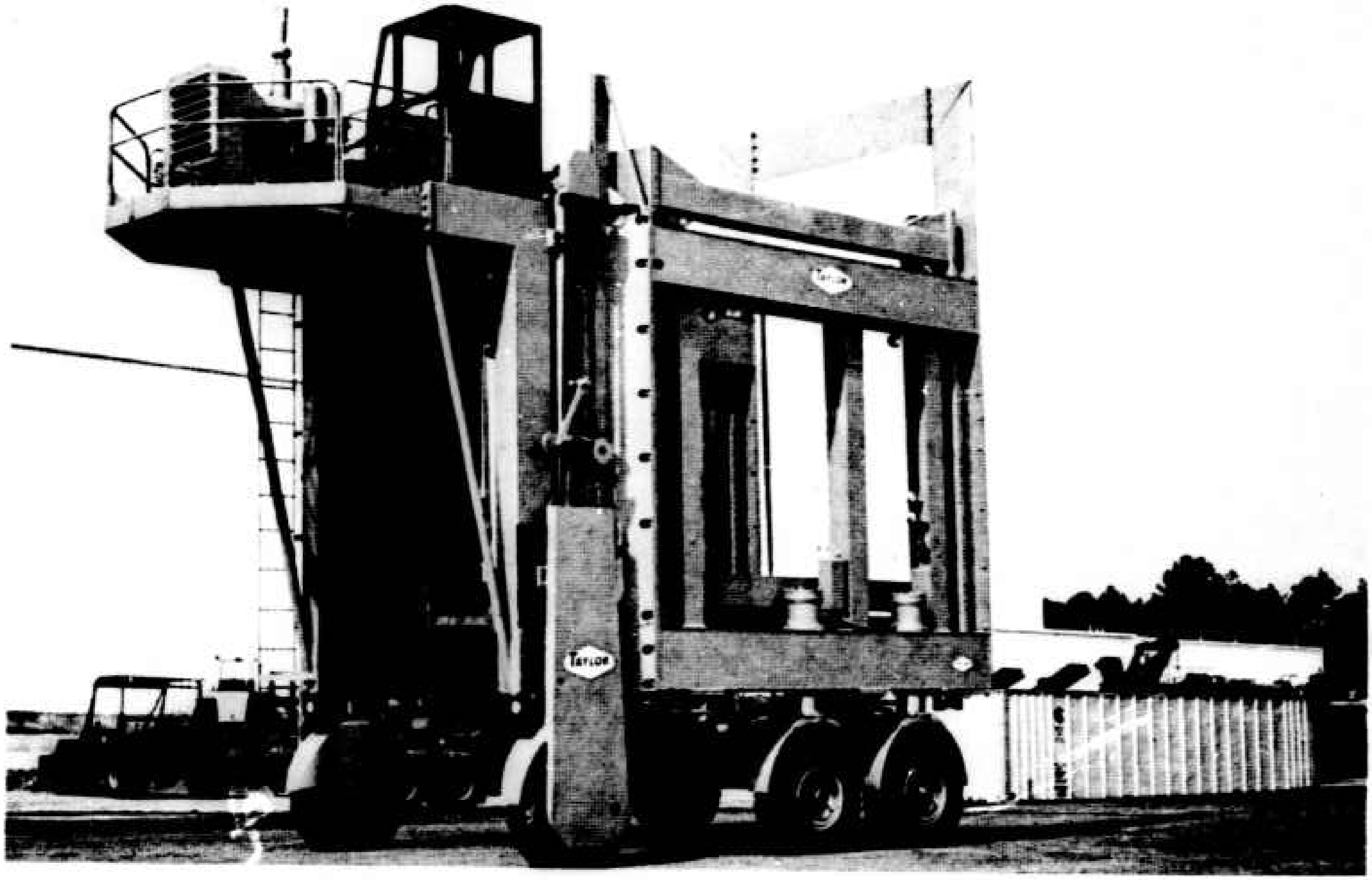
Both types of military containers are dunnaged far in excess of the required limits. Air bags, blocking and bracing, proper pallet spacing, additional restraint bars, exact and proper pallet configuration, i.e., 40 by 48 in. with an allowable 3-inch overhang on all sides and a height of 43 inches, and additional strapping (in many cases this is found to be a package in a class A configuration) of the goods to pallets contribute to a monumental amount of effort in stuffing a military container. The situation is not good; however, prominent individuals have recognized the fact that a total systems approach to containerization is required and the problem of adequate dunnaging apparently will be addressed.

The military owns very little materials-handling equipment (MHE) to handle containers. There are numerous accounts of the port operator actually using his gantry cranes and yard trucks to drag containers into a position such that the crane can be used as it was designed—to load or unload a container from a ship's cellular hold. In some transfer facilities, underrated forklift trucks try to pick up containers and end up by driving their forks through the sidewall. One individual interviewed actually saw two forklift trucks, side by side, moving a container onto a truck. Problems such as those mentioned are being rectified by having the container shipped to modern ports and not allowing the container to be taken from the trailer chassis. New spreader bars prevent buckling loads in the upper rails because they accept this loading and relieve the container of an unusual strength requirement. However, away from a port, the military in numerous cases can only offer the 20-ton Rough Terrain Crane which, with a sling, positions the container on the ground. The loads applied when this is done tend to approach the upper limit of the allowable stress for the upper rail.

Transfer equipment utilizing spreader bars is used by all major port facilities in the world. This equipment falls into three categories:

a. straddle truck (Fig. 7).
b. side load (Figs. 8 and 9).
c. front loader (Fig. 10).

All, when operated correctly convey the container in such a way that little or no damage is imparted. Damage does occur when the operator drives his spreader bar into the roof of the container. This occurs usually when a heavy workload exists and the man is rushing. The equipments identified do have a fine performance record, and the military must begin to procure for their depots these types of commercial MHE to handle the ever-increasing flow of containers. To offer additional incentive to rapid procurement, the Military Traffic Management and Terminal Services (MTMTS), a major command of the United States Army, projects that 80% of all Department of Defense cargos are capable of being transported by container and that, currently, approximately 50% are containerized.

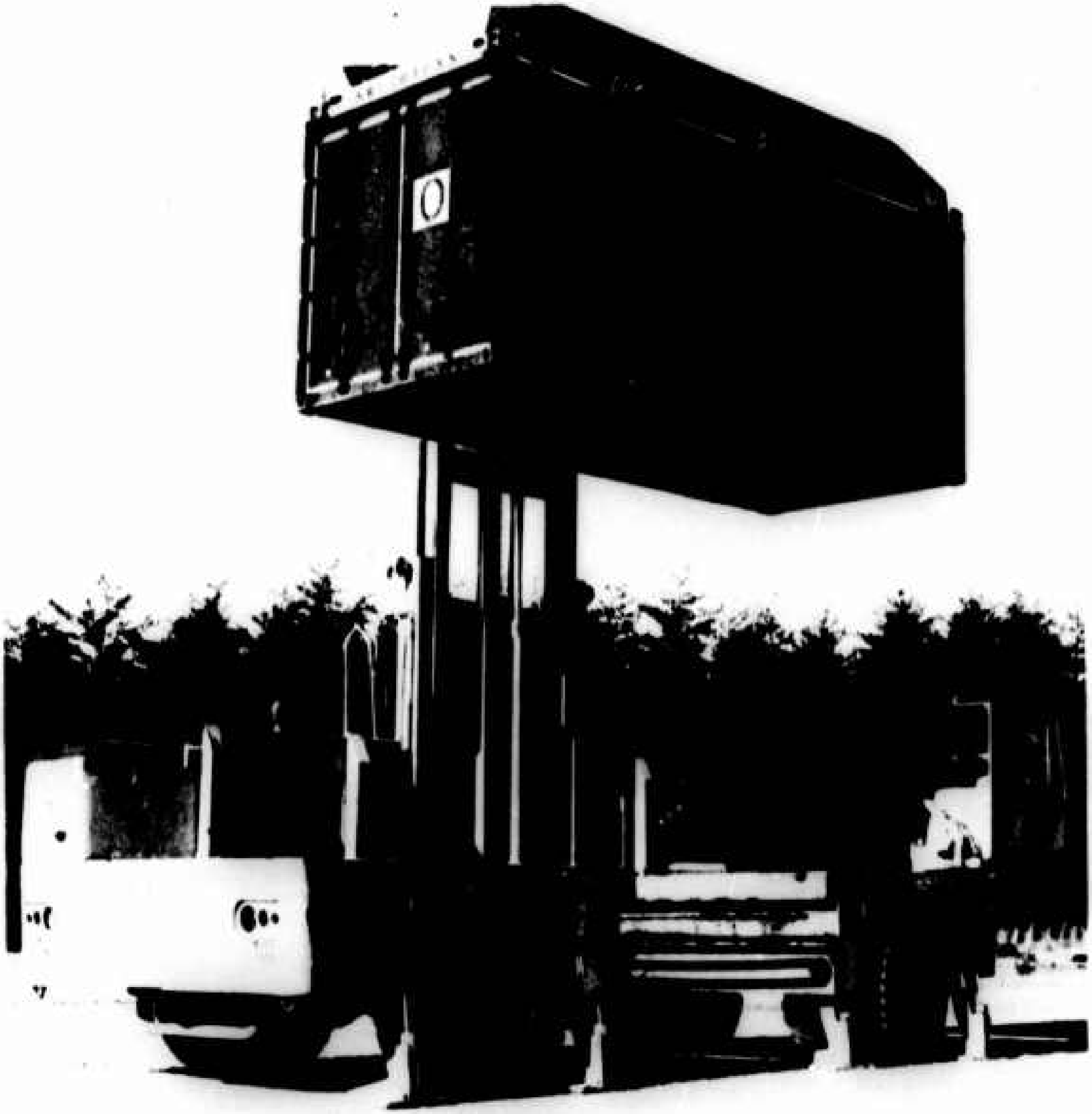


S10481

Fig. 7. Taylor Machine Works straddle carrier capable of stacking three-high 8- by 8- by 20-foot containers.

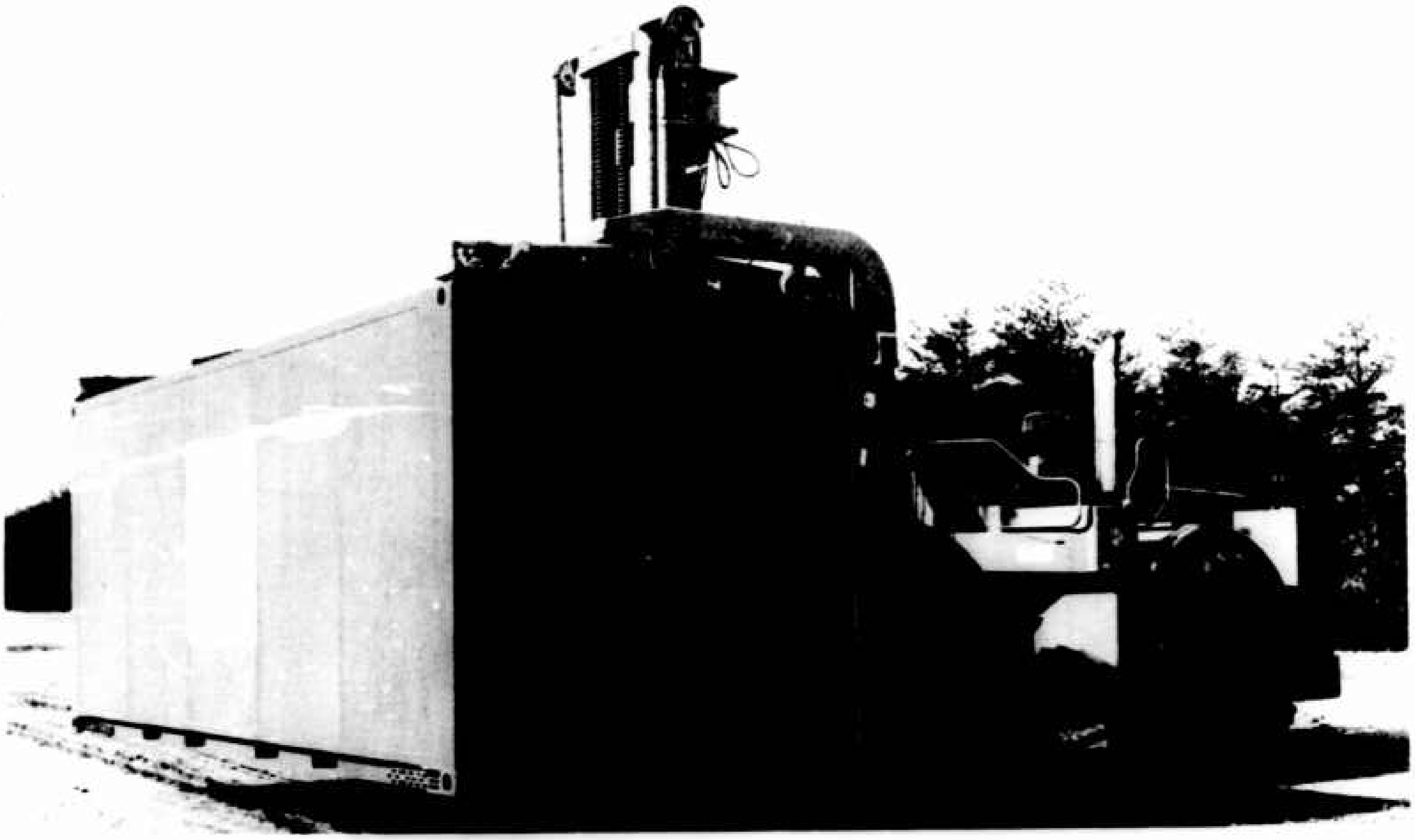
T12419

Fig. 8. Allis Chalmers Lancer series side loader.



V2263

Fig. 9. Lancer Series side loader in operation.



T2870

**Fig. 10. Caterpillar–Towmotor Frontloading Container Handler. This is a special item procured to address the military environment: thus, the combination Caterpillar 824 Sozer with Towmotor mast assembly.**

The military uses containers essentially for storage at the far shore. This is unheard of in commercial practice because the operator is striving to have his container continually in motion. He makes his living this way; thus, there is little time to actually deadline a container for, as an example, preventive maintenance or routine maintenance. Containers used by the U. S. Army can be found throughout the Republic of South Vietnam. An interview with former U. S. Army and U. S. Marine personnel brought the following to light. If at all possible, the container will be moved to a position where it can be readily camouflaged and repainted. In one case, a container was used as an officer's club. In another, a container was used as a signal and map shack with room to sleep. Both were air conditioned, and the men implied that these tended to make life "a little easier." I felt that these particular incidents could contribute guidance to the methodology to be employed in sending containers to a forward area. Perhaps some containers should actually be fitted prior to shipment to be used by the troops for all types of operations including messing, medical, berthing, administrative, maintenance, storage, and the like.

The maintenance of containers in the commercial environment is good when the container has received noticeable damage, but preventive maintenance is essentially nonexistent. This is poor practice, especially with regard to steel which should be sandblasted and repainted once every 2 to 3 years.

The military again far surpasses its counterparts of industry by repairing every damaged spot ranging from dents to the replacement of the entire undercarriage or sidewall. Great time and effort are spent in the process of repairing containers. The most costly item in the repair is paying a man to fix the container. His hourly wage and the total number of hours required to repair the container far surpass the cost of the repair materials. One can again see why American industry will allow a container to move through its system until the container reaches a point where labor is the lowest cost. This point can be found in the Far East, for example. In that part of the world, the materials are the expensive factor. The maintenance performed in both military and industry is adequate. In my opinion, the military does a better job in making a container usable and putting it back into "like new" condition.

Industry does not keep containers on the side awaiting a hopeful load. They procure only as many containers as are necessary so that the containers are supposedly moving constantly. If additional containers are required, these can be leased readily. However, leasing containers is expensive. Shippers try to avoid leasing because, inevitably, the container will suffer damage and leased containers must be returned in excellent condition. This, then, costs extra monies because the repair performed is of high quality. By the very philosophy of usage, the military has a large supply of readily available containers at its major depots. The inference is that a systems approach to the actual utilization of a container has not been fully developed, and one of the imposing loopholes is the fact that most consolidation efforts take place at the depot. Industry will stuff a container at the consignor's plant. The military does little if any of this. Again, this tends to increase costs and in some cases provides evidence that containerization is more expensive than the old-fashioned, break-bulk shipping technique.

**10. Operational Attributes and Evaluation of Container Designs.** Noting the extensive materials work, it seemed most reasonable to consider the manner in which materials and design approaches lend themselves to fabrication, on a large scale, to yield a finished product. This became more interesting as some of the sandwich materials began to receive high ratings under test. The fact that an 8- by 20-ft panel, in one solid piece, could not be delivered is an apparent downfall for this configuration. It was also determined that those thicknesses, sheet sizes, extruded shapes, and the like which were found to have the highest degree of merit were available in adequate quantities from commercial sources. Single-source availability for any item would decrease the credibility of the cost predictions. Combining with the above estimates was the amount of welding and riveting required for normal containers. Problems such as joining dissimilar materials brought new insight to the general problem of corrosion and associated electrolytic effects. Availability of appropriate hardwares, such as hinges, door casings, and corner fittings, compatible with the various designs demonstrates to the author that these types of fittings are obtainable if the quantity desired is substantial.

Investigation in the operational environment addressed whether or not any of the generic approaches to container design provides superior operating attributes. The influence of the transportation mode on design requirements, along with the above, certainly provided clear insight to the advantages of FRP/Plywood over all other containers disregarding costs. It became evident that an extreme, weight-saving design did little in an operational sense to add merits to any containers. The final question centered around the average density of cargo carried by the operator and how frequently the containers are weight limited, volume limited, or limited by available trade. The figure used in this program for gross load was approximately 15 tons per container. From a military point of view, this weight is not as critical as it is to the commercial operator. The U. S. Army is not trying to make money; it is trying to save money: thus, the concept of a container with a long life, low maintenance cost, and immediate availability is established.

The final area of major concern was the dunnaging techniques employed. The military is currently using a very expensive and sophisticated tiedown technique utilizing longitudinal restraint bars. The sad fact of this decision by management was the total lack of adequate structural design considerations prior to embarking on such an expensive adventure. Typical or not, the situation is most cumbersome because the Government procured the cheapest container possible and then spent half again as much money to put in a restraining system which seems most illogical and simply an expedient until a better mechanism is developed.

Taking gross loads in the sidewalls of containers is poor practice. The floor has been constructed in such a manner so as to accept this type of loading and should, therefore, be addressed in affixing unit loads. The MILVAN of today has restraint rails welded to the frame and steel wall. If the practice of installing rails continues, much of the effort contained in this document is unapplicable. For example, adding eight rails to a side of an FRP/Plywood container would increase the overall moment of inertia, the average modulus of elasticity, and, of course, the unit weight. The wall could no longer flex as it does now but, instead, would tend to fight the restraining members. Inevitably, the wall and rail would tend to pull apart. Affixing rails would be detrimental to an otherwise fine material. Other sandwiches would be affected similarly. The aluminum configuration would not experience the same problems and would behave more like the steel. Thus, one would have a wall which is extremely rigid and most vulnerable to failure in the dynamic mode. Clearly, a new or different restraining mechanism is required. This should be designed using the rigors of our engineering discipline rather than the hearsay of those who do not recognize that the designer must attack a given problem by usage of the basic principles of engineering.

The container designer is faced with a typical design problem—choosing a material and a structural configuration that will satisfy all design requirements at minimum cost. The designer's task is made difficult in this case by the fact that the environmental loads are not well defined, and the cost equation is complex since it must account for factors such as weight, available cubage, original cost and maintenance, and repair costs.

It is outside the scope of the present investigation to address the problem of load and cost definition. However, in order to aid in future container design studies, the factors which are judged to be of importance in the choice of container configuration have been identified and are presented in the Evaluation Matrix (Table I). Several factors were chosen to allow evaluation of competing design configurations on the basis of structural response to the external loads, material properties, and also cost.

The Evaluation Matrix presents a ranking of several competing structural configurations including those which are presently in service in the military and commercial sectors. For each performance factor, the various designs were ranked on a one-to-ten basis with the results shown in the table. The appropriateness of these factors in container design is discussed in succeeding sections.

**11. Evaluation of Material Properties.** In any structural application, it is necessary to consider the physical properties of the material in the context of the assumed or known environment. In the present case, the environment is hostile in that the container is subject to both static and dynamic loads and must withstand extremes in temperature, climatic conditions, and the inevitable seawater spray.

In considering only the ability of the container to resist the applied loads, the following material properties are found to be important:

a. Elastic constant
b. Factors of safety based on yield and ultimate strength
c. Elongation at failure
d. Hardness
e. Mass density

These material properties may be combined with the geometric properties of the structure to define additional structural indices which may be used to evaluate the relative effectiveness of several designs. Structural indices which appear appropriate for the container design are:

a. Center deflection of a container wall.
b. Peak stress produced by a mass impacting on the wall.

The material properties and the structural indices which have been defined are discussed in detail.

**a. Elastic Constants.** The elastic constants define the linear relationship between the stress, or force-type quantities, and the strain, or deflection-type quantities, for an elastic material. An elastic material is defined as one for which the same relation between stress and strain holds during both the loading and unloading process.

There may be as many as 21 elastic constants for a very general material or as few as 2 elastic constants for isotropic materials. The common metal materials used in structure are normally considered to be isotropic. Their material behavior is described in terms of the familiar engineering elastic constants: the modulus of elasticity and Poisson's ratio.

One of the popular materials used in container fabrication, fiber-glass reinforced plastic, is orthotropic rather than isotropic. This means that the material behavior is described by 4 elastic constants rather than 2 constants as is the case for an isotropic material. For this reason, it is impossible to evaluate prospective container materials strictly on the basis of elastic constants. It is necessary to define a behavioral function for the structural configuration which includes both the material properties as well as the structural geometry. The center deflection and impact stress were chosen to be appropriate behavioral functions for the container overall material design study.

**b. Ultimate and Yield Stress.** The ultimate and yield stress represents the maximum stress level that can be sustained in a material before failure; and the yield stress represents the limit of elastic behavior while the ultimate strength represents the maximum ordinal to the stress-strain curve. These stress limits are found by physical testing of candidate materials. The most common tests are the uniaxial pull to determine the maximum tensile stresses and a shear load to determine the maximum shear stresses.

It is found that the ultimate and yield stresses vary greatly not only from material to material but also according to heat treatment within a specific material group. Thus, it is not sufficient to state the yield and ultimate for steel, for example, without specifying the type of steel and its heat treatment which may be represented by the hardness of the steel.

These limiting values of stress represent the ability of the materials to sustain an external load; and, thus, they provide a basic structural index which may be used to evaluate relative importance of competing designs. When these stresses are used as structural indices, it is useful to define ratios of actual stress-to-yield stress or actual stress-to-ultimate stress. These ratios are termed the factors of safety based on yield and ultimate, respectively. Given the same load environment for all competing designs, that design for which the factor of safety is greatest would have the highest confidence level of not failing.

**c. Elongation.** The strain, or elongation, at failure is a measure of the ductility of the materials or the ability to deform without failure. Materials that exhibit large elongation at failure are defined as ductile; while materials which exhibit small elongations at failure are defined as brittle. Ductility is a desirable attribute in container design since plastic deformation is allowable within limits. The main concern is protection of the contents rather than container cosmetic appearance.

**d. Hardness.** The hardness of a material is a general measure of yield and ultimate strength. In the context of container design, hardness also includes the attribute of resisting abrasion and small nicks–which may prove to be stress risers. A high hardness indicates good abrasion resistance, high strength, and low ductility. (Hardness was not included in the Evaluation Matrix because its relative importance seems slight.)

**e. Mass Density.** The weight of competing structural designs is dependent on the mass density. If weight is a factor in container selection then, of course, mass density is an important factor. The mass density is also important since it affects the dynamic response. For a specific design, it is found that the peak stress increases with increase in density. In order to reduce the dynamic stresses for a container of a single material, the lowest mass density should be used.

**f. Side Panel Center Deflection.** The side panel deflection is a function of both the material properties and the structural configuration and is, thus, a structural index which may be used to compare the relative stiffness of competing container designs. The center deflection for a uniformly loaded panel with simply supported edges is given by the following relationship:

$$w = \frac{\alpha G_0 a^4}{D}$$

where $\alpha$ is a parameter which accounts for aspect ratio

$G_0$ is the magnitude of the uniform load

a is the length of the longest side

w is the transverse deflection

$$D = \frac{Eh^3}{12(1-\gamma^2)}$$

where E is the modulus of elasticity

h is effective thickness

$\gamma$ is Poisson's ratio

The derivation of the equation is based on the assumption that the transverse deflection is small and that the material is linearly elastic. Deflections which are greater than approximately one-tenth the thickness are beyond the range of the theory; but, since the equation is used only in a comparative sense, deflection of any value is acceptable for the purpose of this study.

**g. Dynamic Impact Stress.** The panels of the containers are subject to dynamic loads which are not considered in the design standards. However, since a great deal of damage does appear to be the result of impact loads, it is important that a structural index be defined which provides a measure of the ability of the structure to respond to this type of load. A suitable structural index is the peak stress produced in the container wall due to the impact of a steel sphere having a given mass and initial velocity.[1]

The peak stress is found to be a function of the cross section, the modulus of elasticity, and the mass of the wall. The method of calculating this stress is also presented in Berger, et al.[2] which also presents a discussion of the computer code that

[1] S. Berger, H. G. Schaeffer, and J. P. Weis, *Container Development Concepts for Improved Resistance to the Dynamic Environment*, dated October 1971, AD 732491, prepared for the United States Army Mobility Equipment Research and Development Center, Fort Belvoir, Virginia, by Control Systems Research, Arlington, Virginia.

[2] *Ibid.*

is used. The analysis is based on the linear bending theory and small transverse deflections: and, while the calculated results may be outside the range of the theory in a quantitative sense, they can be used in a comparative sense.

h. **Preventive Maintenance.** Since preventive maintenance is constantly an area of concern, one must ask himself, "Can this container arrive at the far shore with the contents in acceptable condition?" Jostling, jolting, mishandling, and general environmental abuse tend to cause a degradation in the container's "like new" condition. With steels, one immediately addresses areas where the material has begun corroding. If this is a simple repair with little cost involved, the spot will be repaired. In the Evaluation Matrix, this factor is used to measure the ease in which a material behaves to maintenance and the inherent capability of the material to withstand weathering, for example, such that no preventive maintenance is required.

i. **Repairability.** When a container has sustained damage such that it no longer conforms to the ISO requirements dimensionally or to the shipper's own set of criteria for damage, it is deadheaded. Depending on the extent of damage, the container is either moved to a shop facility or a portable repair rig is sent to the container. The ease of repair is considered. Can the mechanic use a simple plug to repair a sidewall puncture or must he replace an entire panel? The question is addressed in a relative manner. Containers which experience little damage to start with are rated superior to those which have been found to exhibit high damage rates. The repairs for sidewalls differ dramatically. A fiber-glass patch, a welded steel patch, or a riveted aluminum patch for the same size hole takes different amounts of time, from a labor viewpoint, and the material used varies in price. Also, in each case, supporting equipments vary; and, again, this can be quite expensive.

j. **Corrosion Resistance.** Because the container walls are used mainly as a protective covering, their resistance to the environment, either operational or climatic, is imperative. Numerous materials have been addressed which are not affected by salt-water spray or the standing of water in sills or on the roof. The materials which have the inherent properties to fight the environment are rated superior. One obvious conclusion appears to be that low-carbon steel must be painted (this is standard practice in the commercial and military environments). Large users of the aluminum-type containers paint the containers an aluminum color.

k. **Flexibility.** This is a material property which addresses, specifically, modulus of elasticity times moment of inertia of the material divided into one:

$$FLEX = \frac{1}{EI} .$$

Originally used in sandwich panel areas of design, the final figure appears most appealing as it correlated quite well in the laboratory for materials other than foam or honeycomb sandwich. Thus, it was used throughout.

l. **Insulation Properties.** The unit heat conductance and thermal conductivity were addressed. As mentioned earlier, containers, especially those constructed of metal, can become extremely hot inside if left in the open sun. Allowing heat to pass easily could be a detriment to numerous goods. All the sandwich configurations faired extremely well. This would appear most logical because refrigerated containers use a great deal of sandwich construction in depths of section up to 6 inches. A simple dead-air space is most effective; and, when a steel or an aluminum container wall has a plywood liner, the wall then contains a dead air space. Thus, we have another strong reason for the incorporation of a plywood liner in a non-sandwich configuration.

m. **Workability.** Many materials are difficult to form, mold, extrude, or, in general, just fabricate. After fabrication, many materials become difficult to use because they are not amenable to welding, drilling, punching, or repairing without extra cost and loss of material integrity. One can readily deduce that corrugated steel is much easier to make and employ than aluminum on a foam sandwich or aluminum on a honeycomb sandwich. Therefore, the productivity of the wall is incorporated. Ease of repair and preventive maintenance are additional factors which are dependent on the workability of the material.

n. **Flame Resistance.** The military environment addresses flame retardancy and fireproofing in many of its equipments. The question posed in this effort was, "Does the panel support combustion?" The answer for all panels is "no." This answer should be qualified inasmuch as the metals, of course, became much more ductile; the plywood sandwich charred; and although the foam sandwich did not support combustion, the foam appeared to have melted, thus leaving a void under the aluminum or FRP skin. The resin in the fiber-glass reinforced plastic did not burn. The plastics in the expanded metal and punch plate materials tended to lose strength and began to flow.

o. **Joining.** An important concept in the fabrication and repair of a container is the method used to form an 8- by 20-ft wall. The fabricator buys smaller sized sheets and welds or rivets these together. The FRP/Plywood panel is, in reality, a series of 4- by 8-ft panels which are laminated with the fiber-glass to become a one-piece construction which is then sent to the fabricator. For this panel, the fabricator would then rivet the single unit to the frame. For sandwiches which are less than 4 by 8 ft in size the same principle holds—the idea of forming a 20-foot span. Sandwich panels other than FRP/Plywood are not made into a continuous panel but rather are joined mechanically.

**p. Usable Cubage.** In order to have a bench mark to work from, the author determined the usable cubage for a container neglecting liners and other obstructions. Since containers in the 20-foot class appear to be severely volume limited, this relative scoring allows the reader to select a configuration which he feels is acceptable even though it may not have the cubage of a second container. To the military, this parameter appears to rate quite low, while industry has been selecting the higher figures in order to make maximum use of the space available.

**q. Initial Cost/Sq Ft.** The cost of a panel on a per-square-foot basis essentially tells one that the frame and floor costs are constant. The relative scores show, to no surprise, that steel is the most inexpensive material initially, while the elaborate sandwich constructions cost a great deal. Costing has purposely been played down throughout this report because it is the author's belief that enough information has been presented to document the overall costs. Further, it is the author's belief that the competent manager will realize the fact that, in buying anything, there are life-cycle costs involved along with a general amortization and scrapage value pricing which must be considered. These and many more factors establish cost effectiveness. Many of the aforementioned areas of concern are directly related to costs. The best source of information in the particular area is Berger, et al.[3]

**12. Evaluation Matrix.** The Evaluation Matrix (Table I) has been developed in such a manner as to be readily utilized by the interested technical reader. The first vertical column has been established so that one may put a weighting factor on each of the different properties. For example, if one considers impact resistance and initial cost to be of equal and highest importance, he should enter a relative value of, for example, 25 in these leading boxes. The next item of importance could be weight or corrosion resistance; but feeling these to be less significant, one would assign, for example, a weighting factor of 15. Cubage might be considered to be of little importance and would receive a value of 1 or 2 versus the values of 15 and 25 previously assigned. Now, one can readily determine the optimum panel by multiplying the weighting factor by the scores in the matrix. The total score will yield a final value for each candidate material. The highest score achieved will thus give the best panel based upon the biases of the reader. The author feels that each organization has identified the areas of greatest concern; therefore, the organization should be allowed to select the parameters of greatest importance and thereby justify its material selection. For the example cited, the following is offered:

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[3]S. Berger, et al., *A Critical Analysis of the State of the Art in Containerization*, dated December 1970, AD 877259, prepared for the United States Army Mobility Equipment Research and Development Center, Fort Belvoir, Virginia, by Control Systems Research, Arlington, Virginia.

## Table 1. The Evaluation Matrix

| weighting factor | ATTRIBUTES / MATERIALS | Corrugated Steel .047 inches | Corrugated Steel .062 inches | Corten Steel | Muffler Steel | Martinsite Steel | Stainless Steel | Corrugated Aluminum .047 inches | Corrugated Aluminum .062 inches | Corrugated Aluminum .100 inches | Corrugated Aluminum .152 inches | Aluminum Sheet .1875 inches | Aluminum Sheet and Post | 24 ounce FRP Plywood 1/2 inch | 18 ounce FRP Plywood 1/2 inch | .5 inch Plywood Sandwich .040 Aluminum Facing | .5 inch Plywood Sandwich .040 Steel Facings | 24 ounce FRP Plywood 5/8 inch | 18 ounce FRP Plywood 5/8 inch | .625 inch Plywood Sandwich .040 Aluminum Facings | .625 inch Plywood Sandwich .340 Steel Facing | 24 ounce FRP Plywood 3/4 inch | 18 ounce FRP Plywood 3/4 inch | .75 inch Plywood Sandwich .040 Aluminum Facing | .75 inch Plywood Sandwich .040 Steel Facing | .75 inch Plywood Sandwich .040 Aluminum Face and .340 Steel Face |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Preventive Maintenance | 4 | 4 | 8 | 10 | 2 | 6 | 6 | 6 | 8 | 8 | 8 | 4 | 10 | 10 | 6 | 6 | 10 | 10 | 6 | 6 | 10 | 10 | 6 | 6 | 6 |
| | Repairability | 6 | 6 | 6 | 6 | 4 | 4 | 6 | 6 | 6 | 6 | 8 | 4 | 10 | 10 | 4 | 2 | 10 | 10 | 4 | 2 | 10 | 10 | 4 | 2 | 2 |
| | Corrosion Resistance | 4 | 4 | 6 | 8 | 4 | 10 | 8 | 8 | 8 | 8 | 8 | 6 | 10 | 10 | 8 | 6 | 10 | 10 | 8 | 6 | 10 | 10 | 8 | 6 | 8 |
| | Weight | 6.7 | 5.7 | 6.7 | 6.7 | 6.7 | 6.7 | 4.9 | 5.9 | 9.5 | 6.9 | 6.8 | 8 | 7.3 | 8.0 | 7.0 | 3.8 | 6.3 | 6.7 | 6.0 | 3.5 | 5.5 | 5.8 | 5.3 | 3.2 | 4 |
| | Flexibility | 2.3 | 1.9 | 2.3 | 2.3 | 2.3 | 10 | 4.5 | 4 | 2.9 | 2.2 | 10 | 2.4 | 9.1 | 10 | 5.8 | 2.5 | 6.6 | 7.2 | 3.6 | 2.2 | 5.1 | 5.5 | 2.8 | 1.3 | 2.1 |
| | Safety Factor Based On Ultimate Strength | 4.4 | 4.9 | 4.5 | 5 | 10 | 9.8 | 1.0 | 3.2 | 5.9 | 7.3 | 7.1 | 3.2 | 6.8 | 6.3 | 5.3 | 7.0 | 7.7 | 7.3 | 6.3 | 7.5 | 8.3 | 8.1 | 7.1 | 8.0 | 8.0 |
| | Impact Resistance | 1.1 | 2.4 | 2.1 | 1.0 | 5 | 7.4 | 1.0 | 4 | 7.8 | 7.8 | 4.3 | 2.4 | 5.6 | 5.6 | 4.3 | 3.1 | 5.6 | 5.6 | 3.9 | 3.1 | 5.6 | 5.6 | 3.9 | 2.4 | 2.1 |
| | Safety Factor Based On Yield Strength | 4.5 | 4.6 | 4.6 | 1.0 | 8.7 | 8.4 | 2.7 | 4.6 | 6.8 | 8.0 | 7.7 | 4.5 | 7.7 | 7.5 | 6 | 7.1 | 8.5 | 8.2 | 6.9 | 7.6 | 9 | 8.7 | 7.6 | 8.1 | 8.1 |
| | Insulation Properties ** | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.2 | 1 | 1 | 1.0 | 1.1 | 1.1 | 1 | 4.1 | 4 | 2.1 | 2.1 | 5 | 4.9 | 2.2 | 2.2 | 6.5 | 6.7 | 2.3 | 2.3 | 2.3 |
| | Modulus of Elasticity | 1 | 1 | 1 | 1 | 1 | 1 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 10 | 10 | 3.3 | 1 | 10 | 10 | 3.3 | 1 | 10 | 10 | 3.3 | 1 | 1.5 |
| | Deflection | 2.3 | 1.9 | 2.3 | 2.3 | 2.3 | 10 | 4.5 | 4 | 2.9 | 2.2 | 10 | 2.4 | 9.1 | 10 | 5.8 | 2.5 | 6.6 | 7.2 | 3.6 | 2.2 | 5.1 | 5.5 | 2.8 | 1.3 | 2.1 |
| | Workability | 10 | 8 | 10 | 10 | 6 | 8 | 8 | 8 | 8 | 8 | 8 | 6 | 10 | 10 | 8 | 6 | 10 | 10 | 6 | 6 | 10 | 10 | 6 | 6 | 4 |
| | Flame Resistance | 10 | 10 | 10 | 10 | 10 | 10 | 8 | 8 | 8 | 8 | 8 | 8 | 6 | 6 | 8 | 10 | 6 | 6 | 8 | 10 | 6 | 6 | 8 | 10 | 10 |
| | Joining | 10 | 10 | 8 | 8 | 8 | 6 | 8 | 8 | 8 | 10 | 8 | 6 | 10 | 10 | 8 | 6 | 8 | 8 | 8 | 6 | 8 | 8 | 8 | 6 | 6 |
| | Percent Elongation | 10 | 10 | 9.5 | 9 | 6.7 | 5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.8 | 1.8 | 5 | 9.5 | 1.8 | 1.8 | 5 | 9.5 | 1.8 | 1.8 | 5 | 9.5 | 9.5 |
| | Usable Cube | 5.6 | 5.6 | 5.6 | 5.6 | 5.6 | 10 | 5.6 | 5.6 | 5.6 | 5.6 | 9.3 | 2.4 | 8.4 | 8.6 | 8.6 | 8.6 | 7.8 | 7.9 | 8.0 | 8.0 | 7.2 | 7.3 | 7.4 | 7.4 | 7.4 |
| | Initial Cost | 10 | 9.3 | 8.8 | 4.4 | 6.8 | 2.7 | 6.3 | 5.6 | 4.0 | 2.9 | 3.5 | 5.4 | 4.4 | 4.6 | 1.7 | 1.5 | 4.3 | 4.5 | 1.7 | 1.5 | 4.3 | 4.4 | 1.6 | 1.5 | 1.6 |
| | Modulus of Rigidity | 10 | 10 | 9 | 9 | 10 | 10 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 1 | 1 | 3.8 | 9 | 1 | 1 | 3.8 | 9 | 1 | 1 | 3.8 | 9 | 9 |

A

## le 1. The Evaluation Matrix

| [illegible] | .625 inch Plywood Sandwich .040 Aluminum Facings | .625 inch Plywood Sandwich .040 Steel Facing | 24 ounce FRP Plywood 3/4 inch | 18 ounce FRP Plywood 3/4 inch | .75 inch Plywood Sandwich .040 Aluminum Facing | .75 inch Plywood Sandwich .040 Steel Facing | .75 inch Plywood Sandwich .040 Aluminum Face and .040 Steel Face | 2 inch Foam Sandwich 2 pound Density, .040 Aluminum Facings | 2 inch Foam Sandwich 2 pound Density, 24 ounce FRP Facings | 2 inch Foam Sandwich 4 pound Density, .040 Aluminum Facings | 2 inch Foam Sandwich 4 pound Density, 24 ounce FRP Facings | 1 inch Foam Sandwich 2 pound Density, .040 inch Aluminum Facings | 1 inch Foam Sandwich 2 pound Density, 24 ounce FRP Facing | 1 inch Foam Sandwich 4 pound Density, .040 inch Aluminum Facings | 1 inch Foam Sandwich 4 pound Density, 24 ounce FRP Facing | 2 inch Honeycomb Sandwich 2 pound Density, 24 ounce FRP Facings | 2 inch Honeycomb Sandwich 2 pound Density, .040 Aluminum Facings | 2 inch Paper Honeycomb Sandwich 4 pound Density, 24 ounce FRP Facings | 2 inch Paper Honeycomb Sandwich 4 pound Density, .040 Aluminum Facings | 1 inch Paper Honeycomb Sandwich 2 pound Density, 24 ounce FRP Facing | 1 inch Paper Honeycomb Sandwich 2 pound Density, .040 inch Aluminum Facings | Titanium .062 | Expanded Metal Steel and Plastic | Expanded Metal Aluminum and Plastic | Punched Plate Steel and Plastic | Punched Plate Aluminum and Plastic |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 6 | 6 | 10 | 10 | 6 | 6 | 6 | 4 | 6 | 4 | 6 | 4 | 6 | 4 | 6 | 5 | 4 | 4 | 4 | 5 | 4 | 6 | 10 | 10 | 10 | 10 |
| 10 | 4 | 2 | 10 | 10 | 4 | 2 | 2 | 2 | 4 | 2 | 4 | 2 | 4 | 2 | 4 | 2 | 2 | 4 | 2 | 2 | 2 | 1 | 4 | 4 | 4 | 4 |
| 10 | 8 | 6 | 10 | 10 | 8 | 6 | 8 | 8 | 10 | 8 | 10 | 8 | 10 | 8 | 10 | 10 | 8 | 10 | 8 | 10 | 8 | 10 | 10 | 10 | 10 | 10 |
| .7 | 6.0 | 3.5 | 5.5 | 5.8 | 5.3 | 3.2 | 4 | 8.2 | 7.6 | 9.9 | 9.5 | 7.2 | 6.6 | 8.2 | 7.6 | 7.6 | 8.2 | 9.5 | 9.9 | 6.6 | 7.2 | 10 | 6.8 | 9.4 | 4.2 | 8 |
| .2 | 3.6 | 2.2 | 5.1 | 5.5 | 2.8 | 1.3 | 2.1 | 1.0 | 2.4 | 1.0 | 2.4 | 2.9 | 5.6 | 2.9 | 5.6 | 2.4 | 1.0 | 2.4 | 1 | 5.6 | 2.9 | 2.5 | 2.5 | 5.2 | 4 | 7.6 |
| .3 | 6.3 | 7.5 | 8.3 | 8.1 | 7.1 | 8.0 | 8.0 | 8.1 | 8.7 | 8.1 | 8.7 | 7.0 | 6.1 | 5.9 | 7.2 | 8.7 | 8.1 | 8.7 | 8.0 | 7.2 | 7.0 | 5.9 | 9.2 | 8.9 | 8.2 | 7.5 |
| .6 | 3.9 | 3.1 | 5.6 | 5.6 | 3.9 | 2.4 | 2.1 | 1.1 | 8.1 | 1.1 | 5.0 | 3.4 | 5.6 | 3.4 | 5.6 | 8.1 | 1.1 | 5.3 | 3.8 | 5.6 | 3.4 | 5.1 | 8.4 | 7.9 | 10 | 8.2 |
| .2 | 6.9 | 7.6 | 9 | 8.7 | 7.6 | 8.1 | 8.1 | 8.4 | 9.3 | 8.4 | 9.3 | 7.6 | 7.3 | 6.5 | 8.2 | 9.3 | 8.4 | 9.2 | 8.5 | 8.2 | 7.6 | 10 | 9.2 | 9.1 | 8.0 | 8.0 |
| .9 | 2.2 | 2.2 | 6.5 | 6.7 | 2.3 | 2.3 | 2.3 | 10 | 10 | 10 | 10 | 9.6 | 9.6 | 9.6 | 9.6 | 10 | 10 | 9.8 | 9.8 | 9.1 | 9.1 | 1.5 | 1.6 | 1.6 | 1.6 | 1.6 |
| 10 | 3.3 | 1 | 10 | 10 | 3.3 | 1 | 1.5 | 3.3 | 10 | 3.3 | 10 | 3.3 | 10 | 3.3 | 10 | 10 | 3.3 | 10 | 3.3 | 10 | 3.3 | 2 | 1 | 3.3 | 1 | 3.3 |
| .2 | 3.6 | 2.2 | 5.1 | 5.5 | 2.8 | 1.3 | 2.1 | 1.0 | 2.4 | 1.0 | 2.4 | 2.9 | 5.6 | 2.9 | 5.6 | 2.4 | 1.0 | 2.4 | 1 | 5.6 | 2.9 | 2.5 | 2.5 | 5.2 | 4 | 7.6 |
| 10 | 6 | 6 | 10 | 10 | 6 | 6 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 6 | 8 | 10 | 6 | 6 | 8 | 10 | 10 | 4 | 6 | 4 | 6 | 4 | 6 | 4 | 6 | 4 | 4 | 4 | 4 | 4 | 4 | 10 | 2 | 2 | 2 | 2 |
| 8 | 8 | 6 | 8 | 8 | 8 | 6 | 6 | 4 | 6 | 4 | 6 | 2 | 4 | 2 | 4 | 4 | 2 | 6 | 4 | 4 | 2 | 2 | 8 | 6 | 10 | 8 |
| .8 | 5 | 9.5 | 1.8 | 1.8 | 5 | 9.5 | 9.5 | 5.0 | 1.8 | 5.0 | 1.8 | 5.0 | 1.8 | 5.0 | 1.8 | 1.8 | 5.0 | 1.8 | 5 | 1.8 | 5 | 5.0 | 10 | 5 | 10 | 5 |
| .9 | 8.0 | 8.0 | 7.2 | 7.3 | 7.4 | 7.4 | 7.4 | 1.1 | 1.0 | 1.0 | 1.0 | 6.1 | 5.9 | 6.1 | 5.9 | 1.0 | 1.0 | 1.0 | 1.0 | 5.9 | 6.1 | 5.6 | 9.0 | 9.0 | 9.0 | 9.0 |
| .5 | 1.7 | 1.5 | 4.3 | 4.4 | 1.6 | 1.5 | 1.6 | 1.6 | 1.4 | 1.3 | 1.1 | 1.9 | 1.7 | 1.5 | 1.4 | 1.1 | 1.3 | 1.0 | 1.2 | 1.4 | 1.7 | 1.0 | 1.6 | 1.4 | 1.6 | 1.4 |
| 1 | 3.8 | 9 | 1 | 1 | 3.8 | 9 | 9 | 3.8 | 1 | 3.8 | 1 | 3.8 | 1 | 3.8 | 1 | 1 | 3.8 | 1 | 3.8 | 1 | 3.8 | 5.9 | 10 | 3.8 | 10 | 3.8 |

Weight

25 Impact Resistance
25 Initial Cost
15 Weight
15 Corrosion Resistance
1 Cubage

With this rating, the top five materials for sidewalls are:

(1) Corrugated Aluminum, .100 in. thick
(2) Punched Plate Aluminum and Plastic
(3) Expanded Metal Aluminum and Plastic
(4) 18-ounce FRP/Plywood, ½ in. thick
(5) 24-ounce FRP/Plywood, ½ in. thick

The above materials have been determined by utilizing the following methodology:

(1) Multiply all scores in the row marked Impact Resistance by 25.
(2) Multiply all scores in the row marked Initial Cost by 25.
(3) Multiply all scores in the row marked Weight by 15.
(4) Multiply all scores in the row marked Corrosion Resistance by 15.
(5) Multiply all scores in the row marked Cubage by 1.

Now, for each material, go straight down the column adding the newly acquired scores. In this example, there are 5 scores to sum. (One can actually use all the parameters–thus, there will be 18 scores to add.) The total for each column having been attained, the material with the highest score ranks as number one, the second highest score yields the number two panel, and so on down the line through all 44 material choices.

The past narrative addresses the utilization of the Evaluation Matrix. The avid reader may wish to pursue the relative scores within the matrix. These were all obtained by normalizing a spread of values ranging, for example, from 82 to 901 with the lower score being best. It was then deduced from these data, for example, that a curve could be plotted (in most cases linear) such that 82 compared with 10, the highest score possible, and 901 compared with 1, the lowest score possible. From this curve, all intermediate values could immediately be determined. Some cases proved far more complicated, but a logarithmic plot offered a possibility to handle the range of values that occurs. In one case, for example, the fourth root of the numbers was taken so that the procedure described above could then be used. The most important thing to remember is that throughout the entire matrix the method was consistent. The scores shown are

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relative, but this is the only kind of meaningful figure the engineer or scientist can use in selection of an optimum panel for his particular application. It is felt that the Evaluation Matrix represents the true technical worth of this report and justifies all of the expenditures in the past. One is now able forthrightly to select a panel design which is most acceptable.

13. **Aluminum Alloys.** All the combinations of steel alloys and aluminum alloys were not presented in the Evaluation Matrix. Since steel has been sufficiently covered in the Evaluation Matrix and numerous aluminum alloys have been left unidentified, the following detailed discussion of these alloys is presented. The aluminum properties used in the matrix were average values; thus, the exact aluminum used is really a combination of several panels and cannot be identified in the Evaluation Matrix.

To clarify an apparent ambiguity, the Aluminum Matrix (Table II) identifies those properties which tend to change with the major alloying agents. The performance factors listed in the Aluminum Matrix appear to be the only ones which show a dramatic change. To review the aluminum alloy classifications in brief, the following is offered:

| Alloy Number | Major Alloying Element |
|---|---|
| 1000 | None |
| 2000 | Copper |
| 3000 | Manganese |
| 4000 | Silicon |
| 5000 | Magnesium |
| 6000 | Magnesium and Silicon |
| 7000 | Zinc |
| 8000 | Other Elements |

Noting the above, six readily available materials have been selected for use in the Aluminum Matrix. It is interesting to note that if the manufacturer of containers buys any of these materials in sufficient quantity the costs are all in the same general neighborhood.

The values obtained from this matrix follow closely the procedure outlined for the Evaluation Matrix. The Aluminum Matrix simply relates the most critical areas of variance. One can utilize this matrix to identify the aluminum which appears to best suit the user's purpose. (The Selected Bibliography contains a vast amount of information regarding these alloys.) However, one must stop and question the Aluminum Matrix. Earlier, it was mentioned that if aluminum were corrugated, much like steel, its performance attributes would definitely increase. Not all the materials identified in the Aluminum Matrix are amenable for forming as suggested due to the low ductility of some of the aluminum alloys. Thus, the shape of material, i.e., its vertical cross section, will vary.

A flat sheet does not require any forming, thus the rationale for aluminum sheet and post construction. However, from the Evaluation Matrix (Table I), one can readily see that this type of construction rates low when compared to the corrugated aluminum configuration.

Table II. Aluminum Matrix

| Attribute \ Aluminum Alloy | 7075 – T6 | 6061 – T6 | 5052 – H34 | 5090 – H38 | 3003 – H14 | 2014 – T6 |
|---|---|---|---|---|---|---|
| Impact Resistance | 10 | 4.5 | 2.8 | 8 | 1 | 7.8 |
| Safety Factor Based on Yield Strength | 10 | 4.5 | 2.8 | 8 | 1 | 7.8 |
| Safety Factor Based on Ultimate Strength | 10 | 4.2 | 1.8 | 7.5 | 1 | 8 |
| % Elongation | 3.5 | 8 | 1 | 1 | 10 | 4 |
| Workability | 5 | 7 | 6 | 6 | 8 | 4 |
| Corrosion Resistance | 5 | 9 | 10 | 10 | 10 | 3 |

## V. CONCLUSIONS AND REMARKS

14. **Conclusions and Remarks.** The narrative has presented a variety of insights into the construction and applicability of materials as related to use in a large dry freight shipping container. Also discussed were the attributes a container must present in order to cope with its environment. To synopsize the manuscript, a matrix has been prepared which presents numerous candidate materials versus a large number of significant parameters which tend to either influence the purchase of a specific configuration or to mathematically rate numerous quantitative data. The end result is a numerical ranking of the candidate sidewall materials based upon the author's best judgment for the nebulus design criteria and the results of extensive structural calculations for the design and material property type criterion.

Numerous immediate conclusions are readily apparent and are substantiated by the Evaluation Matrix. Other conclusions are established from the matrix and relevant references.

a. The current state of containerization is an ambiguous subject when one considers the numerous materials-design interrelationships along with the varied philosophies. Of all words used to describe container performance, "ruggedness" is the one key word which stands far above all others. The commercial carrier is currently paying for ruggedness because, in general, FRP/Plywood is being well received. Steel containers are being procured by the U. S. Government and, in very small quantities, by leasing corporations; however, it has been found that the leasing organizations have become stabilized to a point where they are procuring FRP/Plywood. Aluminum is being procured in a different configuration than the regular sheet and post. A container with a 0.1875 in. thick wall of corrosion-resistant aluminum has appeared on the market, and it is the author's understanding that this container is being well received.

b. A weight savings in the container appears to be a moot subject. The small containers (8 by 8 by 20 ft) are found in 90% of the cases investigated to be cube-limited rather than weight-limited. Thus, the trend is to the longer 40-foot container with a gross load of 67,200 pounds. For a doubling of allowable usable cube, the allowable gross weight increases by one-half. If one were to find container weight a significant factor, it would seemingly appear as an important design consideration in the longer containers; but, as of this writing, lightness of weight has not been found. The operator will not compromise his principles--he wants a rugged container no matter what the size or configuration may be.

c. National, international, and military standards attempt to identify the loading conditions which must be resisted in service. These documents have been severely criticized by the author as not being representative of the real situation. Efforts made to check the adequacy of these standards showed that one true discrepancy exists. This is the criteria for the end wall. In this case, the majority of standards miss by a factor of approximately four. It is interesting to note that in the majority of current container designs additional material has been added to absorb the impulsively applied loadings. On the other hand, the specifications for the sidewall appear adequate. For example, in a rough sea state on the North Atlantic, one ship being monitored registered sidewall loadings of less than the required test criteria of .6g. The loadings at sea were, of course, dynamic. A strong case can be made for the current specifications requiring numerous static-loading-type tests. However, over the long haul, a dynamic testing procedure will undoubtedly prove to be superior.

d. Sandwich-type materials clearly tend to have an advantage over aluminum or steel sheet. The heat-transfer characteristics of a sandwich with a foam core of 2 inches rate as much as 1000 times better in allowing heat to transfer from the outside to the inside when compared to the basic sheet material. It must be realized that in the tropical or desert environment the containers eventually behave as ovens and could, therefore, be detrimental to the stored goods. On impact, the sheet can be punctured easily. The same sheet backed by foam or honeycomb and another skin is obviously much stronger. The ideal sandwich has not been identified; however, 0.040 in. aluminum on 2-inch foam with 0.040-in. aluminum as the inside face faired well in test. FRP/Plywood is a sandwich that has faired well in all tests. This is not to say that this particular sandwich is an optimum, but it does appear to exhibit characteristics which are most acceptable.

e. The integration of all structural members into a more unified structure would lead to weight savings and improved damage resistance. The matter of various bottom members is only one case in point. The possibility exists that a design could evolve which integrates all panels, rails, and other structural members to provide a total container with adequate bending resistance while being handled and at the same time to allow the panels enough weight, moment of inertia, etc. to resist handling abuse. An excellent example of this is a controlled filament winding or rotomolding process which tends, for the most part, to satisfy the above requirements. Additionally, these processes reduce manpower costs because the assembly line could be fully automated.

f. Containers should be designed to meet a given set of requirements rather than the present practice of evolution, i.e., value engineering of a current design which may have basic inadequacies. If rational design techniques were used, then one could immediately determine areas of maximum stress and design to meet these. One could effectively reduce expenditures by employing design shapes of less weight and strength where deemed desirable. If the military were to undertake the task of designing a true military container, there is no question that industry would follow and procure much the same article especially if the two groups value the same performance. It must be realized that the sophisticated companies, i.e., those with a great deal of experience, have outstanding handling facilities; and the need for the most durable container decreases as the amount of refined handling gear increases. The military lacks refined equipments that address containerization and must, therefore, pay the price for a very rugged, maintenance-free container.

g. Procurement of containers with sandwich sidewalls along with the standard aluminum and steel has provided USAMERDC with data to formulate many of the opinions offered. Much has been learned in the additional investigation of materials and design. Highlighted have been those areas which consistently rated superior. For example, if a container wall is not a one-piece construction, the wall does not behave as well as would be desired. The sandwich construction had the inherent design plan of being multipieced. FRP/Plywood of multipiece construction was found to be very poor in service whereas the one-piece siding rated superior. The design-material interrelationship for FRP/Plywood has been proven to be critical. The designer must consider not only the material behavior but also its relationship with a framework and the dynamic environment in general.

h. The work performed herein addressed shipping containers which were at least 20 feet in length. If a smaller configuration is considered, for instance a TRICON (8- by 8- by 6-2/3-ft) container, one must realize that the design material relationship differs because the walls no longer behave as in the larger container. From a design point of view, the TRICON is a box and not a container. One must select a material for a TRICON siding which will best serve the purpose of the container. In most cases, a strong argument can be made for the material which is of least cost. Clearly, steel would appear to have an advantage, but new materials innovations allow the designer to examine expanded wiremesh with a plastic-type covering. Certainly, prior to a major procurement, all innovative ideas must be considered. The intangibles which may exist in the large containers are eliminated in the box. For example, fork tine puncture would appear to be a major source of damage; and, rather than adding extra material to the entire wall, the area about the tineway slots should be addressed. Loadings on the smaller boxes are not the same as those found in larger structures. The modules when coupled or nested either transmit loadings more effectively or, in the case of nesting, do not experience the same loadings as the large dry freight shipping container.

i. A computer program now exists for the dynamic comparison of materials. An impacting sphere is used in the simulation. Within the program is the capability to vary the sphere's mass and impacting velocity. The results appear to be accurate throughout the elastic range for all isotropic materials. Anisotropic materials also appear to have been modeled effectively so that firm conclusive results can be obtained. An experimental effort is currently in progress to determine the validity of the computer program for numerous sandwich materials. The results of this simulation have tended to place FRP/Plywood and expanded metals in a superior category when compared to the standard aluminum and steel panels. The preliminary experimental results have justified this position and ranking.

j. The military environment is substantially different than that of the commercial. This immediately implies that containers procured for use solely within the military environment must meet criteria which are more stringent than the ISO recommendations. Specifically, the framework must address the logistical system employed today. With acknowledged shortcomings, such areas as corner fittings, upper rails, sidewalls, doors, door framework, endwalls, and transverse rails must be upgraded. This will reduce maintenance costs and should relate well to the handling environment over-the-beach or at inland depots where proper handling gear is not currently available. To address the military's entire capability, a select number of containers should be used within present-day aircraft without need for 463L pallets. The container should be locked directly into the aircraft's restraining system and be required to meet requirements which are realistic. Much work should be undertaken to adequately describe the air transport environment. If light weight is the one overriding area of consideration, this should be substantiated; and the design can accommodate this criterion.

k. No attempt was made to numerically rate the several container designs. The relative importance of the design attributes is a management decision. Thus, a column has been provided on the Evaluation Matrix so that the reader may assign his own weight and, thereby, perform his own evaluation. (Reference is also made to the numerical example presented in Section IV where relative values were selected and utilized.)

l. Generally speaking, it is seen that the impact resistance of designs which incorporate walls made from material having a low modulus of elasticity shows better performance. Other attributes which lead to a higher performance rating are:

(1) Low panel weight
(2) High cross sectional moment of inertia
(3) High yield stress

It can be seen from Table I that the designs which incorporate FRP as a face sheet material give a high performance index. Other attractive materials include the punch and expanded plate. These materials incorporate a low modulus face sheet which undergoes large deformation and thus attenuates the contact force and the resulting stress. It is an anomaly that the steel material, with a superior rating to that of aluminum considering the density of steel compared to aluminum, is expected to lead to the opposite results. Since the present investigation was to use available information, no effort was made to identify the mechanical reason for this behavior.

m. The highest performance numbers associated with factors of safety result from configurations which have low working stress and high yield or ultimate strengths. It is seen that the sandwich panels with steel, fiber-glass, or aluminum facings all rate well and give entirely satisfactory safety factors. Of noteworthy significance is the fact that Martinsite, stainless steel, and the expanded steel rate highest in the safety factors based on ultimate strength; and titanium, expanded metals, and 2-inch-thick foam and honeycomb sa iches with FRP facings rate quite well in the safety factor based upon yield strength.

n. The highest performance parameters are associated with the configurations which have a high flexibility and an attendant large center deflection. Since the impact resistance of the configuration is enhanced by high flexibilities, the judgment was made that large deflection was a positive attribute. The reader who disagrees can reverse the ranking by subtracting the value given in the Evaluation Matrix from eleven which will then rate small deflection as the desired attribute.

o. The highest ratings associated with elongation were given to those materials with a high elongation which is indicative of the ability to absorb energy through plastic deformation. High ratings are thus given to the ductile metals which exhibit large elongation while the configurations utilizing FRP face sheets rate relatively low. This rating obviously does not account for the ability of sandwich cores to crush and absorb energy. Because of the difficulty of including this important effect in this performance parameter, it is felt that a low weighting factor, relative to the other panel attributes, should be given to elongation in evaluating potential design configuration

p. Military Specification MIL-C-52661(ME) should be scrutinized for possible changes with respect to the following areas:

(1) Restraint System: Without question, this area must be addressed since the mechanical restraint system, as currently employed, does not address, satisfactorily, FRP/Plywood or aluminum sided containers. The specification is biased in this regard.

(2) Walls: The side and end walls are critical areas for failure due to dynamic loadings. The static criteria is not capable of producing a container which is applicable to the military environment. Dynamic criteria must be established, especially for the end wall.

q. If the lowest bidding type of procurement must remain, then the Military Specification should be changed to reflect a preference for the FRP/Plywood panel material. The materials currently being utilized in containerization should be changed. Innovative procedures have evolved which yield a superior container, but current procurement practices do not allow potential offerors to quote since the Military Specification is biased toward steel.

r. Aluminum sheet and post constantly faired poorly; however, the new aluminum sheet construction offers promise. Also, the high ratings for stainless steel must be acknowledged. To up-grade the military's capability to procure quality end items, the steel unit as it currently exists must be disregarded in favor of corrosion resistant steels with a greater wall thickness. The punched plate and expanded metal plates with plastic face sheets and filler result in a very low modulus material at the outermost position of the material combination. For impact resistance this is excellent.

s. The above addresses actions which should be initiated in the near future through FY 77. During the next few years, capabilities of manufacturing containers may have changed to a point where new and different materials will prove to be cost-effective. Thus, although the answer to today's current containerization problem is at hand, that is, procurement and utilization of FRP/Plywood containers, it may be that this particular container may not be the most cost-effective in 5 years.

t. Impact resistance has to be accommodated satisfactorily. Usable cube must also be addressed. The standard 20-foot configuration must be re-evaluated to determine if this truly represents the type of container the military requires. It is severely cube limited. Noting the types of container vessels currently in service, another length dimension does not appear to be unreasonable.

u. FRP/Plywood containers should be considered in the refrigerated mode of transport. This panel faired favorably with the currently preferred foams and honeycomb sandwich-type construction. If doubt exists, the reader should use the Evaluation Matrix and weight each factor appropriately. This material certainly appears to be a universal type which deserves further consideration.

v. Ammunition containers are by no means special because they currently comprise over 50 percent of the available military container inventory. Thus, noting this most important fact, the military should consider heavier gauged steels, stainless steel, punched plate, expanded metals, and FRP/Plywood. The latter should not be addressed without an acceptable restraint system in the floor. Restraint bars on the sidewalls of FRP/Plywood are seemingly most impractical. A thorough design analysis, however, could be conducted for little expenditure of funds when one considers the total dollar value of a procurement of containers.

w. The military at the far shore will have a large surplus of empty containers. With this fact realized, there appears to be little reason why usage by the troops cannot be addressed. The U. S. Navy in their Tactical Container Shelter System (TACOSS) or

Quick Camp programs address usage by military personnel as well as the U. S. Air Force in their Bare Base efforts. Thus, if the container were to be utilized as a protective unit, for example, the military has an obligation to make its containers readily adaptable for field usage.

x. Shelters, much like refrigerated containers, appear to address like materials. The modulus of rigidity is most important in sandwich panel construction, and the illustrative efforts in this report tended to over-emphasize this attribute. However, additional computer runs, which have not been presented, indicate a strong tendency toward the same materials as those identified with refrigerated containers. Thus, to those individuals involved with shelter work, it appears again that specifications which are essentially antiquated are being used by the modern-day services. These should be severely critiqued such that new sandwich materials can be addressed and evaluated through a small research and development effort. Again, the computer program should be employed using weighting factors which appeared to be most appropriate to shelter design in order to identify materials.

y. To specifically address the initial two directives posed, the following suggestions are offered:

(1) It is most advisable to consider a material other than low grade carbon steel for sidewalls in dry freight shipping containers.

(2) It is most advisable to consider materials other than steel for the entire container except the superstructure, undercarriage and corner fittings which should remain steel or comparable high-strength metals.

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## APPENDIX

### A SAMPLING OF RESULTS OBTAINED FROM THE EVALUATION MATRIX AND A DISCUSSION ON THE UTILIZATION OF THE PROGRAM

The following are representative results obtained from the Evaluation Matrix and the total of all the author's efforts in trying to obtain a solution to a most ambiguous problem. The weighting factors employed were all normalized to a common base, percentage-wise; thus, if the figure 25% is used, the reader should immediately say to himself, "In this particular case, utilizing all 18 parameters the author has deemed one particular criteria as being worth 25% of the total; thus, the 17 other criteria are, in total, worth 75%."

a. DRY FREIGHT CARGO CONTAINERS

(1) CASE I

Weightings for the attributes are as follows:

| | |
|---|---|
| Impact resistance | 20% |
| Flexibility | 7.69% |
| Safety factor based on yield | 7.69% |
| Modulus of elasticity | 7.69% |
| Deflection | 7.69% |
| Usable cube | 7.69% |
| Repairability | 6.15% |
| Corrosion Resistance | 6.15% |
| All Others | negligible |

RESULTS: FRP/Plywood in all thicknesses and weights of fiber glass along with stainless steel rated above the 85th percentile. Aluminum sheet, punched plates, and expanded metals were above the 70th percentile; and, the majority of other sandwich materials along with the steel configurations rated below the 50th percentile along with the aluminum sheet and post construction.

(2) CASE II

Weightings for the attributes are as follows:

| | |
|---|---|
| Impact resistance | 20.37% |
| Usable cube | 20.37% |
| Flexibility | 6.17% |

| | |
|---|---|
| Safety factor based on yield | 6.17% |
| Modulus of elasticity | 6.17% |
| Deflection | 6.17% |
| Repairability | 4.94% |
| Corrosion Resistance | 4.94% |
| Initial Cost | 4.94% |
| Safety factor based on ultimate | 4.32% |
| All others | negligible |

RESULTS: FRP/Plywood in all thicknesses and weights of woven roving, stainless steel, and the two punched-plate configurations rated above the 85th percentile. The expanded metals and aluminum sheet rated above the 70th percentile. The foam and honeycomb sandwich construction with FRP facings rated above the 50th percentile along with the numerous aluminum designs except aluminum sheet and post. The steel configurations rated poorly.

(3) CASE III

Weightings for the attributes are as follows:

| | |
|---|---|
| Impact Resistance | 20.34% |
| Initial Cost | 20.34% |
| Flexibility | 5.81% |
| Safety factor based on yield | 5.81% |
| Modulus of elasticity | 5.81% |
| Deflection | 5.81% |
| Usable cube | 5.81% |
| Corrosion resistance | 4.65% |
| Repairability | 4.65% |
| Safety factor based on ultimate | 4.07% |

RESULTS: FRP/Plywood with a variable thickness and weight of fiber glass dominates above the 85th percentile. Aluminum sheet, punched plates, and the expanded metals rated above the 70th percentile. Steel, aluminum, and numerous sandwich constructions with FRP facings rated above the 50th percentile. Sandwich configurations with metal skins faired poorly.

(4) CASE IV

Weightings for the attributes are as follows:

| | |
|---|---|
| Impact Resistance | 20% |
| Usable Cube | 20% |
| Initial Cost | 20% |
| Safety factor based on yield | 4% |

| | |
|---|---|
| Modulus of elasticity | 4% |
| Deflection | 4% |
| Flexibility | 4% |
| All others | negligible |

RESULTS: FRP/Plywood with the various thicknesses and weights of fiber glass, stainless steel, and the two punched-plate configurations rated above the 85th percentile. Martinsite steel, the two expanded metals, and corrugated aluminum (0.100 in. thick) rated above the 70th percentile. The steels, 1-in. thick foam and honeycomb sandwiches, and plywood in various thicknesses with aluminum facings rated above the 50th percentile. The thicker sandwich constructions faired poorly along with the aluminum sheet and post design.

(5) CASE V

Weightings for the attributes are as follows:

| | |
|---|---|
| Impact Resistance | 16.76% |
| Usable cube | 8.38% |
| Safety factor based on yield | 7.26% |
| Flexibility | 6.70% |
| Initial cost | 6.70% |
| Deflection | 6.70% |
| Safety factor based on ultimate | 6.14% |
| All others | negligible |

RESULTS: FRP/Plywood in all thicknesses and weights of fiber-glass facings along with stainless steel rated above the 85th percentile. The two punched plates and expanded metals plus the aluminum sheet rated above the 70th percentile. The sandwich constructions with FRP facings and the corrugated aluminum designs rated above the 50th percentile. The sandwiches with aluminum skins and the steel designs faired poorly.

b. REFRIGERATED CONTAINERS

(1) CASE VI

Weightings for the attributes are as follows:

| | |
|---|---|
| Insulation properties | 19.9% |
| Preventive maintenance | 14.9% |
| Flame resistance | 11.9% |
| Modulus of Elasticity | 7.5% |
| Safety factor based on ultimate | 7.5% |
| Corrosion resistance | 7.5% |

All others ........................................................................negligible

RESULTS: Two-inch foam sandwiches, 2- and 4-pound density with FRP facings, and all FRP/Plywood panels rated above the 90th percentile. One-inch foam sandwiches, 2- and 4-pound density with FRP facings and 2-inch honeycomb sandwiches with aluminum (0.040 in. thick) and FRP facings. 2-pound density cores rated above the 75th percentile. All other sandwich configurations except plywood with metal facings rated above the 50th percentile. The metals faired poorly.

(2) CASE VII

Weightings for the attributes are as follows:

Insulation properties ..............................................................16.6%
Initial cost ........................................................................16.6%
Preventive maintenance ............................................................12.4%
Flame resistance ....................................................................10.0%
Corrosion resistance ................................................................ 6.2%
Safety factor based on ultimate ................................................ 6.2%
Safety factor based on yield ..................................................... 6.2%
Modulus of Elasticity ................................................................ 6.2%
All others ........................................................................negligible

RESULTS: FRP/Plywood in all varieties rated above the 90th percentile. Two-inch foam sandwiches with 2- and 4-pound density cores and FRP facings rated above the 75th percentile. One-inch foam sandwiches with 2- and 4-pound density cores, 2-inch paper honeycomb with 2- and 4-pound density cores, and 1-inch paper honeycomb with a 2-pound density core, all with FRP facings, rated above the 50th percentile.

(3) CASE VIII

Weightings for the attributes are as follows:

Initial cost ........................................................................25.83%
Insulation properties ..............................................................14.76%
Preventive maintenance ............................................................11.07%
Flame resistance .................................................................... 8.86%
Corrosion resistance ................................................................ 5.54%
Safety factor based on ultimate ................................................ 5.54%
Safety factor based on yield ..................................................... 5.54%
Modulus of elasticity ................................................................ 5.54%
All others ........................................................................negligible

RESULTS: FRP/Plywood in all configurations rated above the 90th percentile. No materials rated above the 75th percentile except those just mentioned. The sandwich materials discussed in Case VII, corrugated steel (0.047 and 0.062 in. thick), and Corten steel rated above the 50th percentile. The punched plates, expanded metals, and plywood with metal facings faired poorly.

c. AMMUNITION CONTAINERS

(1) CASE IX

Weightings for the attributes are as follows:

| | |
|---|---|
| Impact resistance | 16.8% |
| Flame resistance | 16.8% |
| Safety factor based on yield | 8.4% |
| Workability | 7.6% |
| Safety factor based on ultimate | 7.6% |
| Joining | 6.7% |
| Percent elongation | 6.7% |
| Repairability | 5.9% |
| Modulus of rigidity | 5.0% |
| All others | negligible |

RESULTS: Stainless steel rated solely above the 85th percentile. All the various configurations of FRP/Plywood, punched plate (steel), aluminum sheet, corrugated aluminum (0.100 and 0.152 in. thick), and all the steels except muffler grade rated above the 70th percentile. All plywood cores with metal facings, expanded metals, punched plate, and titanium rated above the 50th percentile. Aluminum sheet and post rated under the 30th percentile.

(2) CASE X

Weightings for the attributes are as follows:

| | |
|---|---|
| Impact resistance | 14.6% |
| Initial cost | 14.6% |
| Flame resistance | 14.6% |
| Safety factor based on yield | 7.3% |
| Safety factor based on ultimate | 6.6% |
| Workability | 6.6% |
| Joining | 5.8% |
| Percent elongation | 5.8% |
| Repairability | 5.1% |
| All others | negligible |

RESULTS: All steels, except muffler grade, and ½ inch thick plywood with FRP facings rated above the 90th percentile. The rest of the FRP/Plywood panels rated above the 85th percentile. Steel punched plate, aluminum sheet, and the corrugated aluminum (0.100 and 0.152 in. thick) rated above the 70th percentile. The remaining expanded metals and punched plate along with plywood clad with metal rated above the 50th percentile. The remaining sandwiches rated lowest.

(3) CASE XI

Weightings for the attributes are as follows:

| | |
|---|---|
| Initial cost | 25.48% |
| Impact resistance | 12.74% |
| Flame resistance | 12.74% |
| Safety factor based on yield | 6.37% |
| Safety factor based on ultimate | 5.73% |
| Workability | 5.73% |
| Joining | 5.1% |
| Percent elongation | 5.1% |
| All others | negligible |

RESULTS: All steels except muffler grade rated above the 85th percentile. Corrugated aluminum (0.100 in. thick) and all FRP/Plywood panels rated above the 70th percentile. All other corrugated aluminums, plywood clad with aluminum or steel in all thicknesses, steel expanded metal, and steel punched plate rated above the 50th percentile. The remaining sandwich materials faired poorly.

d. SECONDARY USAGE

(1) CASE XII

Weightings for the attributes are as follows:

| | |
|---|---|
| Preventive maintenance | 9.01% |
| Safety factor based on yield | 9.01% |
| Insulation properties | 9.01% |
| Flame resistance | 9.01% |
| Usable cube | 9.01% |
| Joining | 8.10% |
| Repairability | 7.21% |
| Corrosion resistance | 7.21% |
| Workability | 7.21% |
| All others | negligible |

RESULTS: FRP/Plywood in all the various combinations rated above the 85th percentile. Aluminum sheet rated above the 70th percentile. The majority of the panels excluding foam and honeycomb sandwich and aluminum sheet and post rated above the 50th percentile.

(2) CASE XIII

Weightings for the attributes are as follows:

| | |
|---|---|
| Initial cost | 25.34% |
| Usable cube | 6.85% |
| Preventive maintenance | 6.85% |
| Safety factor based on yield | 6.85% |
| Insulation properties | 6.85% |
| Flame resistance | 6.85% |
| Joining | 6.16% |
| All others | negligible |

RESULTS: FRP/Plywood in all the various configurations, corrugated steel (0.047 and 0.062 in. thick), and Corten steel rated above the 85th percentile. Aluminum sheet, stainless steel, and Martinsite steel rated above the 70th percentile. Muffler grade steel and all corrugated aluminum designs rated above the 50th percentile. A large number of other panels rated in the 40 to 50 percentile region with few rating poorly.

e. SHELTERS

(1) CASE XIV

Weightings for the attributes are as follows:

| | |
|---|---|
| Modulus of rigidity | 30.77% |
| Insulation properties | 7.69% |
| Modulus of elasticity | 7.69% |
| Safety factor based on ultimate | 6.15% |
| Impact resistance | 6.15% |
| Deflection | 5.38% |
| Flexibility | 5.38% |
| Safety factor based on yield | 5.38% |
| All others | negligible |

RESULTS: Stainless steel rated superior and was the only material over the 85th percentile. Martinsite steel, steel expanded metal, and steel punched plate rated above the 70th percentile. The remaining steels, metal clad plywood in all thicknesses, and the aluminum sheet rated above the 50th percentile. Numerous sandwich materials rated between the 40th and 50th percentile.

(2) CASE XV

Weightings for the attributes are as follows:

Modulus of rigidity ........................................................................14.92%
Preventive maintenance ............................................................ 7.46%
Repairability ............................................................................ 7.46%
Impact resistance ..................................................................... 7.46%
Insulation properties ................................................................ 7.46%
Modulus of elasticity ................................................................ 7.46%
Usable cube ............................................................................. 7.46%
All others ............................................................................negligible

RESULTS: All FRP/Plywood configurations, stainless steel punched plate, and steel expanded metal rated above the 85th percentile. Aluminum sheet rated above the 70th percentile. The remaining steels, corrugated aluminums, metal clad plywood in all thicknesses, and aluminum expanded metal rated above the 50th percentile.

(3) CASE XVI

Weightings for the attributes are as follows:

Initial cost ...............................................................................25.00%
Modulus of rigidity ...................................................................25.00%
Modulus of elasticity ................................................................ 5.68%
Insulation properties ................................................................ 5.68%
Safety factor based on ultimate ................................................ 4.55%
Impact resistance ..................................................................... 4.55%
All others ............................................................................negligible

RESULTS: All steels except muffler grade rated above the 85th percentile. No materials rated above the 70th percentile. Muffler grade steel, steel expanded metal, steel punched plate, and all FRP/Plywood configurations rated above the 50th percentile. As in numerous cases before, the majority of the sandwich configurations rated between the 40th and 50th percentile.

The above 16 cases which were run using the enclosed computer program (see Annex) cover a multitude of areas, and the interested reader can readily see how the weighting factors can be altered depending upon the type of container or shelter being addressed. These examples are by no means the final product, especially in the area of shelter design. This program was presented, however, to show that the Evaluation Matrix can be utilized for that particular configuration.

For the reader to use this short program as listed, it is only necessary to first read in the Evaluation Matrix which the author has entitled "ZWOL." To enter this correctly, the 44 values listed after each attribute should be key punched by entering the first value for preventive maintenance in column 2 of the data card. After the number is written, follow it immediately with a comma; then, continue with the next number, and so on until the first line approaches column 72, the last usable column. If the row of numbers ends at column 68 be sure to place a comma and go to the next card again starting in column 2. Repeat this until the last number of the 44 is reached, and follow that number with a comma. Now, go to the next card and begin entering the second row of data as described above. Continue until all the rows have been punched onto the data cards. The last number should be followed by a comma. On completion of this exercise, the Evaluation Matrix is now ready to be entered. The author utilized the CDC 6600 computer; however, the above should hold for other computers. To enter the weighting factors, one goes first to the Evaluation Matrix and enters a value for each attribute. Thus, one has 18 values to enter. This data is entered differently. In columns 2 through 9 of the data card, enter the following: $WGHT B = . In column 11, write the first weighting factor followed by a comma. Continue until column 72 is approached where the last entry should be a comma, and then proceed to the next card starting a new number in column 2 until all the weighting factors are entered. Now, instead of ending this row with a comma, the following symbol should be entered immediately after the last number: $ . To enter a second or third or however many sets of weighting factors, continue to follow the above. In one operation, the user can obtain the relative rankings for any number of combinations or variations of weighting factors. From this, one can obtain his own conclusions. If questions exist, an individual at your computational facility can readily assist in running this program.

One of the author's major goals is that this document can and will be used by the reader as a tool to justify materials of construction.

## ANNEX TO APPENDIX

### • ENTIRE PROGRAM LISTING

```
      PROGRAM ARMY(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      DIMENSION A(44,18), B(18), C(44), D(44,7), IJ(44)
      NAMELIST /ZWCL/A/WGHT/B
      READ(5,3000) ((D(I,J), J=1,7),I=1,44)
 3000 FORMAT(A2,6A10)
      READ(5,ZWCL)
      WRITE(6,ZWCL)
    1 READ(5,5000)
      READ( 5,WGHT)
      WRITE(6,WGHT)
 5000 FORMAT(72H
     +                  )
      WRITE(6,6000)
 6000 FORMAT(1H1)
      WRITE(6,5000)
      DO 3 I=1,44
      SUM=0.
      DO 2 J=1,18
    2 SUM=SUM+A(I,J)*B(J)
    3 C(I)=SUM
      WRITE(6,6001)
 6001 FORMAT(1H0,* RANK*,6X,*SCORE*, 5X, *DESIGN NUMBER AND DESIGN CONCE
     1PT*, /)
      DO 5 I=1,44
    5 IJ(I) = I
   10 IFLAG= 10
      DO 20 I= 1,43
      IF(C(IJ(I)).GE.C(IJ(I+1))) GO TO 20
      M = IJ(I+1)
      IJ(I+1) = IJ(I)
      IJ(I) = M
      IFLAG = 1
   20 CONTINUE
      IF(IFLAG.EQ.1) GO TO 10
      DO 4 I=1,44
    4 WRITE(6,6002) I, C(IJ(I)), (D(IJ(I),J),J=1,7)
 6002 FORMAT(3X,I2,2X,E12.5,3X,A2,3X,6A10)
      GO TO 1
      END
```

1CORRUGATED STEEL 0.047 IN.(STANDARD)

2CORRUGATED STEEL 0.062 IN.

3CORTEN STEEL

4MUFFLER GRADE STEEL

5MARTINSITE STEEL

6STAINLESS STEEL

7CORRUGATED ALUMINUM 0.047 IN.

8CORRUGATED ALUMINUM 0.062 IN.

9CORRUGATED ALUMINUM 0.100 IN.

10CORRUGATED ALUMINUM 0.152 IN.

11ALUMINUM SHEET 0.1875

12ALUMINUM SHEET AND POST (STANDARD)

1324 OUNCE FRP/PLYWOOD-1/2 IN.

1418 OUNCE FRP/PLYWOOD-1/2 IN.

151/2 IN. PLYWOOD SANDWICH - 0.040 AL FACINGS

161/2 IN. PLYWOOD SANDWICH - 0.040 ST FACINGS

1724 OUNCE FRP/PLYWOOD - 5/8 IN.

1818 OUNCE FRP/PLYWOOD - 5/8 IN.

195/8 IN. PLYWOOD SANDWICH - 0.040 AL FACINGS

205/8 IN. PLYWOOD SANDWICH - 0.040 ST FACINGS

2124 OUNCE FRP/PLYWOOD - 3/4 IN. (STANDARD)

2218 OUNCE FRP/PLYWOOD - 3/4 IN.

233/4 IN. PLYWOOD SANDWICH - 0.040 AL FACINGS

243/4 IN. PLYWOOD SANDWICH - 0.040 ST FACINGS

253/4 IN. PLYWOOD SANDWICH - 0.040 AL FACE, 0.040 ST FACE

262 IN. FOAM SANDWICH 2 LB DENSITY - 0.040 AL FACINGS

272 IN. FOAM SANDWICH 2 LB DENSITY - 24OZ FRP FACINGS

282 IN. FOAM SANDWICH 4 LB DENSITY - 0.040 AL FACINGS

292 IN. FOAM SANDWICH 4 LB DENSITY - 24OZ FRP FACINGS

301 IN. FOAM SANDWICH 2 LB DENSITY - 0.040 AL FACINGS

311 IN. FOAM SANDWICH 2 LB DENSITY - 24OZ FRP FACINGS

321 IN. FOAM SANDWICH 4 LB DENSITY - 0.040 AL FACINGS

331 IN. FOAM SANDWICH 4 LB DENSITY - 24OZ FRP FACINGS

342 IN. HONEYCOMB SANDWICH 2 LB DENSITY - 24OZ FRP FACINGS

352 IN. HONEYCOMB SANDWICH 2 LB DENSITY - 0.040 AL FACINGS

362 IN. HONEYCOMB SANDWICH 4 LB DENSITY - 24OZ FRP FACINGS

372 IN. HONEYCOMB SANDWICH 4 LB DENSITY - 0.040 AL FACINGS

381 IN. HONEYCOMB SANDWICH 2 LB DENSITY - 24OZ FRP FACINGS

391 IN. HONEYCOMB SANDWICH 2 LB DENSITY - 0.040 AL FACINGS

40TITANIUM 0.062 IN.

41EXPANDED METAL STEEL AND PLASTIC

42EXPANDED METAL ALUMINUM AND PLASTIC

43PUNCHED PLATE STEEL AND PLASTIC

44PUNCHED PLATE ALUMINUM AND PLASTIC

```
$ZWOL    A=
4.0,4.0,8.0,10.0,2.0,6.0,6.0,6.0,8.0,8.0,8.0,4.0,10.0,10.0,6.0,6.0,
10.0,10.0,6.0,6.0,10.0,10.0,6.0,6.0,6.0,4.0,6.0,4.0,6.0,4.0,6.0,4.0,
6.0,5.0,4.0,4.0,4.0,5.0,4.0,6.0,10.0,10.0,10.0,10.0,
6.0,6.0,6.0,6.0,4.0,4.0,6.0,6.0,6.0,6.0,8.0,4.0,10.0,10.0,4.0,2.0,10.0,
10.0,4.0,2.0,10.0,10.0,4.0,2.0,2.0,2.0,4.0,2.0,4.0,2.0,4.0,2.0,4.0,2.0,
2.0,4.0,2.0,2.0,2.0,1.0,4.0,4.0,4.0,4.0,
4.0,4.0,6.0,8.0,4.0,10.0,8.0,8.0,8.0,8.0,8.0,6.0,10.0,10.0,8.0,6.0,
10.0,10.0,8.0,6.0,10.0,10.0,8.0,6.0,8.0,8.0,10.0,8.0,10.0,8.0,10.0,8.0,
10.0,10.0,8.0,10.0,8.0,10.0,8.0,10.0,10.0,10.0,10.0,10.0,
6.7,5.7,6.7,6.7,6.7,6.7,4.9,5.9,9.5,6.9,6.8,8.0,7.3,8.0,7.0,3.8,6.3,
6.7,6.0,3.5,5.5,5.8,5.3,3.2,4.0,8.2,7.6,9.9,9.5,7.2,6.6,8.2,7.6,7.6,
8.2,9.5,9.9,6.6,7.2,10.0,6.8,9.4,4.2,8.0,
2.3,1.9,2.3,2.3,2.3,10.0,4.5,    4.0,2.9,2.2,10.0,2.4,9.1,10.0,5.8,2.5,
6.6,7.2,3.6,2.2,5.1,5.5,2.8,1.3,2.1,1.0,2.4,1.0,2.4,2.9,5.6,2.9,5.6,
2.4,1.0,2.4,1.0,5.6,2.9,2.5,2.5,5.2,4.0,7.6,
4.4,4.9,4.5,5.0,10.0,9.8,1.0,3.2,5.9,7.3,7.1,3.2,6.8,6.3,5.3,7.0,7.7,
7.3,6.3,7.5,8.3,8.1,7.1,8.0,8.0,8.1,8.7,8.1,8.7,7.0,6.1,5.9,7.2,8.7,
8.1,8.7,8.0,7.2,7.0,5.9,9.2,8.9,8.2,7.5,
1.1,2.4,2.1,1.0,5.0,7.4,1.0,4.0,7.8,7.6,4.3,2.4,5.6,5.6,4.3,3.1,5.6,
5.6,3.9,3.1,5.6,5.6,3.9,2.4,2.1,1.1,8.1,1.1,5.0,3.4,5.6,3.4,5.6,8.1,
1.1,5.3,3.8,5.6,3.4,5.1,8.4,7.9,10.0,8.2,
4.5,4.6,4.6,1.0,8.7,8.4,2.7,4.6,6.8,8.0,7.7,4.5,7.7,7.5,6.0,7.1,8.5,
8.2,6.9,7.6,9.0,8.7,7.6,8.1,8.1,8.4,9.3,8.4,9.3,7.6,7.3,6.5,8.2,9.3,
8.4,9.2,8.5,8.2,7.6,10.0,9.2,9.1,8.0,8.0,
1.1,1.1,1.1,1.1,1.1,1.2,1.0,1.0,1.0,1.1,1.1,1.0,4.1,4.0,2.1,2.1,5.0,
4.9,2.2,2.2,6.5,6.7,2.3,2.3,2.3,10.0,10.0,10.0,10.0,9.6,9.6,9.6,9.6,10.0,
10.0,9.8,9.8,9.1,9.1,1.5,1.6,1.6,1.6,1.6,
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10.0,3.3,1.0,10.0,10.0,3.3,1.0,1.5,3.3,10.0,3.3,10.0,3.3,10.0,3.3,10.0,
10.0,3.3,10.0,3.3,10.0,3.3,2.0,1.0,3.3,1.0,3.3,
2.3,1.9,2.3,2.3,2.3,10.0,4.5,4.0,2.9,2.2,10.0,2.4,9.1,10.0,5.8,2.5,6.6,
7.2,3.6,2.2,5.1,5.5,2.8,1.3,2.1,1.0,2.4,1.0,2.4,2.9,5.6,2.9,5.6,2.4,
1.0,2.4,1.0,5.6,2.9,2.5,2.5,5.2,4.0,7.6,
10.0,8.0,10.0,10.0,6.0,8.0,8.0,8.0,8.0,8.0,8.0,6.0,10.0,10.0,8.0,6.0,
10.0,10.0,6.0,6.0,10.0,10.0,6.0,6.0,4.0,4.0,4.0,4.0,4.0,4.0,4.0,4.0,
4.0,2.0,2.0,2.0,2.0,2.0,2.0,2.0,2.0,2.0,2.0,2.0,
10.0,10.0,10.0,10.0,10.0,10.0,8.0,8.0,8.0,8.0,8.0,8.0,6.0,6.0,8.0,10.0,
6.0,6.0,8.0,10.0,6.0,6.0,8.0,10.0,10.0,4.0,6.0,4.0,6.0,4.0,6.0,4.0,6.0,
4.0,4.0,4.0,4.0,4.0,4.0,10.0,2.0,2.0,2.0,2.0,
10.0,10.0,8.0,8.0,8.0,6.0,8.0,8.0,8.0,10.0,8.0,6.0,10.0,10.0,8.0,6.0,
8.0,8.0,8.0,6.0,8.0,8.0,8.0,6.0,6.0,4.0,6.0,4.0,6.0,2.0,4.0,2.0,4.0,4.0,
2.0,6.0,4.0,4.0,2.0,2.0,8.0,6.0,10.0,8.0,
10.0,10.0,9.5,9.0,6.7,5.0,1.5,1.5,1.5,1.5,1.5,1.5,1.8,1.8,5.0,9.5,1.8,
1.8,5.0,9.5,1.8,1.8,5.0,9.5,9.5,5.0,1.8,5.0,1.8,5.0,1.8,5.0,1.8,1.8,
5.0,1.8,5.0,1.8,5.0,5.0,10.0,5.0,10.0,5.0,
5.6,5.6,5.6,5.6,5.6,10.0,5.6,5.6,5.6,5.6,9.3,2.4,8.4,8.6,8.6,8.6,7.8,
7.9,8.0,8.0,7.2,7.3,7.4,7.4,7.4,1.1,1.0,1.0,1.0,6.1,5.9,6.1,5.9,1.0,
1.0,1.0,1.0,5.9,6.1,5.6,9.0,9.0,9.0,9.0,
10.0,9.3,8.8,4.4,6.8,2.7,6.3,5.6,4.0,2.9,3.5,5.4,4.4,4.6,1.7,1.5,4.3,
4.5,1.7,1.5,4.3,4.4,1.6,1.5,1.6,1.6,1.4,1.3,1.1,1.9,1.7,1.5,1.4,1.1,
1.3,1.0,1.2,1.4,1.7,1.0,1.6,1.4,1.6,1.4,
10.0,10.0,9.0,9.0,10.0,10.0,3.8,3.8,3.8,3.8,3.8,3.8,1.0,1.0,3.8,9.0,
1.0,1.0,3.8,9.0,1.0,1.0,3.8,9.0,9.0,3.8,1.0,3.8,1.0,3.8,1.0,3.8,1.0,
1.0,3.8,1.0,3.8,1.0,3.8,5.9,10.0,3.8,10.0,3.8$
```

```
EVALUATION CRITERIA NO 1
$WGHT B= 3.08,6.15,6.15,0.77,7.69,5.38,20.0,7.69,2.31,7.69,7.69,3.84,
0.77,3.08,3.84,7.69,4.61,1.54$
EVALUATION CRITERIA NO 2
$WGHT B= 2.47,4.94,4.94,0.62,6.17,4.32,20.37,6.17,1.85,6.17,6.17,3.09,
0.62,2.47,3.09,20.37,4.94,1.23$
EVALUATION CRITERIA NO 3
$WGHT B= 2.32,4.65,4.65,0.58,5.81,4.07,20.34,5.81,1.74,5.81,5.81,2.91,
0.58,2.32,2.91,5.81,20.34,1.16$
EVALUATION CRITERIA NO 4
$WGHT B=1.739,3.478,3.478,0.435,4.348,3.043,20.0,4.348,1.304,4.348,
4.348,2.174,0.435,1.739,2.174,20.0,20.0,0.869$
EVALUATION CRITERIA NO 5
$WGHT B= 2.793,4.469,5.586,2.235,6.704,6.145,16.76,7.263,5.028,5.586,
6.704,4.469,2.235,4.469,3.352,8.38,6.704,1.117$
EVALUATION CRITERIA NO 6
$WGHT B= 14.925,4.975,7.463,4.975,1.99,7.463,1.99,2.463,19.9,7.463,
1.99,2.488,11.94,0.995,0.995,0.995,0.995,0.995$
EVALUATION CRITERIA NO 7
$WGHT B= 12.448,4.149,6.224,4.149,1.66,6.224,1.66,6.224,16.598,6.224,
1.66,2.075,9.959,0.83,0.83,0.83,16.598,0.83$
EVALUATION CRITERIA NO 8
$WGHT B= 11.07,3.69,5.535,3.69,1.476,5.535,1.476,5.535,14.76,5.535,
1.476,1.845,8.856,0.738,0.738,0.738,25.83,0.738$
EVALUATION CRITERIA NO 9
$WGHT B= 3.36,5.88,1.68,0.84,2.52,7.56,16.8,8.4,0.84,4.2,2.52,7.56,
16.8,6.72,6.72,0.84,1.68,5.04$
EVALUATION CRITERIA NO 10
$WGHT B= 2.92,5.11,1.46,0.73,2.19,6.57,14.6,7.3,0.73,3.65,2.19,6.57,
14.6,5.84,5.84,0.73,14.6,4.38$
EVALUATION CRITERIA NO 11
$WGHT B= 2.55,4.46,1.27,0.64,1.91,5.73,12.74,6.37,0.64,3.18,1.91,5.73,
12.74,5.1,5.1,0.64,25.48,3.82$
EVALUATION CRITERIA NO 12
$WGHT B= 9.01,7.21,7.21,1.80,3.6,4.5,0.9,9.01,9.01,3.6,1.8,7.21,9.01,
8.1,4.5,9.01,1.8,2.7$
EVALUATION CRITERIA NO 13
$WGHT B= 6.85,5.48,5.48,1.37,2.74,3.42,0.68,6.85,6.85,2.74,1.37,5.48,
6.85,6.16,3.42,6.85,25.34,2.05$
EVALUATION CRITERIA NO 14
$WGHT B= 3.85,3.85,1.54,1.54,5.38,6.15,6.15,5.38,7.69,7.69,5.38,3.08,
3.85,1.54,3.08,1.54,1.54,30.77$
EVALUATION CRITERIA NO 15
$WGHT B= 7.46,7.46,1.49,1.49,5.22,5.97,7.46,5.22,7.46,7.46,5.22,2.99,
3.73,5.97,2.99,7.46,1.49,14.92$
EVALUATION CRITERIA NO 16
$WGHT B= 2.84,2.84,1.14,1.14,3.98,4.55,4.55,3.98,5.68,5.68,3.98,2.27,
2.84,1.14,2.27,1.14,25.0,25.0$
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