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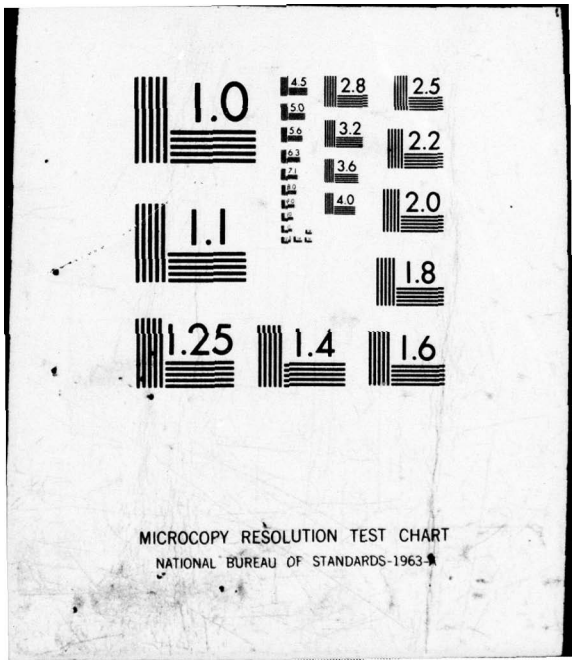
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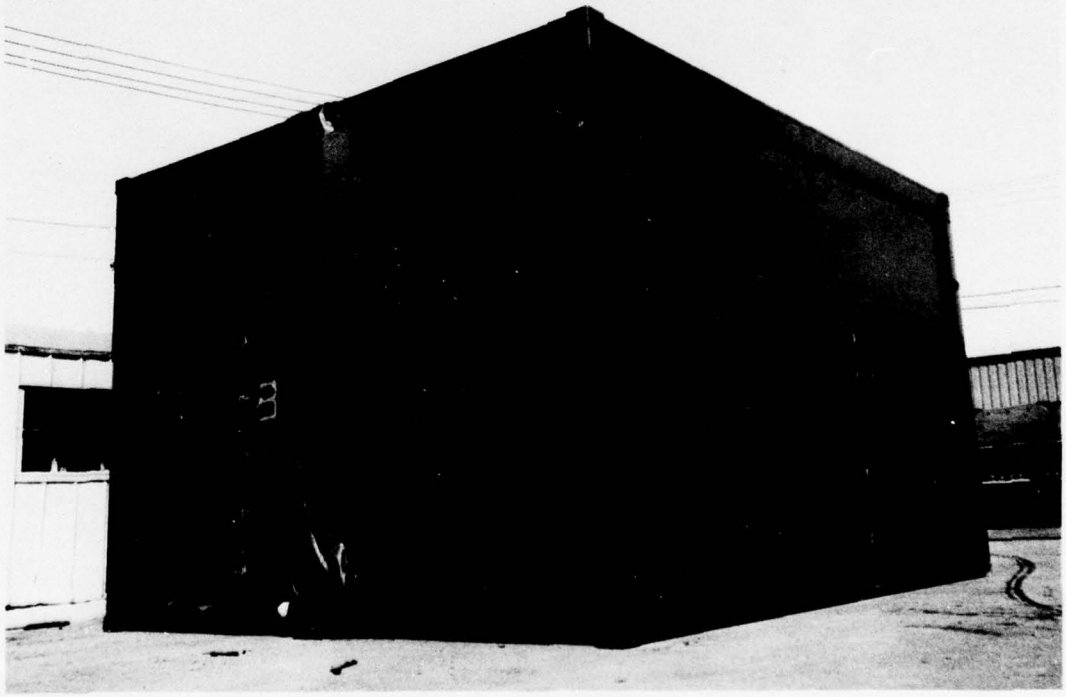

EXPLORATORY DEVELOPMENT OF STRUCTURES FOR TACTICAL CONTAINER-SHELTER SYSTEM (TACOSS) UNITS XI AND XII

By Richard H. Seabold

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Structures for two types of container-shelters were developed for use as part of the Tactical Container-Shelter System (TACOSS). Both types are to serve as 8 x 8 x 20-ft (2.438 x 2.438 x 6.096-m) intermodal shipping containers and as portable shelters. TACOSS XI has removable side panels and telescoping corner posts. Cargo handling can take place through the personnel door and through both sides with any number of side panels removed. In the extended configuration, the roof can be extended upward by means of the telescoping

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corner posts to obtain a 10-ft (3.048-m) clear ceiling height, and closure panels can be inserted to increase the wall height. In the complexed configuration, side panels are removed and units can be coupled together to form shelters of any length, depending on the number of units used. The units also can be extended and complexed simultaneously to form shelters about 20 ft (6.096 m) wide, with a 10-ft (3.048-m) clear ceiling height, and of any length in increments of 8 ft (2.438 m). TACOSS XII has a detachable pallet base. In the pallet configuration, the entire upper structure is lifted away in one piece and stored elsewhere. The floor of the structure in this configuration serves as an 8 x 20-ft (2.438 x 6.096-m) pallet for ordinary cargo, for a large equipment base, or for a floor of a prefabricated building module. Cargo handling can take place from both sides and both ends. Both types were designed, analyzed, fabricated, and tested. Two experimental models of type XI and one of type XII were fabricated and tested. Neither type fully qualified as a container due to lack of weatherproofness and qualification as shelters was not fully validated due to the cancellation of drop and rain tests, but both concepts were found to be feasible. The operating principles work and need not be changed. The payload, tare weight, dimensional, and residual deflection requirements can be met for all configurations of use and all modes of transportation.

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Structures for two types of container-shelter were developed for use as a part of the Tactical Container-Shelter System (TACOSS). Both types are to serve as 8 x 8 x 20-ft (2.438 x 2.438 x 6.096-m) intermodal shipping containers and as portable shelters. TACOSS XI has removable side panels and telescoping corner posts, allowing formation into an extended configuration (to a 10-ft ceiling clearance height) or a complexed configuration (to any length, depending on the number of units used). The units can also be extended and complexed simultaneously. TACOSS XII has a detachable pallet base, allowing the entire upper structure to be lifted away in one piece and stored elsewhere. The floor serves as an 8 x 20-ft pallet for ordinary cargo or as a floor for a prefabricated building module. Two experimental models of type XI and one of type XII were fabricated and tested. Neither type fully qualified as a container, but both concepts were found to be feasible; the operating principles work and need not be changed. The payload, tare weight, dimensional, and residual deflection requirements can be met for all configurations of use and all modes of transportation.

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INTRODUCTION

Objective

Structures for two types of container-shelters were developed for use as part of the Tactical Container-Shelter System (TACOSS). The type designated TACOSS XI has been known as the Multipurpose Unit and as the Pop-Top Box; TACOSS XII has been known as the Covered Pallet Unit and as the Flip-Top Box.

Definitions

TACOSS XI and XII are classified as Series 1C freight containers by the International Organization for Standards (ISO) (1), as closed van dry cargo containers by the American National Standards Institute (ANSI) (2,3), and as special-purpose containers by the Department of Defense (DOD) (4). They are to serve as ANSI containers and as portable shelters.

Scope

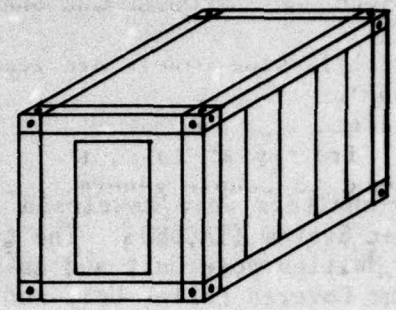
Although the scope was limited to the structural subsystems, interfacing with utility subsystems was considered because, as shelters, the structures are intended for a variety of uses requiring environmental control. Time and funding constraints precluded research to improve materials, fasteners, or bonding methods; therefore, an attempt was made to achieve the objective by innovative design, static and dynamic analysis, fabrication, and testing. Two models of type XI and one of type XII were fabricated and tested. The models were full scale, primarily for structural testing.

REQUIREMENTS AND CRITERIA

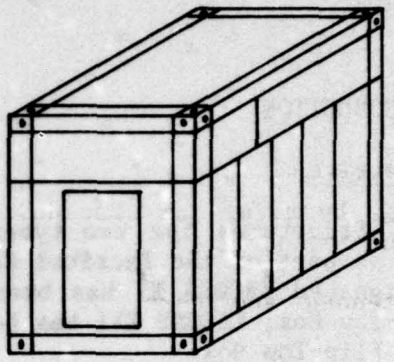
Configurations and Principles of Operation

Multipurpose Unit. TACOSS XI has four configurations as depicted in Figure 1. It serves as an ANSI container in the shipping configuration and as a portable shelter in the other configurations.

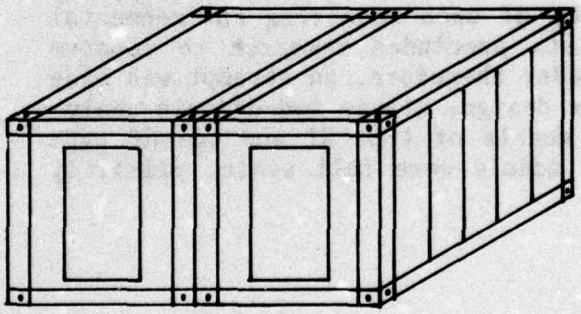
In the shipping configuration (Figure 1a), nominal dimensions are 8 x 8 x 20 ft (2.438 x 2.438 x 6.096 m), and it has a personnel door at one end and five side panels of equal width on each side. Cargo handling can take place through the personnel door and through both sides with any number of side panels removed.



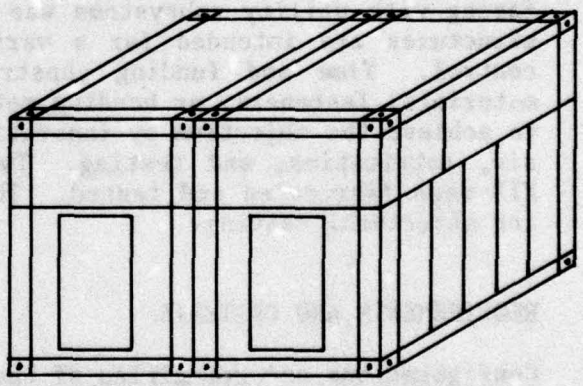
(a) Shipping.



(b) Extended.



(c) Complexed.



(d) Extended and complexed.

Figure 1. Operational configurations of TACOSS XI.

In the extended configuration (Figure 1b), the roof can be extended upward by means of telescoping corner posts to obtain a 10-ft (3.048-m) clear ceiling height. Six closure panels can be inserted to increase the wall height, two panels of unequal length for each side and one for each end.

In the complexed configuration (Figure 1c), side panels are removed and units are coupled together to form shelters about 20 ft (6.096 m) wide, 8 ft (2.438 m) high, and of any length in increments of 8 ft (2.438 m). Coupling of units is achieved directly at the corner castings by using the same devices that are used to couple general-purpose containers.

In the extended and complexed configuration (Figure 1d), units are extended and complexed simultaneously to form shelters about 20-ft (6.096 m) wide, with a 10-ft (3.048-m) clear ceiling height, and of any length in increments of 8 ft (2.438 m), depending on the number of units used. Coupling of units is achieved in the same manner as in the complexed mode, and closure panels are inserted as in the extended mode.

Covered Pallet Unit. TACOSS XII has two configurations as depicted in Figure 2. It serves as an ANSI container in the container configuration and either as a cargo pallet or as part of the floor of a shelter in the pallet configuration.

In the container configuration (Figure 2a), it has nominal dimensions of 8 x 8 x 20 ft (2.438 x 2.438 x 6.096 m) and has a personnel door at one end. Cargo handling can take place through the personnel door in this configuration, but normally will take place in the pallet configuration.

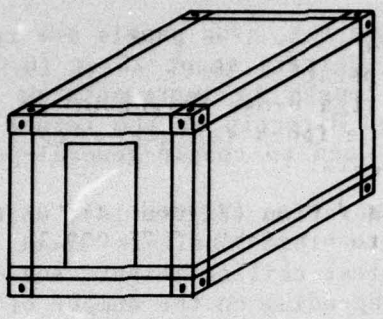
In the pallet configuration (Figure 2b), the entire upper structure is lifted away as one piece and stored elsewhere. The floor of the structure in this configuration serves as an 8 x 20-ft (2.438 x 6.096-m) pallet for ordinary cargo, for a large equipment base, or for a floor of a prefabricated building module. Cargo handling can take place from both sides and both ends.

Payload Capacity

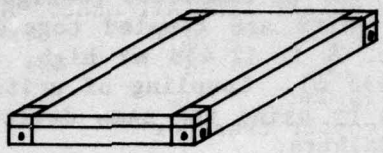
Intended usage requires a payload capacity of about 35,000 lb (155.7 kN) for all configurations and for all modes of transportation. This load was used in design in accordance with ANSI standards (2,3) for the shipping configuration of TACOSS XI and the container configuration of TACOSS XII and was assumed to be a uniformly distributed static floor load for the other configurations. Weights of closure panels and couplers for TACOSS XI were assumed to be part of the payload.

Transportation and Handling Requirements and Criteria

Standards. The structures were designed as containers in accordance with ANSI MH5.1-1971, "Basic Requirements for Cargo Containers" (2); ANSI MH5.1.1-1971, "Requirements for Closed Van Containers" (3); and ANSI MH5.4-1972, "Specifications for International (ISO) Freight Containers" (1). Loads, load factors, and stresses are discussed in Reference 5.



(a) Container.



(b) Pallet.

Figure 2. Operational configurations of TACOSS XII.

Modes of Transportation and Handling. The structures were designated as marine-highway-rail containers (Section 1.3, Reference 2). They could not be designated for the air mode, because the maximum payload exceeds the fixed wing aircraft operating gross weight (Section 5.2, Reference 2).

The structures were designed for all modes of transportation (marine, highway, rail, fixed wing air, and rotary wing air) and include provisions for handling by forklifts and straddle carriers as well as the usual means by cranes, side loaders, and front loaders. They may be handled as twin twenties* and may be stuffed** and unstuffed by means of small forklifts. Two operational constraints apply to the fixed wing air mode: (1) reduced payload capacity and (2) special handling on a modular slave pallet (Section 4.5.4.1, Reference 2).

Size and Weight. The structures are Type 1C containers, which have nominal dimensions of 8 x 8 x 20 ft (2.438 x 2.438 x 6.096 m) and a design gross weight of 44,800 lb (199.3 kN). The operating gross weight for the highway mode was assumed to be equal to the design gross weight; therefore, the maximum allowable tare weight is 9,800 lb (43.59 kN) to obtain the payload capacity of 35,000 lb (155.7 kN).

---

*Twin twenties are 20-ft-long (6.096-m-long) containers that can be coupled end-to-end and handled as a 40-ft-long (12.192-m-long) container in terminal operations.

**"Stuffed" refers to placing cargo into the container.

Optional Features. Optional features are forklift pockets in accordance with Section 8.2 of Reference 2 and gantry or straddle-lift handling provisions in accordance with Section 8.3 of Reference 2. Each structure has two forklift pockets spaced 34.5 in. (0.8763 m) center-to-center.

Rotary Wing Air Mode. All of the provisions for the rotary wing air mode were used in design, and the operating gross weight for that mode was assumed to be equal to the design gross weight of 44,800 lb (199.3 kN). Thus, the containers were designed for qualification for helicopter transportation on a separate basis.

Fixed Wing Air Mode. Most of the fixed wing air mode criteria were used, including the standard operating gross weight of 25,000 lb (111.2 kN) as listed in Section 5.2 of Reference 2, which limits the payload at about 15,200 lb (67.61 kN). Flat bottoms and restraint slots (Section 4.5.4, Reference 2) were not included. In general, the containers were designed to meet the load and stress requirements for use in commercial air transportation, but their bottoms were not configured to interface with rollers and latches of aircraft cargo-handling systems. It appears to be impossible to incorporate a flat bottom, aircraft restraint slots, marine-highway-rail bottom requirements, and the optional forklift and straddle carrier provisions into a single design.

Closed Van Requirements. Specific requirements for closed van containers (3) were applied except for the bottom requirements for the air mode as mentioned in the previous section and the cargo door openings. The removable side panels of TACOSS XI and the removable top of TACOSS XII are interpreted as exceeding the dimensional requirements of cargo doors in general-purpose containers.

Load Factors and Allowable Stresses. Design load factors and design stress criteria as specified in Section 6 of Reference 2 were used for all the modes of transportation. In addition, ultimate load factors and ultimate stress criteria as specified in that same section were used for the air modes. The material supplier's test data of moment capacity and deflection were used to design all fiberglass reinforced plastic (FRP) and plywood panels. Industry standard allowable stresses were used to design all other components.

Building Code Requirements and Criteria

Loads. Transportation loads dominated building loads in the design of virtually every structural element. A few comparisons are cited here to show the magnitude of dominance.

The Uniform Building Code (6) requires a uniform floor load of 150 psf (7.182 kPa) for armories. For the TACOSS units as portable shelters, a uniform floor load of 219 psf (10.49 kPa) was used. In comparison, the floor load for the container in terminal operations is 625 psf (29.93 kPa) on the center section and 254 psf (12.16 kPa) on the remainder. Therefore, the container floor load requirement is about twice that for the shelter and thrice that for an armory.

Roof loads for flat roofs vary from 20 psf (0.9576 kPa) with no snow load to about 50 psf (2.394 kPa) with very heavy snow load; whereas, the TACOSS roof panels were designed for a load of 106 psf (5.075 kPa), governed by the fixed wing air mode of transportation. Therefore, the container roof load requirement is about twice that for a building with a heavy snow load.

Concentrated load requirements for the floors and roofs are greater for containers than for buildings. For instance, the building code specifies a concentrated load of 3,000 lb (13.34 kN) for heavy manufacturing and for wholesale stores, but spacing of floor beams was dependent on a 12,000-lb (53.38-kN) load, consisting of two 6,000-lb (26.69-kN) wheel loads from a forklift in terminal operations. The transportation-type load is four times greater than its companion building-type load.

For buildings less than 30 ft (9.144 m) in height, the building code specifies a wind load of 40 psf (1.915 kPa) for those areas in the United States that receive the highest winds. In comparison, the side wall panels were designed to resist a uniform load of 132 psf (6.320 kPa), governed by the marine mode of transportation, and the end wall panels were designed to resist a uniform load of 219 psf (10.49 kPa), governed by the marine and rail modes. Thus, transportation loads are the greater by threefold or fourfold. The wind load applies to the closure panels of TACOSS XI because those panels are used exclusively in the portable shelter configurations.

Deflections and Allowable Stresses. The code specifies a maximum allowable deflection of L/240, where L is the length of the member in the same units as the deflection. All deflections due to building-type loads are believed to be less than that limit. Allowable stresses are the same as those under transportation requirements and criteria.

Special Requirements and Criteria

Twin-Twenty Lifting. The structures were designed to be connected end-to-end and then handled as Type 1A containers. Type 1A has nominal dimensions of 8 x 8 x 40 ft (2.438 x 2.438 x 12.192 m) and a design gross weight of 67,200 lb (298.9 kN). It was assumed that the gross weight is divided equally between the containers; therefore, the maximum allowable payload for a 20-ft (6.096-m) container in twin-twenty service is 23,800 lb (105.9 kN). Loads, load factors, and stresses are discussed in Reference 5.

Transit Drop. Military transit edge and corner drops are specified (6), but drop heights are limited to 6 in. (0.1524 m) for the 44,800-lb (199.3-kN) gross weight and 12 in. (0.3048 m) for the 9,800-lb (43.59-kN) tare weight. The limits are based on estimates of technical and economic feasibility, considering the dimensions and weights of the containers.

Rain. In addition to the transportation weatherproofness criteria, the standard military rain test is specified (7) to cover weatherproofness of TACOSS XI in its shelter configurations. A rain test is not required for TACOSS XII.

DISCUSSION

Background

Standardization of Containers. ANSI Committee MH5 was formed in 1958 to study standardization of intermodal containers within the United States, and ISO Committee TC-104 was formed in 1961 to study standardization worldwide. The original version of the ANSI standard was published in 1965, and a number of ISO recommendations were published in 1968. All were limited to the marine, highway, and rail modes of transportation. Society of Automotive Engineers (SAE) Committee AGE-2 studied the fixed wing air mode, and in 1968 SAE published its own aerospace standard for air-land demountable cargo containers, a standard which was adopted by ANSI in 1969.

Advantages of containerization were cited by the Chief of Naval Operations (8) in 1968 when he provided policy guidelines for the development of containerization and assigned the Chief of Naval Material and the Commander, Military Sea Transport Service (later reorganized as the Military Sealift Command) primary responsibility for introducing greater usage of containerization. Army development of specifications for the Military Van (MILVAN) (9) and the Triple Container (TRICON) (general-purpose containers) led the way toward military use of ANSI/ISO standardization in 1969. The office of the DOD project manager for surface container systems was established, and in 1973 the DOD project master plan for a surface container-supported distribution system (4) was approved.

The current ANSI standards, approved in 1971, are the first major revision of the originals. The SAE provisions for the fixed wing mode were revised and incorporated, and new provisions were added for the rotary wing mode. In addition, revised ISO recommendations were published by ANSI as an information document. Therefore, all of the provisions - national and international - for all modes became available with ANSI titles and numbers, but the marriage of former standards appears to have resulted in a direct conflict between bottom requirements for the fixed wing and other modes.

Containerized Shelters. "Conlabs" are containerized laboratories designed and developed by the Twin Hull Boat Company to reduce the cost of research expeditions. They provide extra space for living quarters, wet or dry laboratories, housing of heavy equipment, and maintenance and shop areas. They were designed to meet the 1965 standards and were marketed prior to 1969. The structures were modified commerical containers and were available in 10-ft (3.048-m) and 20-ft (6.096-m) lengths. On 1 January 1969 the price was $4,850 for an 8 x 8 x 20-ft (2.438 x 2.438 x 6.096-m) container-shelter with double loading door, single access door, overhead lighting, strip electric outlet, electric panel box, and six windows. Additional cost options included bunks, lockers, desks, sinks, work benches, and additional access doors. An austere berthing unit for six men would have been $7,000. These products are believed to have been the first containerized shelters.

Conlab containers have an all-aluminum frame, 3/4-in. (0.01905-m) FRP/plywood* panels, and a 1-1/8-in. (0.02858-m) finished oak floor. They were manufactured by Veenema & Wiegers, using panels by Lunn Laminates. Advantages of the panels are ease of modification, ease of repair or replacement, high surface durability, high impact and puncture resistance, and relatively good insulating capability without the addition of insulation. Advantages of the frame are low maintenance and relatively light weight. The main advantage of the final product was low price.

Quick Camp modules (10) are containerized camping facilities developed by the Civil Engineering Laboratory (CEL) to improve operational expediency, logistical support, and pilfer resistance. The facilities include berthing, messing, sanitation, administration, medical treatment, shop, laundry, recreation, and storage. They were designed to meet the 1968 recommendations, and fabrication of three prototype modules was completed in 1971. Estimated prices varied from $6,400 for the all purpose module to $10,300 for the kitchen module. The modules are believed to have been the first military containerized shelters.

Quick Camp modules have an all-steel frame, 3/4-in. (0.01905-m) FRP/plywood panels, and a 1-1/8-in. (0.02858-m) finished oak floor. The containers were manufactured by the Container Division of Hussman Refrigeration, were tested by Miner Enterprises, were certified by the American Bureau of Shipping (ABS), and then were outfitted as shelters by the Tulsa Division of North American Rockwell.

The Quick Camp system provided additional benefits at the same cost as Conlabs. The additional benefits included a higher level of habitability and a total system operational concept. The system provided for complexing of modules, a master plan for combining modules to form camps, and for system self-containment through utility subsystems for electrical power and distribution and for water filtering, storage, and distribution. The six-man berthing module was priced at about $7,000, the same price as the six-man Conlab unit.

Standards for the early development of Air Force Bare Base (11) shelters were based on C-130 and C-141 aircraft and the 463L pallet cargo handling system. Emphasis was placed on lightweight construction and air mobility; intermodalism was not an objective. The shelters were not designed to ANSI or ISO container provisions and, thus, are not defined as containerized shelters in the context of this report. In general, Bare Base units were smaller, lighter, less durable, and more expensive than Conlabs and Quick Camp modules.

Expandable shelters were required to satisfy Bare Base objectives, and a number of construction materials and expansion methods were investigated. One shelter of particular interest, because of its influence on later developments, was a three-to-one rigid-wall expandable shelter, which was expanded by the hinged-panel method and was made of aluminum-skinned paper honeycomb panels. Problems with the sandwich panels included poor impact and puncture resistance, delamination of panels,

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*Seamless fiberglass reinforced plastic sheets sandwiched over 3/4-in. (0.01905-m) marine plywood.

poor repairability, and the need for high-technology fabrication. Since these problems persisted through subsequent Army, Navy, and Air Force developments and remain unsolved, a technical working group of members from government and industry was formed in 1974 to study them. The working group was coordinated by the National Bureau of Standards.

The Army MUST (medical unit, self-contained, transportable) is similar to the Bare Base in that shelters are of nonstandard size and have sandwich panels.

TACOSS I through X are containerized camping facilities developed by the Navy for use by Seabees (12). The units are:

1. TACOSS I: Detachment Subsistence Unit
2. TACOSS II: Detachment Sanitary Unit
3. TACOSS III: Detachment Medical Unit
4. TACOSS IV: Provision Storage Unit
5. TACOSS V: Equipment and Shop Unit
6. TACOSS VI: Detachment Personnel Unit
7. TACOSS VII: Utility Unit
8. TACOSS VIII: Frozen Storage Unit
9. TACOSS IX: Galley Unit, Large
10. TACOSS X: Sanitary Unit, Large

The three-to-one expandable shelter concept of Bare Base was used in TACOSS to develop containerized shelters with interior clear spans greater than those of Conlabs and Quick Camp modules. Units I, III, V, VI, IX, and X are expandables, and the others are nonexpandables. Nearly all have aluminum-skinned paper honeycomb panels and floors. They were designed to meet the 1968 recommendations, and fabrication of one prototype of each type of unit was completed in 1972. Some of these first ten TACOSS units did not satisfy the ISO load requirements in tests and, thus, were redefined as assimilated containers. Assimilated containers are in accordance with standard dimensions and location of corner fittings, but do not carry standard container loads. A complete definition is given in Reference 1. Estimated prices varied from $19,000 for the nonexpandable sanitary unit to $64,250 for the expandable large galley unit. Berthing for 12 men was priced at about $26,000 compared to $14,000 for Conlabs and Quick Camp modules. The expandable TACOSS units are believed to have been the first military containerized expandable shelters.

In general, TACOSS I through X provide a higher level of habitability, but the structures are less durable, have less load capacity, are less expedient due to longer setup and strike-down times, and are more expensive than Conlabs and Quick Camp modules. The TACOSS is practical over a wider range of camp sizes (numbers of men supported at a single location). Quick Camp is for 13 to 104 men, TACOSS is for 13 to 750 men, and Bare Base is for 1,000 to 2,000 men; therefore, the systems are not directly comparable.

The Marine Corps Expeditionary Shelter System (MCESS) includes seven shelters listed as follows and a logistic trailer for transporting them:

1. A 20 x 33-ft (6.096 x 10.06-m) steel building which can be disassembled and shipped in 8 x 8 x 20-ft (2.438 x 2.438 x 6.096-m) containers.
2. A 32 x 73-ft (9.754 x 22.25-m) steel building which can be disassembled and shipped in 8 x 8 x 20-ft (2.438 x 2.438 x 6.096-m) containers.
3. A 60 x 128-ft (18.29 x 39.01-m) steel building which can be disassembled and shipped on 8 x 8 x 40-ft (2.438 x 2.438 x 12.19-m) flat racks.
4. An 8 x 8 x 20-ft (2.438 x 2.438 x 6.096-m) knockdown shelter which can be shipped in its erected configuration or can be folded flat and shipped with others as an 8 x 8 x 20-ft (2.438 x 2.438 x 6.096-m) assimilated container.
5. An 8 x 8 x 20-ft (2.438 x 2.438 x 6.096-m) rigid shelter, an assimilated container.
6. An 8 x 8 x 20-ft (2.438 x 2.438 x 6.096-m) EMI (electromagnetic interference shielded) shelter, an assimilated container.
7. An 8 x 8 x 10-ft (2.438 x 2.438 x 3.048-m) EMI shelter, an assimilated container.

These shelters were designed for undesignated functions and missions to achieve high flexibility of use and to minimize the number of types of shelters. The structures are intended to conform to the corner locations and stacking and racking loads of the 1971 standards but do not conform to standard cargo loadings.

Sandwich panels used in the Marine Corps shelters have paper honeycomb cores and either metal or plywood skins. The outer skins are protected by an FRP wearing surface, which provides durability and impact and puncture resistance. The Marine Corps family of shelters provides the most flexibility in using the shelter at relatively low cost, but also provides the least floor load capacity of all the systems studied.

The data in Table 1 show the degree to which the various shelter systems were standardized in accordance with ANSI/ISO provisions. These data indicate objectives and do not necessarily confirm achievements. They can be used to compare the objectives of TACOSS XI and XII relative to those of the previously developed shelters.

Table 1. ANSI/ISO Requirements Used in the Development of Shelter Systems

Shelter System	Standards or Recommendations Used (yr)	Structures Designed to Meet ANSI/ISO Requirements					
		Corner Locations	Bottom Configurations[a]		Cargo Loadings		
			Fixed Wing Air Mode	All Other Modes	Marine, Rail, and Highway Modes	Fixed Wing Air Mode	Rotary Wing Air Mode
Conlabs	1965	Yes	No[b]	Yes	Yes	No[b]	No[c]
Bare Base	None	No	No	No	No	No	No
MUST	None	No	No	No	No	No	No
Quick Camp	1968	Yes	No[b]	Yes	Yes	Yes[d]	No[c]
TACOSS I through X	1968	Yes	No[b]	No	No[e]	No[b]	No[c]
MCESS	1971	Yes	No	No	No	No	No
TACOSS XI and XII	1971	Yes	No	Yes	Yes	Yes	Yes

[a]It appears impossible to meet the requirements of both configurations.

[b]No ANSI/ISO criteria were available until 1969.

[c]No ANSI/ISO criteria were available until 1971.

[d]SAE criteria were used and were adopted by ANSI in 1969.

[e]Load requirements were reduced during development.

Helicopter Lifting Capability. Helicopter lifting capability is controversial because it depends on a number of variables which change frequently and are often oversimplified. Some of the variables are the make, model, availability, and fuel capacity of the helicopter; the altitude, air temperature, and retrieval radius involved in the flight; and the configuration of the load.

In 1969 the operating gross weights of the Quick Camp modules were limited to 16,000 lb (71.17 kN), based on a particular scenario, but the structures were designed for a design gross weight of 44,800 lb (199.3 kN) for ease in updating the system as helicopter capability increased. The scenario was for the CH-54B helicopter, a retrieval radius of 150 statute miles (241.4 km), an altitude of 3,000 ft (914.4 m), an air temperature of 90F (305 K), and no refueling. Neither the ANSI standards nor the ISO recommendations contained any rotary wing mode requirements or criteria at that time.

In 1971 rotary wing requirements and criteria were added to the ANSI standards. The rotary wing aircraft operating gross weight for a 20-ft-long (6.096-m-long) container is 44,800 lb (199.3 kN) as listed in Table IIA of Reference 2.

In 1972, when system requirements and design criteria for TACOSS XI and XII were determined, an absolute upper limit on tare weight of 16,000 lb (71.17 kN) was used to make sure that empty container-shelters could be carried as in the scenario for Quick Camp. Eventually, due to other considerations, the allowable tare weight was determined to be 9,800 lb (43.6 kN), which permits a payload of 6,200 lb (27.6 kN) for the scenario and transport of empty container-shelters by several types of helicopters. The structures were designed for a gross weight of 44,800 lb (199.3 kN) in accordance with the ANSI standard. The 44,800-lb (199.3-kN) gross weight will apply when commerical heavy-lift helicopters are available.

Preliminary Studies

Alternatives. Several alternative preliminary designs were created. For TACOSS XI, alternatives included (a) special longitudinal composite floor beams as well as the selected conventional lateral floor beams and (b) a drop-down floor as well as the selected popup roof. For TACOSS XII, they included conventional edge beams for the pallet as well as the selected prestressed edge beams. For both TACOSS XI and XII, they included (a) aluminum/paper honeycomb panels as well as the selected FRP/plywood panels and (b) conventional fasteners as well as the selected special shear developers.

Attributes and Figures of Merit. Lightness of weight was sacrificed to reduce the development risk and to favor intermodalism, ruggedness, simplicity, and economy, which were given higher figures of merit. Intermodalism includes amount of cargo-carrying capacity, degree of conformance to ANSI standards, number of modes of transportation, and number of modes of handling. Ruggedness includes strength margin of safety, impact resistance, puncture resistance, weather resistance, and

repairability. Simplicity concerns ease of conversion from one operational configuration to another, number of components, number of moving parts, number of removable parts, number of instructions required, amount of training required, and the degree of selfcontainment. Economy was pursued by designing for the use of low-technology manufacturing techniques.

Selection of Materials. Selections of basic materials were important decisions in system synthesis. Details are given in Appendix A about studies which led to the selection of FRP/plywood side, end, and roof panels; steel frames; and wooden floors on steel floor beams. The studies were mostly the application of TACOSS system requirements and figures of merit to the method, attributes, and data in the Army container material study (13).

Side Panels of TACOSS XI. A feasibility study of using FRP/plywood for the side panels of TACOSS XI was made in conjunction with the study of material preferences. It was found that panels with cores over 1 in. (25.4 mm) thick would make the container too heavy and those with cores under 7/8 in. (22.2 mm) thick would not meet the strength requirements. This rather narrow window was fine with respect to thermal transmission, but doubtful with respect to weathersealing, because of large elastic deflections. The 1-in. (25.4-mm) core was chosen. Details of the study are presented in Appendix B.

Design and Analysis

Approach and Assumptions. The designs were created at CEL. The approach, assumptions, and calculations for TACOSS XI were presented in Reference 14.

Procedure. Design stresses in accordance with standard engineering practice were used with the design loads for terminal operations and marine, highway, and rail modes of transportation to size members and fasteners in initial design, with the use of computer programs limited to sectional properties and moment distribution. After detailing was completed and preliminary drawings and specifications were prepared, two design reviews were conducted. A review by the Civil Engineer Support Office (CESO) concentrated on human factors, weathertightness, and responsiveness to operational requirements; whereas, a review by CEL concentrated on structural loads and stress analyses. The loads analysis (5) included the air modes as well as the other modes of transportation and the ultimate load as well as the design load provisions of the ANSI standards. The stress analyses made use of:

1. the loads analysis
2. the material and sectional properties provided by the designer
3. the finite element method
4. the Structural Analysis Program (SAP)

The reviews revealed points of misunderstanding which were explained, points of weakness which were corrected, and points of uncertainty which were cited as subjects for test and evaluation. Finally, the specifications were completed, and the designs were completely redrawn. The specifications, including reduced drawings, are available in References 15 and 16.

Points of Uncertainty. Side panel weathertightness of TACOSS XI was uncertain because of its dependence on deflection, which was estimated by using extrapolated data. The risk of unsatisfactory weathersealing was justified by the potential benefits in simplicity and economy. It was assumed that remedial action, if necessary, would involve details rather than change in the basic structural concept.

Ease in raising and lowering the roof of TACOSS XI after application and removal of the racking loads was the most important uncertainty. Proper telescoping of the corner posts depends on tolerance, friction, lubrication, and deflection of the column and on the effectiveness of the panels in bracing the frame. It was assumed that the racking load would be transferred from the upper corner to the upper rail, to the panel by means of the upper shear developers, to the lower rail by means of the lower shear developers, and finally to the reaction at the lower corner. Deflection analysis of the telescoping corner posts indicated marginal tolerance between the inner and outer parts, but the accuracy of the analysis was limited by a simplifying assumption of the end condition at the top of the column. The risk of binding in the column was justified by the potential benefits of having no removable fasteners on either the panels or the rails and, thus, very rapid conversion from one configuration to another.

It was difficult to design TACOSS XI within the allowable tare weight. A few hundred pounds (newtons) overweight was estimated. This risk was justified by economy and simplicity in standardization of container components. For instance, all side and end panels are the same thickness. Making them of different thicknesses to save weight would complicate the structure and probably increase the cost.

The finite element analyses predicted buckling of the outstanding webs of the corner posts and high stress in the lateral rail under the personnel door. The original design calculations, because of simplifying assumptions, did not predict them. The uncertainty concerned the significance of the different analytical results, not the correctness of either calculation. The final consensus was that the results might be classical rather than realistic and should be tested; therefore, the risk was accepted.

There was some concern about ease and safety of installation and removal of the upper panels of TACOSS XI because those operations appeared to require climbing onto the container or onto an adjacent object. It was assumed that a satisfactory procedure could be developed during operational testing of the prototypes.

Confidence in the TACOSS XII design was high. Tare weight was not a problem; therefore, the designer could afford to make conservative decisions. The only point of uncertainty was the load-carrying capabil-

ity of the floor (pallet) in terminal operations and in the rotary wing air mode of transportation. The risk was believed to be in quality control of the fabrication of the prestressed steel beams. These nonconventional beams were necessary to make the floor thin enough to meet all of the operational requirements.

Some doubt also existed about the ease of fabricating the rails of both containers. Built-up sections were necessary to realize the benefits of the shear developers.

Fabrication of Models

Two TACOSS XI and one TACOSS XII experimental models were fabricated by a contractor. Two Type XI models were needed for testing in the extended and complexed configuration. The Navy furnished specifications, design drawings, and specification control drawings. The contractor prepared bills of material and shop drawings.

The contractor signed a fixed-price contract on 6 December 1974 to deliver the units within 8 mo (240 days). More than 2 yr (732 days) later, on 7 December 1976, the Navy accepted the units. The shop drawings are not usable for future development efforts, and the units were accepted with about 25 discrepancies. In general, welding quality and adherence to dimensional tolerances were excellent, but the wooden floor, the FRP/plywood side panels, and all door hardware and seals were poorly done.

TESTING

Planning

A testing program was planned to cover all of the requirements and criteria. The first phase, for qualification as containers, covered the payload capacity, the transportation and handling requirements, and the special twin-twenty lifting requirement. The second phase, for qualification as shelters, covered the conversions between configurations, the building-type requirements, and the special transit drop and rain requirements.

Container Qualification. Tests for qualification as containers were planned in five parts as follows:

I. Qualification for the Marine, Highway, and Rail Modes of Transportation

   A. Dimensional Check
   B. Stacking
   C. Lifting from the Top
   D. Lifting from the Bottom

E. Restraint
F. Racking
G. Lashing
H. End Wall
I. Side Wall
J. Roof
K. Floor
L. Dimensional Check
M. Weatherproofness

II. Qualification for the Optional Modes of Handling

A. Dimensional Check
B. Forklift Pockets
C. Straddle-lift Handling
D. Dimensional Check
E. Weatherproofness

III. Qualification for the Rotary Wing Mode of Transportation

A. Dimensional Check
B. Lifting from the Top
C. Lifting from the Bottom
D. Dimensional Check
E. Weatherproofness

IV. Special Tests for the Fixed Wing Mode of Transportation

A. Dimensional Check
B. Roof
C. Upward Load
D. Dimensional Check

V. Special Tests for Twin-Twenty Service

A. Dimensional Check
B. Lifting from the Top
C. Lifting from the Bottom
D. Dimensional Check

Parts I through V were conducted in sequence and were in order of importance; the most important tests were in Part I and were conducted first. Part I covered all of the testing requirements for ANSI containers designated as marine-highway-rail containers - the requirements which are absolutely essential. Part II covered the optional features to be included (those not essential but desirable and designed to meet ANSI provisions without exception). Part III covered nearly all of the testing required to qualify the containers for the rotary wing air mode

on a separate basis. Side wall tests for the rotary wing air mode were not included, because the side wall load is only about 11% greater than for the marine-highway-rail containers; end wall tests were not included, because the end walls were overdesigned for simplicity and, thus, were not likely to be critical. Part IV, which covered the fixed wing air mode, consisted of special tests deemed appropriate for the limited air transportation requirements. Part V concerned a secondary, nonessential (but desirable) mode of operation. The lifting tests in Part V were conducted with less than the maximum allowable payload, because of the limited capacity of available connectors for the end-to-end coupling of the containers.

Shelter Qualification. Tests for qualification as shelters were planned in two parts as follows:

I. Operational Testing

A. Conversion of TACOSS XI from the Shipping Configuration to the Extended Configuration

B. Conversion of TACOSS XI from the Extended Configuration to the Extended and Complexed Configuration

C. Conversion of TACOSS XII from the Container Configuration to the Pallet Configuration

D. Conversion of TACOSS XII from the Pallet Configuration to the Shipping Configuration

II. Special Testing

A. Transit Drop Test

B. Rain Test

Structural testing as shelters was unnecessary because the building-type loads were all dominated by associated transportation-type loads. Part II was not executed due to lack of funds.

Execution

Qualification as containers was tested by Dayton T. Brown, Inc., an independent testing company. Details of the test plan are in the contract schedule of work (17) and details of the procedure and results are in the contractor's report (18).

Qualification as shelters was tested by CEL. The tests included only the operational testing part of the plan. Tests A through D were conducted in sequence. Photographs taken during the tests are presented as Figures 3 through 9.

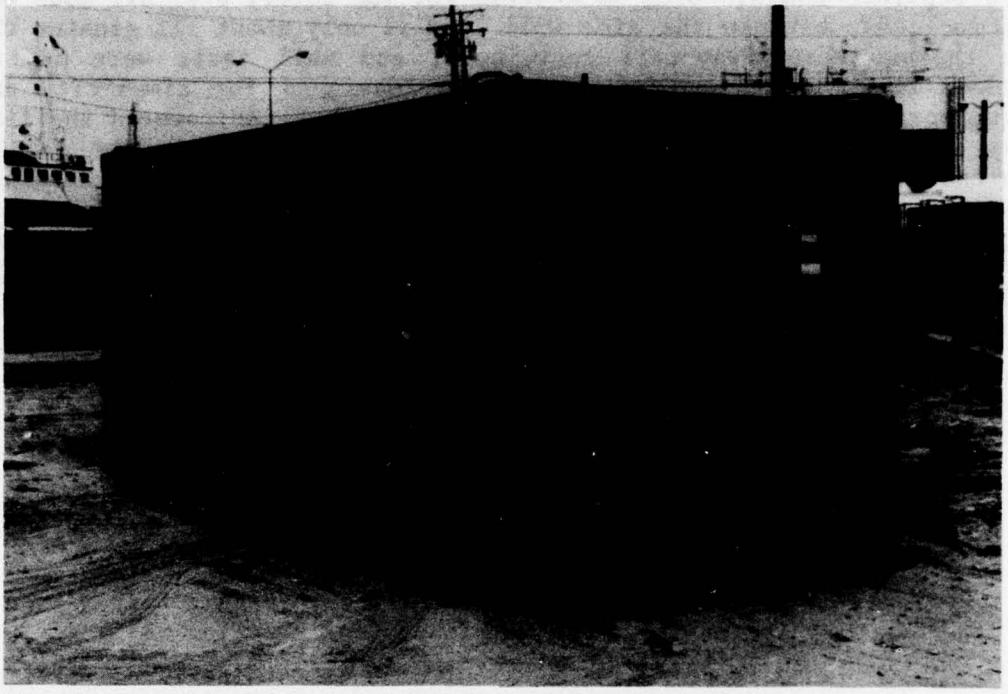

Figure 3. TACOSS XI in the shipping configuration with all side panels secured.

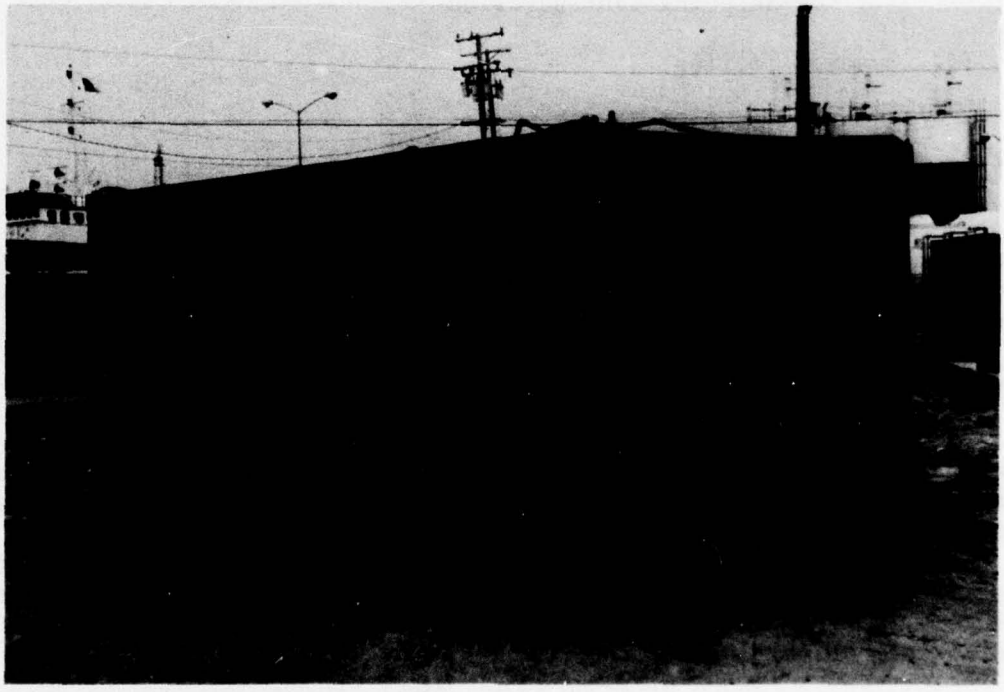

Figure 4. TACOSS XI in the shipping configuration with all of the side panels on one side removed for loading cargo or for complexing with a like unit.

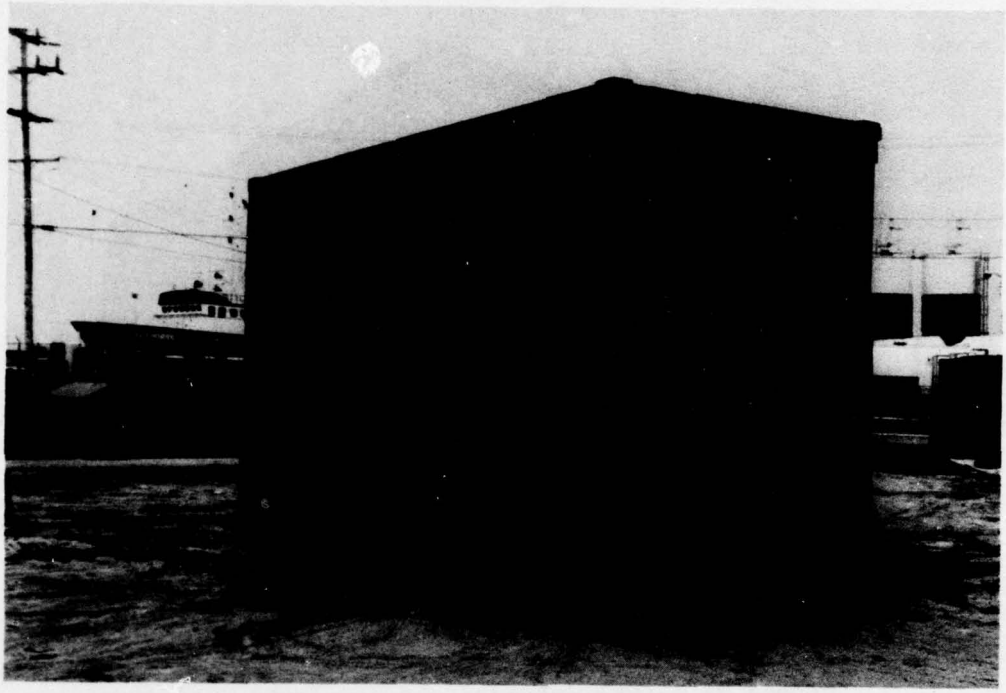

Figure 5. TACOSS XI in the extended configuration.

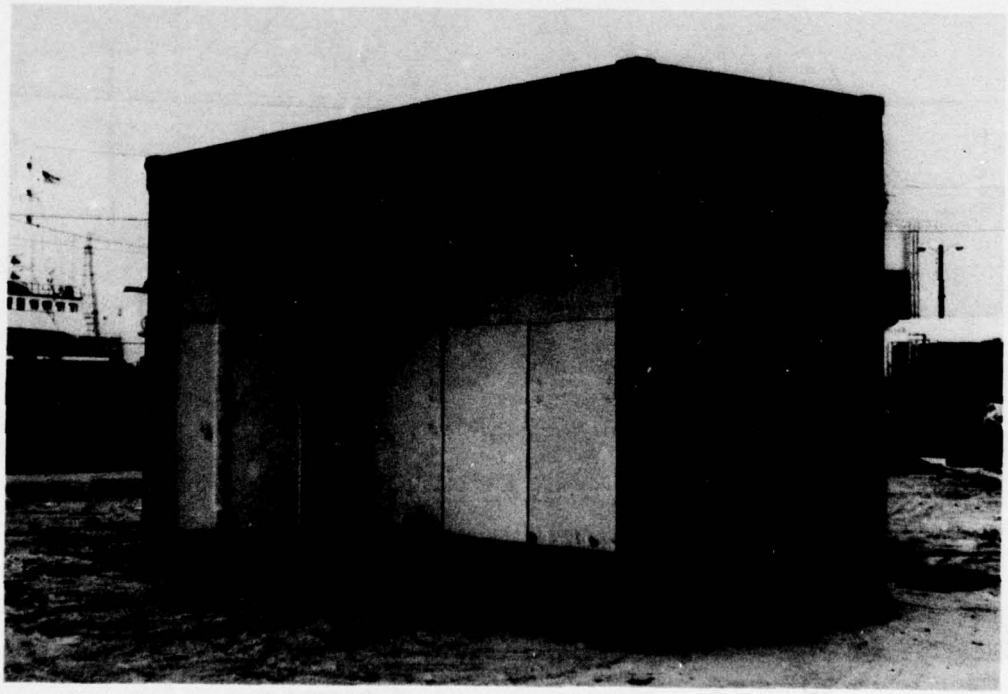

Figure 6. TACOSS XI with the roof extended and all of the side panels on one side removed for complexing with a like unit.

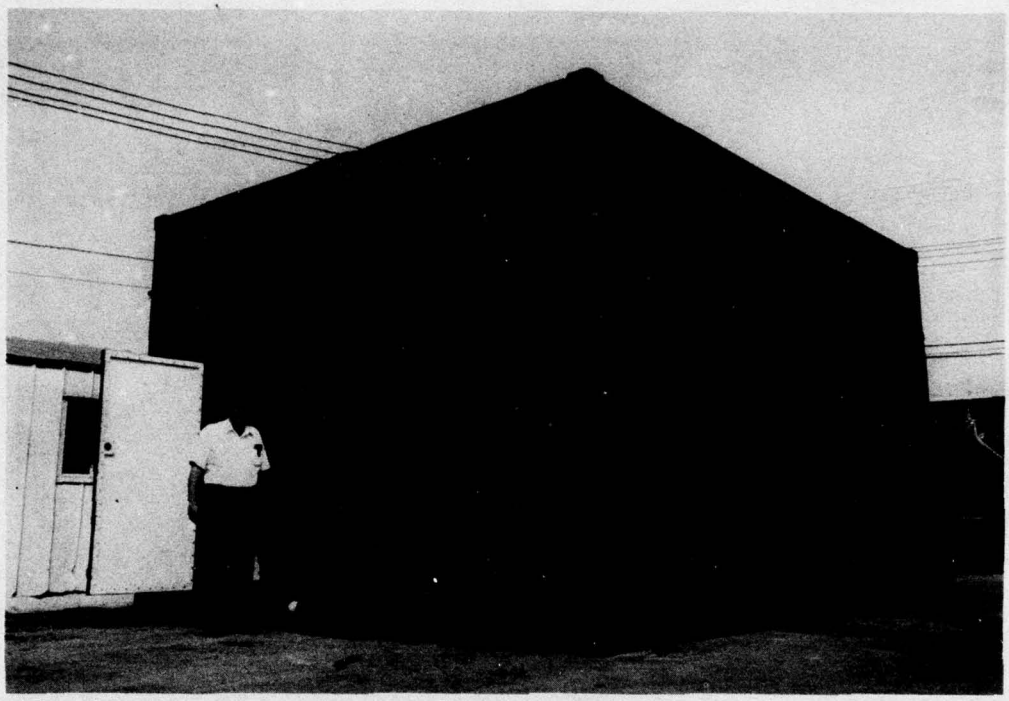

Figure 7. TACOSS XI in the extended and complexed configuration.

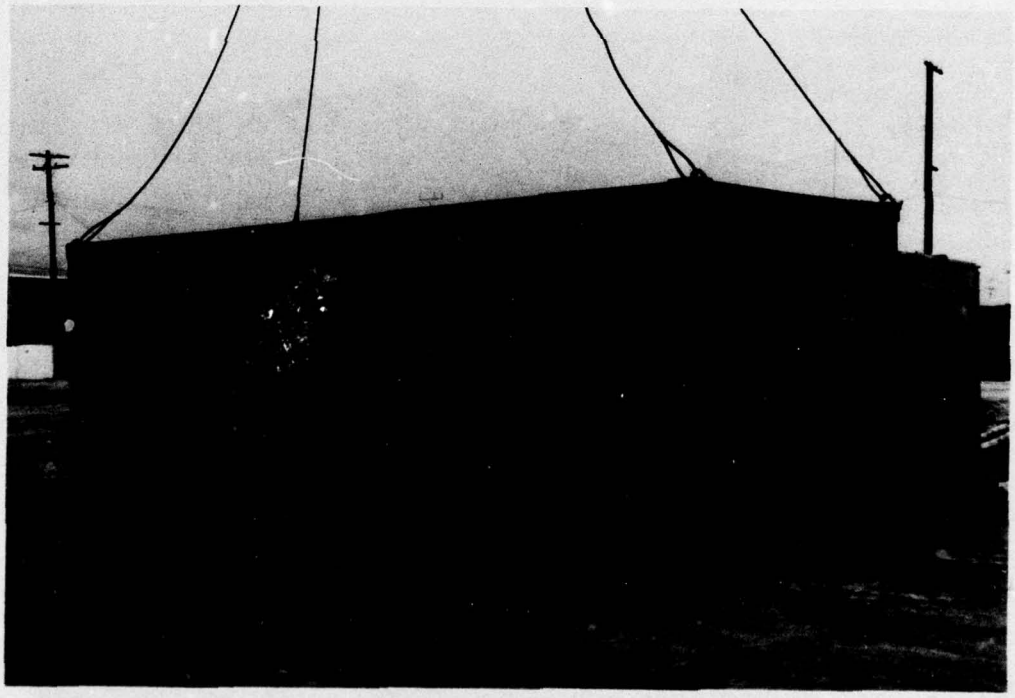

Figure 8. Upper structure of TACOSS XII.

Figure 9. TACOSS XII in the pallet configuration.

Results

Summary. The measured tare weights are 10,250 lb (45.6 kN) for TACOSS XI and 8,250 lb (36.7 kN) for TACOSS XII, compared to the maximum allowable tare weight of 9,800 lb (43.6 kN). Subtracting these values from the standard gross weight rating of 44,800 lb (199.3 kN), the maximum payloads are 34,550 lb (153.7 kN) for TACOSS XI and 36,550 lb (162.6 kN) for TACOSS XII, compared to the user's payload requirement of 35,000 lb (155.7 kN). Therefore, TACOSS XI has a payload capacity 1% below the goal, and TACOSS XII has a payload capacity 4% above the goal.

Types XI and XII passed virtually all of the dimension, deflection, and stress criteria for all of the loading requirements, but failed the weatherproofness criteria. Two structural failures occurred during the tests due to manufacturing errors. In both cases, after the specimen was corrected in accordance with the drawings, it was retested and passed.

The units were exercised successfully in all configurations in the manufacturer's plant as part of the acceptance inspection and then again at CEL after completion of testing as containers. Some of the aforementioned points of uncertainty developed as problems, and others did not.

Side panel weathertightness of TACOSS XI was unsatisfactory due to lack of initial tolerance control and also excessive elastic deflection under load. Design changes will be required.

Raising and lowering the roof of TACOSS XI after application and removal of the racking loads was no trouble at all. The telescoping corner posts worked very well.

The tare weight of TACOSS XI was 450 lb (2,002 N) too heavy (as predicted). It should be possible to reduce the weight by that amount by design refinement.

No evidence of buckling of the outstanding webs of the corner posts was noted, but cracks in welds at the corners of door frames indicated high stress concentrations there. Changes in the details of the door frames will be required.

Installing the upper panels of TACOSS XI was not as difficult as envisioned - but was not smooth either. Changes will be necessary to make tolerances less tight so the upper panels will slide into position more easily.

The prestressed steel beams in TACOSS XII successfully carried the load. The built-up rails of both TACOSS XI and XII were successful also.

Qualification as Containers. Dimensional results are shown in Table 2. The lower values at the start of Part I were measured during lower temperature; therefore, the height of TACOSS XII, shown as 1/16 in. (1.6 mm) too short, is considered acceptable. The height of TACOSS XI at the end of Part I, shown as 1/8 in. (3.2 mm) too long, appears to be a data anomaly and is not understood.

Table 2. Dimensional Test Results

Event	TACOSS XI			TACOSS XII		
	Height (in.)	Width (in.)	Length (in.)	Height (in.)	Width (in.)	Length (in.)
Start of Part I	$95\frac{7}{8}$	$95\frac{7}{8}$	$238\frac{3}{8}$	$95\frac{3}{4}$ [a]	96	$238\frac{1}{4}$
End of Part I	$96\frac{1}{8}$ [b]	96	$238\frac{1}{2}$	96	96	$238\frac{1}{2}$
End of Part II	96	96	$238\frac{1}{2}$	96	96	$238\frac{1}{2}$
End of Part III	96	96	$238\frac{1}{2}$	96	96	$238\frac{1}{2}$
End of Part IV	96	96	$238\frac{1}{2}$	96	96	$238\frac{1}{2}$
End of Part V	96	96	$238\frac{1}{2}$	96	96	$238\frac{1}{2}$

[a] 1/16 in. too short.

[b] 1/8 in. too long.

Differences in diagonals (2) are shown in Table 3. All were within tolerance, except that the end-wall diagonal difference K2 for TACOSS XII appears to have exceeded the limit by 1/8 in. (3.2 mm) during Part II, "Qualification for the Optional Modes of Handling," and then remained constant during subsequent parts. These K2 data are not understood because (a) no change was recorded in Part I when large lateral racking forces were applied and (b) a change was recorded in Part II when no lateral racking forces should have been present.

Table 3. Residual Racking Test Results, Showing Difference in Diagonals

Event	TACOSS XI		TACOSS XII	
	K1 (in.)	K2 (in.)	K1 (in.)	K2 (in.)
Start of Part I	$\frac{5}{16}$	$\frac{1}{8}$	$\frac{1}{16}$	0
End of Part I	$\frac{1}{4}$	0	$\frac{1}{4}$	0
End of Part II	0	0	$\frac{1}{2}$	$\frac{1}{2}$ [a]
End of Part III	0	0	$\frac{1}{2}$	$\frac{1}{2}$ [a]
End of Part IV	0	0	$\frac{1}{2}$	$\frac{1}{2}$ [a]
End of Part V	0	0	$\frac{1}{2}$	$\frac{1}{2}$ [a]

[a] 1/8 in. too much.

After each of the tests involving application and removal of loads (18 times), the containers were exercised to check the fit of detent pins, doors, and panels. This included operating the telescoping corner posts of TACOSS XI and the pallet base of TACOSS XII. The detent pins became progressively more difficult to operate. Finally, some of them had to be pulled out with pliers and inserted by tapping with a hammer. At all times, it was difficult to guide the edges of the panels into the grooves of the rails when securing the panels. This resulted in minor damage to the panels. Thus, modifications appear to be necessary to improve operation of detent pins and panels.

Both structural types failed the weatherproofness test. Leakage was severe in TACOSS XI and slight in TACOSS XII. Additional testing will be necessary to trouble-shoot this problem.

Qualification as Shelters. The structures were exercised successfully in all of the shelter configurations, but shelter qualification was not fully validated because the drop and rain tests were not conducted. Difficulties with the detent pins and panels were the same as in the container tests. These difficulties were severe in TACOSS XI and slight in TACOSS XII.

CONCLUSIONS

1. The concepts for TACOSS XI and XII are feasible. The operating principles work and need not be changed. In general, TACOSS XII is almost acceptable as it is, but TACOSS XI needs many changes in details.

2. The payload, tare weight, dimensional, and residual deflection requirements can be met for all configurations of use and all modes of transportation.

3. Elastic deflections are a problem only in the side panels of TACOSS XI, but considerable effort will be required to solve this problem.

4. Neither type fully qualified as a container due to lack of weatherproofness. This lack of performance is severe for TACOSS XI and slight for TACOSS XII.

5. Qualification as shelters was not fully validated due to the cancellation of drop and rain tests.

6. Ease of operation can be improved by detailing changes. Cited difficulties were many for TACOSS XI and few for TACOSS XII.

RECOMMENDATIONS

TACOSS XI and XI are recommended for advanced development. Technical objectives for advanced development should be:

1. To revise details and weatherseals to achieve the required weatherproofness.

2. To revise details to obtain smoother operation of detent pins and panels.

3. To add the pressure equalization devices required for the fixed wing air mode of transportation.

4. To add the necessary electrical and mechanical subsystems.

The technical approach should include:

1. Design modifications and additions.

2. Production prototype and limited production (Level 2) drawings.

3. Fabrication of two units of TACOSS XI and one unit of TACOSS XII.

4. Testing: weatherproofness, pressure equalization, side and end walls in the rotary wing air mode, operation of detent pins and panels, drop, rain, electrical, hot environment, and cold environment.

ACKNOWLEDGMENTS

CDR Brockwell, LCDR J. Brennan, and Mr. W. C. Brazele of the Civil Engineer Support Office (CESO) at the Naval Construction Battalion Center, Port Hueneme, originated the concepts. Mr. Brazele also coordinated the design review by CESO.

Mr. S. Goldberg and Mr. K. Mack of the Design Division of CEL designed the structures and performed the operational testing. Mr. Goldberg also assisted the author at inspections at the contractors' plants.

Mr. J. Crawford and Mr. F. Johnson of the Structures Division performed the structural analysis and design review by CEL.

Mr. W. Schaaf of Dayton T. Brown, Inc., is especially acknowledged for outstanding performance in the testing of the units for qualification as containers. Detailed information obtained through his notes, telephone calls, and other communications should be helpful for making design modifications and additions. The firm of Dayton T. Brown showed good judgment and took appropriate action each time difficulties were encountered.

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Appendix A

SELECTION OF MATERIALS

INTRODUCTION

This appendix documents a preliminary study to select materials for two different types of special-purpose intermodal containers. The containers are part of a larger system known as the Tactical Container Shelter System (TACOSS) and have been designated TACOSS XI and XII. They are basically ISO (International Organization for Standards) Series 1C dry cargo containers with additional features.

The development goal was pursued by innovative design, static and dynamic finite element analysis, test, and evaluation; time and funding constraints precluded research to improve materials. The following materials were selected:

1. FRP (fiberglass reinforced plastic)/plywood for side, end, and roof panels.
2. Steel for the floor beams and the frames.
3. Wood for the floors.

PANELS

End and roof panels present no particular design problem, because loads are, and details can be, essentially the same as for ordinary 1C containers. Several alternatives are satisfactory. ISO end wall loads usually govern end wall designs, but side racking loads might influence some of the end wall details in the special containers. Roof loads are small compared to other loads; therefore, roof panel designs are usually based on secondary considerations such as standardization, detailing, and weight. For these reasons, particularly standardization, end and roof panels should be made from the same materials as the side panels.

The TACOSS XI's special feature requiring removable side panels is a large departure from ordinary container designs and presents difficult problems. Many alternatives are available, but all have disadvantages, which require complex avoidance-avoidance decision making. FRP/plywood panels are preferred, because they present the fewest technical problems. The large deflection of FRP/plywood panels under 1C sidewall loading is an advantage in ordinary containers, but a disadvantage in the special removable panels, which must be subdivided for handling, must be sealed, and have different edge conditions.

A benefit-cost study by CEL, using the MERDC (Army Mobility Equipment Research and Development Center) evaluation matrix (13), confirms the preference for FRP/plywood. The following materials were eliminated early in the study, becasue they do not satisfy minimum requirements for weight or insulation:

1. 0.047-in. Corrugated Steel
2. 0.062-in. Corrugated Steel
3. Corten Steel
4. Muffler Steel
5. Martinsite Steel
6. Stainless Steel
7. 0.047-in. Corrugated Aluminum
8. 0.062-in. Corrugated Aluminum
9. 0.100-in. Corrugated Aluminum
10. 0.152-in. Corrugated Aluminum
11. 0.1875-in. Aluminum Sheet
12. Aluminum Sheet and Post
13. 1/2-in. Plywood/24-oz FRP
14. 1/2-in. Plywood/18-oz FRP
15. 1/2-in. Plywood/0.040-in. Aluminum
16. 1/2-in. Plywood/0.040-in. Steel
17. 5/8-in. Plywood/18-oz FRP
18. 5/8-in. Plywood/0.040-in. Aluminum
19. 5/8-in. Plywood/0.040-in. Steel
20. 3/4-in. Plywwod/0.040-in. Aluminum
21. 3/4-in. Plywood/0.040-in. Steel
22. 3/4-in. Plywood/0.040-in. Aluminum/0.040-in. Steel
23. 0.062-in. Titanium
24. Expanded Metal Steel and Plastic
25. Expanded Metal Aluminum and Plastic
26. Punched Plate Steel and Plastic
27. Punched Plate Aluminum and Plastic

The following weights were assigned to the attributes considered in the study:

Attribute	Weight (%)
Preventive Maintenance	1
Repairability	1
Corrosion Resistance	1
Weight	15
Flexibility	1
Safety Factor Based on Ultimate Strength	2

continued

Attribute	Weight (%)
Impact Resistance	1
Safety Factor Based on Yield Strength	12
Insulation Properties	5
Modulus of Elasticity	1
Deflection	2
Workability	1
Flame Resistance	1
Joining	4
Percent Elongation	1
Usable Cube (volume)	5
Initial Cost	45
Modulus of Rigidity	1
Total	100

Cost and volume were assigned half the total weight; performance benefits were assigned the other half. Total utility scores were computed for 17 alternatives by applying the weights to the evaluation matrix and summing utilities of attributes for each alternative. The rank order and scores are given in Table A-1 and results show that:

1. For core material, plywood is better than foam; foam is better than paper honeycomb.
2. For facing material, FRP is better than aluminum.
3. 3/4-in. plywood/18-oz FRP is the best combination of panel materials.
4. 2-in. foam/4-lb density/24-oz FRP is the best combination that does not employ plywood.

Table A-1. Results of Benefit-Cost Study

Rank	Score	Panel Type
1	5.9	3/4-in. plywood, 18-oz FRP
2	5.9	5/8-in. plywood, 24-oz FRP
3	5.8	3/4-in. plywood, 24-oz FRP
4	4.6	2-in. foam, 4-lb density, 24-oz FRP
5	4.5	1-in. foam, 4-lb density, 24-oz FRP
6	4.4	2-in. foam, 2-lb density, 24-oz FRP
7	4.4	2-in. paper honeycomb, 4-lb density, 24-oz FRP
8	4.4	1-in. foam, 2-lb density, 24-oz FRP
9	4.3	2-in. foam, 4-lb density, 0.040-in. aluminum
10	4.3	1-in. foam, 2-lb density, 0.040-in. aluminum
11	4.3	2-in. paper honeycomb, 4-lb density, 0.040-in. aluminum
12	4.2	1-in. paper honeycomb, 2-lb density, 24-oz FRP
13	4.2	2-in. foam, 2-lb density, 0.040-in. aluminum
14	4.2	1-in. paper honeycomb, 2-lb density, 0.040-in. aluminum
15	4.2	2-in. paper honeycomb, 2-lb density, 24-oz FRP
16	4.1	1-in. foam, 4-lb density, 0.040-in. aluminum
17	4.0	2-in. paper honeycomb, 2-lb density, 0.040-in. aluminum

A performance-biased study was made by setting the weights for cost and volume equal to zero and normalizing the weights of the rest of the attributes (performance benefits), resulting in the following:

Attribute	Weight (%)
Preventive Maintenance	2
Repairability	2
Corrosion Resistance	2
Weight	30
Flexibility	2
Safety Factor Based on Ultimate Strength	4
Impact Resistance	2
Safety Factor Based on Yield Strength	24
Insulation Properties	10

continued

Attribute	Weight (%)
Modulus of Elasticity	2
Deflection	4
Workability	2
Flame Resistance	2
Joining	8
Percent Elongation	2
Modulus of Rigidity	2
Total	100

Results of the performance-biased study are given in Table A-2. The results in the table indicate that if cost and volume are not considered:

1. For core material, foam is better than paper honeycomb, which is better than plywood.
2. For facing material, FRP is better than aluminum.
3. 2-in. foam/4-lb density/24-oz FRP is the best combination of panel materials.
4. 2-in. paper honeycomb/4-lb density/24-oz FRP is the best combination without foam.

Comparisons of data in Tables A-1 and A-2 indicate that with or without cost and volume considerations:

1. The best panel with a plywood core is the 3/4-in. plywood/ 18-oz FRP.
2. The best panel with a foam core is the 2-in. foam/4-lb density/ 24-oz FRP.
3. The best panel with a paper honeycomb core is the 2-in. paper honeycomb/4-lb density/24-oz FRP.

Therefore, the contenders were reduced to three, and the ranking of them was studied with respect to the importance of cost and volume. Results are shown in Figure A-1.

Points in the upper half of Figure A-1 represent systems which are generally better than average, those in the left half are performance-biased, and those in the right half are cost-biased. The plywood core is the least cost sensitive (least slope in the figure) and has above-average utility from 0% to 90% cost consideration. It is definitely preferred, because it has the most utility from 20% to 100% cost consideration. The foam core and paper honeycomb core would be preferred only for a very highly performance-biased design.

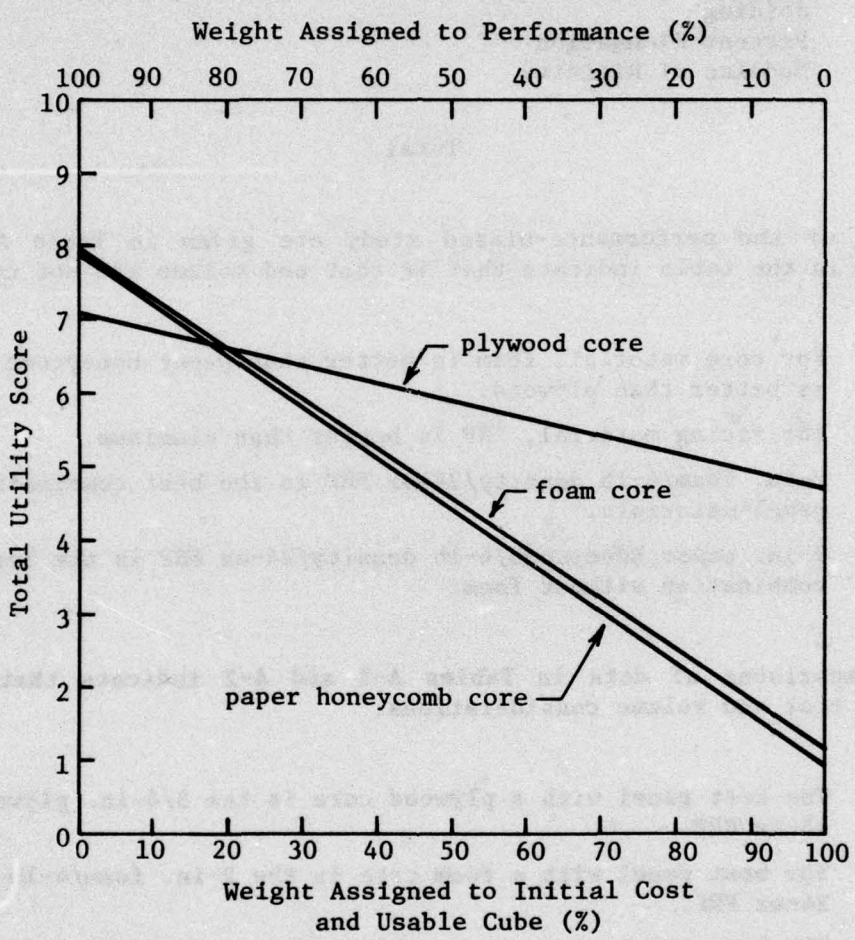

Figure A-1. Sensitivity of panel utility to cost and volume considerations for three basic panel types.

Table A-2. Results of Performance-Biased Study

Rank	Score	Panel Type
1	8.0	2-in. foam, 4-lb density, 24-oz FRP
2	7.9	2-in. paper honeycomb, 4-lb density, 24-oz FRP
3	7.5	2-in. foam, 2-lb density, 24-oz FRP
4	7.4	2-in. paper honeycomb, 4-lb density, 0.040-in. aluminum
5	7.4	2-in. foam, 4-lb density, 0.040-in. aluminum
6	7.2	2-in. paper honeycomb, 2-lb density, 24-oz FRP
7	7.1	1-in. foam, 4-lb density, 24-oz FRP
8	7.1	3/4-in. plywood, 18-oz FRP
9	7.1	5/8-in. plywood, 24-oz FRP
10	7.0	3/4-in. plywood, 24-oz FRP
11	6.9	2-in. foam, 2-lb density, 0.040-in. aluminum
12	6.7	2-in. paper honeycomb, 2-lb density, 0.040-in. aluminum
13	6.6	1-in. paper honeycomb, 2-lb density, 24-oz FRP
14	6.6	1-in. foam, 2-lb density, 24-oz FRP
15	6.3	1-in. foam, 2-lb density, 0.040-in. aluminum
16	6.3	1-in. foam, 4-lb density, 0.040-in. aluminum
17	6.2	1-in. paper honeycomb, 2-lb density, 0.040-in. aluminum

The difference in utility between foam and paper honeycomb is insignificant; thus, those two types are considered to be equally good.

The weights apply to the special containers; whereas, the scores in the MERDC matrix apply to ordinary containers. This limits the validity of the study. Therefore, the results are viewed as a suggestion of what is likely to be best, not as proof of what is best. Regardless of the materials selected, side panel thickness will have to be greater in the special containers.

FRAME

It was stated in the MERDC report "that a container was not found with an all-aluminum frame which could pass the requirements of a cargo container specification." Future research to improve this type of frame could possibly make it best, but for the present this type of frame is not feasible.

Steel and aluminum frames are usually used in designs when commitments are made to steel corner castings for the frame and aluminum facings for the panels. Standard practice is to make the corner castings and corner posts of steel and the rails and the panel fasteners of aluminum. This type of frame is undesirable because of the connection of dissimilar metals. Special joints are located where welding would otherwise be preferred.

None of the three preferred panel types contain aluminum; therefore, the problem of dissimilar metals can be avoided by use of an all-steel frame and steel fasteners. In conclusion, a steel frame is preferred because there is no other good alternative.

FLOOR

The floor system presents uncertainty in design. Three different loadings are likely to influence the sizes and spacings of components:

1. the forklift wheel loading
2. the standard 1C floor loading
3. the special transit drop requirement

The forklift wheel loading is no particular problem but puts a limit on deck thickness versus beam spacing.

For the standard 1C floor loading, allowable design stresses shall not be exceeded under a uniformly distributed static design load of 625 psf on the center half of the span and a lesser intensity on the remainder. The problem here is simply the magnitude of the load coupled with the special feature of a detachable floor. In addition, floor thickness is limited by overhead clearance requirements.

For the special transit drop requirements, the floor must remain elastic when the gross weight of 44,800 lb is dropped a distance of 6 in. from rest onto a concrete surface. A more ambitious drop of 12 in. was found not feasible.

The approach taken is to design the floor for the standard 1C floor load, analyze it for the drop, and then revise the design if necessary. The computerized, finite element, dynamic analysis is expensive and time consuming, but appears to be necessary. The weak link in the analysis is the assumption of a load impulse shape, which limits accuracy regardless of the number of elements used and the accuracy of other input data.

In conclusion, analyses of preliminary designs and past experience with somewhat similar problems indicate that rigorous analysis is required and that a wood and steel floor is the only type with sufficient resilience to absorb the energy of the drop within the elastic range.

Appendix B

FRP/PLYWOOD PANELS USED IN INTERMODAL CONTAINERS

INTRODUCTION

Panels made of plywood overlaid on both sides with FRP are often used for roofs, end walls, and side walls of 8 x 8 x 20-ft intermodal containers. Weights of FRP from 18 to 24 oz/sq yd and plywood thicknesses from 1/2 to 3/4 in. have been used in general-purpose containers and have been evaluated by the Army (13). Panels with 3/4-in. plywood cores were used and evaluated by CEL (10) in Quick Camp modules, which are special-purpose containers. A plywood thickness of 7/8 in. has been used in commercial containers but was not included in either evaluation.

Side panels were nominally 8 x 20 ft and were fixed along all edges, either by bolts or rivets. These panels have high resistance to puncture, impact, and surface wear but respond with large elastic deflections. End and roof panels are either the same thickness as the sides for the sake of simplicity or thinner for the sake of weight savings.

Various FRP/plywood thicknesses and container applications are discussed here to explain why CEL recommended 1-in.-thick plywood core for panels for TACOSS. TACOSS XI and XII are special-purpose containers. Side panels must resist the same loads as those in general-purpose containers, but effective spans and edge conditions are different, and satisfactory weather sealing is more difficult to achieve. TACOSS XI sidewalls are subdivided into five panels, nominally 4 x 8 ft, spanning the long direction, partially fixed at the ends, and free along the sides. TACOSS XII sidewalls are 8 x 20 ft, fixed on three sides, and partially fixed on one side. End panels must resist the same loads as those in general-purpose containers, but one end panel contains an opening for a personnel door.

GENERAL-PURPOSE APPLICATIONS

Side panels made from 1/2-in. plywood have been used in general-purpose containers for the marine, highway, and rail modes of transportation. The safety factors based on both yield strength and ultimate strength were found to be poorer than average when 44 types of containers were considered. "Trident" test specimens deflect about 3 in. under ASTM C-393-62 conditions, but other panels in containers often experience center deflections exceeding 6 in. The standards prior to 1971 did not require any safety factor against yielding, and shippers of low density cargos were willing to gamble in considering container cost, cargo value, and probability of maximum payload occurrence.

Safety factors based on both yield strength and ultimate strength for side panels with 5/8-in. cores were better than average. The centers of full panels in containers deflect about 5 in. Maximum stresses are higher than ordinary design stresses, but appear to be

within the elastic regime. In-service performance has been satisfactory, mainly because the maximum allowable load occurs infrequently, if at all. However, use of these panels is expected to decline because the 1971 standards charge the designer with the responsibility of using appropriate safety factors (design stresses).

Containers having 3/4-in. side and end panel cores are the most numerous. Roofs have either 5/8-in. or 3/4-in. cores. In-service performance has been outstanding. The side panel combination of 3/4-in. plywood and 24-oz FRP ranked eighth of 44 in yield-strength safety factor and ninth of 44 in ultimate-strength safety factor. Panel centers under maximum loading deflect about 3 in. It is difficult to determine whether panels with 1/2-in., 5/8-in., or 3/4-in. cores behave as membranes, plates, or beams, because of the large deflections and the large length-to-height ratio. It is also difficult to determine the relative strength contributions from the FRP and the plywood. It appears that the FRP makes a significant contribution in both bending and shear and that simple beam action in the 8-ft direction is an overconservative assumption. The panels provide all of the diagonal bracing and, thus, much of the container racking resistance.

Containers with 7/8-in. panel cores are the least numerous, and no technical information was obtained. No application of 1-in. cores to 8 x 8 x 20-ft containers were cited.

SPECIAL-PURPOSE APPLICATIONS

General-purpose containers were modified by North American Rockwell, Tulsa, Okla., for use as special-purpose containers in the Quick Camp system. The containers were built by Hussman Refrigeration, Container Division, Seattle, Wash., using panels manufactured by Brooks and Perkins, Livonia, Mich. The roof, sidewall, and end-wall panels were 3/4-in. plywood overlaid on both sides with FRP. Structural modifications were limited to addition of forklift tineways, addition of personnel doors, small penetrations for utility subsystems, and two threaded holes in each corner post. No major changes were made to panel loadings or edge conditions.

Prior to modification, the containers were tested by Miner Enterprises, Chicago, Ill., and certified by the American Bureau of Shipping. In addition to the standard tests in accordance with the ISO recommendation prior to 1972, they passed special Army racking and twin-twenty tests and a special Australian roof tightness test.

After modification, the containers were not tested under maximum load, but they performed in an outstanding manner under a payload of about 15,000 lb during in-service testing at Vandenberg Air Force Base, Calif., and practical use in Thailand. A finite element analysis using SAP (Structural Analysis Program) suggested that local (partial) yielding at stress concentration points would have occurred in the frame adjacent to the openings for personnel doors, if the maximum load had been applied.

Panels with 7/8-in. cores and panels with 1-in. cores have been manufactured successfully, but no applications to special-purpose containers were cited. Trident panels by Brooks and Perkins, similar to those used in the Quick Camp modules, are available with cores from 1/2 to 1 in. at increments of 1/8 in. The thickest panel has a total panel thickness of 1.085 in. and a unit weight of 3.8 psf. Thicker panels were not considered because they would make TACOSS containers too heavy.

REMOVABLE SIDE PANELS FOR TACOSS

The most difficult panels to design for TACOSS are the removable side panels for Type XI. They are nominally 4 x 8 ft, span the 8-ft direction, and fasten at the ends by unique shear developers.

In bending, the panel acts as a simple beam under uniformly distributed load. The span L is 85.3 in., and the maximum load w, governed by the marine mode of transportation, is 132 psf. Therefore, the required moment capacity M_m is:

$$M_m = \frac{wL^2}{8} \qquad (1)$$

For a strip 1 ft wide,

$$w = (132 \text{ lb/ft})(1/12 \text{ ft/in.}) = 11.0 \text{ lb/in.}$$

$$M_m = \frac{wL^2}{8} = \frac{11.0(85.3)^2}{8} = 10{,}000 \text{ in.-lb}$$

Unjointed Trident panels tested by Brooks and Perkins had the following moment capacities parallel or perpendicular to the face grain, according to core thickness:

Thickness (in.)	Parallel (in.-lb)	Perpendicular (in.-lb)
5/8	8,630	9,910
3/4	9,910	13,000
7/8	11,100	15,000
1	12,300	16,700

Therefore, if simple bending stress was the only criterion and a safety factor was not applied, 5/8-in. cores would be unsatisfactory, 3/4-in.

cores would be satisfactory only in one orientation, and 7/8-in. cores would be satisfactory in either orientation. In other words, 3/4-in. cores would have met the minimum standards prior to 1971.

If a capacity reduction factor of 10% were used to account for combined stresses and a capacity reduction factor of 15% were used to account for fluctuations in quality of material and construction, design moment capacities can be obtained by multiplying the moment capacities of the test specimens as follows:

$$\left(\frac{100 - 10}{100}\right)\left(\frac{100 - 15}{100}\right) = 0.90(0.85) = 0.765$$

For those factors of safety, unjointed Trident panels have the following design moment capacities parallel or perpendicular to the face grain, according to core thickness:

Thickness (in.)	Parallel (in.-lb)	Perpendicular (in.-lb)
3/4	7,590	9,940
7/8	8,490	11,500
1	9,410	12,800

Therefore, if the design moment capacity is used as the criterion, either 7/8-in. or 1-in. cores may be used, but the span must be perpendicular to the face grain. In other words, cores at least 7/8-in. thick are needed to meet the 1971 minimum standards.

In order to maintain a satisfactory weather seal between panels when those panels are under different loads, the maximum deflection should be less than the panel thickness. Optimistic and pessimistic estimates of maximum deflection and expected deflections are:

Core Thickness (in.)	Panel Thickness (in.)	Optimistic Estimate (in.)	Expected Value (in.)	Pessimistic Estimate (in.)
7/8	0.960	0.986	1.54	2.09
1	1.085	0.684	1.06	1.45

The optimistic values are theoretical values based on a modulus of elasticity of 8,700,000 psi, which was derived from test data for Trident panels with 3/4-in. cores. The pessimistic values are rough esti-

mates extrapolated in two dimensions: (a) Trident tests to Army studies and (b) 1/2-in. cores to 7/8- and 1-in. cores. The expected value is simply the average of the optimistic and pessimistic values.

Only the 1-in. core passed the expected deflection versus panel thickness criterion and, thus, was selected for the TACOSS XI side panels. A considerable risk was accepted with regard to weathertightness because, essentially, no safety factor at all exists.

Another consideration in panel selection was the coefficient of heat transfer U. Panels were not designed to meet a particular value of U, but the following scale was used to study the relative merits of alternatives:

Performance Quality	Coefficient of Heat Transfer U (Btu/hr/sq ft/F)
Excellent	0.20
Good	0.25
Poor	0.30

Since the functional use of the shelters was undesignated and the outside environment undefined, a range of probable values of U were computed for each alternative. Over the entire range, an inner surface temperature of 66F with a convective heat transfer to air of 0.40 Btu/hr/sq ft/F was assumed. The one end of the range was based on the assumption of an outer surface temperature of 0F and a convective heat transfer to air of 0.44 Btu/hr/sq ft/F. Values for the other end were determined by neglecting convective heat transfer on the outer surface. The following theoretical values of U are based on conductivities of 0.07 Btu/hr/ft/F for wood and 2.35 Btu/hr/ft/F for FRP:

Core Thickness (in.)	Range of U-values (Btu/hr/sq ft/F)
1/2	0.19 to 0.32
5/8	0.18 to 0.31
3/4	0.18 to 0.29
7/8	0.17 to 0.28
1	0.17 to 0.27

These data show a lack of sensitivity of U-values to core thickness, but a strong sensitivity of U-values to the assumed outside environmental conditions. In any case, it appears that the FRP/plywood panels with

1-in. cores will be satisfactory without the addition of insulation. The center of the range of U-values for panels with 1-in. cores is 0.22 Btu/hr/sq ft/F, which is considered excellent.

Bolt bearing strength for panels with 7/8- and 1-in. cores was not available; therefore, the data available for 3/4-in. cores were used and is conservative. Bolt bearing strength was not critical.

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NAVFACENGCOM Code 043 Alexandria, VA; Code 044 Alexandria, VA; Code 0451 Alexandria, VA; Code 0453 (D. Potter) Alexandria, VA; Code 0453C, Alexandria, VA; Code 0454B Alexandria, Va; Code 04B3 Alexandria, VA; Code 04B5 Alexandria, VA; Code 06, Alexandria VA; Code 101 Alexandria, VA; Code 1023 (M. Carr) Alexandria, VA; Code 1023 (T. Stevens) Alexandria, VA; Code 2014 (Mr. Taam), Pearl Harbor HI; Morrison Yap, Caroline Is.; P W Brewer; PC-22 (E. Spencer) Alexandria, VA; PL-2 Ponce P.R. Alexandria, VA
NAVFACENGCOM - CHES DIV. Code 101 Wash, DC; Code 402 (R. Morony) Wash, DC; Code 405 Wash, DC; Code FPO-1 (C. Bodey) Wash, DC; Code FPO-1 (Ottsen) Wash, DC; Code FPO-1SP (Dr. Lewis) Wash, DC; Code FPO-1SP13 (T F Sullivan) Wash, DC; Code FPO-IP12 (Mr. Scola), Washington DC; Scheessele, Code 402, Wash, DC
NAVFACENGCOM - LANT DIV.; Eur. BR Deputy Dir, Naples Italy; RDT&ELO 09P2, Norfolk VA
NAVFACENGCOM - NORTH DIV. Code 09P (LCDR A.J. Stewart); Code 1028, RDT&ELO, Philadelphia PA; Code 114 (A. Rhoads); Design Div. (R. Masino), Philadelphia PA; ROICC, Contracts, Crane IN
NAVFACENGCOM - PAC DIV. Code 09DG (Donovan), Pearl Harbor, HI; Code 402, RDT&E, Pearl Harbor HI; Commander, Pearl Harbor, HI
NAVFACENGCOM - SOUTH DIV. Code 90, RDT&ELO, Charleston SC; Dir., New Orleans LA
NAVFACENGCOM - WEST DIV. 112; 408, San Bruno CA; AROICC, Contracts, Twentynine Palms CA; Code 04B; 09P/20; RDT&ELO Code 2011 San Bruno, CA
NAVFACENGCOM CONTRACT AROICC, Point Mugu CA; AROICC, Quantico, VA; Eng Div dir, Southwest Pac, Manila, PI; OICC, Southwest Pac, Manila, PI; OICC/ROICC, Balboa Canal Zone; ROICC (Ervin) Puget Sound Naval Shipyard, Bremerton, WA; ROICC LANT DIV., Norfolk VA; ROICC, Keflavik, Iceland; ROICC, Pacific, San Bruno CA
NAVHOSP LT R. Elsbernd, Puerto Rico
NAVMIRO OIC, Philadelphia PA
NAVNUPWRU MUSE DET Code NPU80 (ENS W. Morrison), Port Hueneme CA; OIC, Port Hueneme CA
NAVOCEANSYSCEN Code 3400 San Diego CA; Code 52 (H. Talkington) San Diego CA; Code 5224 (R.Jones) San Diego CA; Code 6565 (Tech. Lib.), San Diego CA; Code 7511 (PWO) San Diego, CA
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NAVPETOFF Code 30, Alexandria VA
NAVPGSCOL Code 1424 Monterey, CA; E. Thornton, Monterey CA; LCDR K.C. Kelley Monterey CA
NAVPHIBASE C O ACB ONE San Diego CA; CO, ACB 2 Norfolk, VA; COMNAVBEACHGRU TWO Norfolk VA; Code S3T, Norfolk VA; Dir. Amphib. Warfare Brd Staff, Norfolk, VA; Harbor Clearance Unit Two, Little Creek, VA; OIC, UCT ONE Norfolk, Va
NAVREGMEDCEN Code 3041, Memphis, Millington TN; SCE (D. Kaye); SCE (LCDR B. E. Thurston), San Diego CA
NAVSCOLCECOFF C35 Port Hueneme, CA; C44A (R. Chittenden), Port Hueneme CA; CO, Code C44A Port Hueneme, CA
NAVSEASYSCOM Code 0325, Program Mgr, Washington, DC; Code OOC (LT R. MacDougal), Washington DC; Code SEA OOC Washington, DC
NAVSEC Code 6034 (Library), Washington DC; Code 715 (J. Quirk) Panama City, FL
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NMCB 133 (ENS T.W. Nielsen); 5, Operations Dept.; 74, CO; Forty, CO; THREE, Operations Off.
NORDA Code 440 (Ocean Rsch, Off) Bay St. Louis, MS
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NSC Code 54.1 (Wynne), Norfolk VA
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NTC Code 54 (ENS P. G. Jackel), Orlando FL; Commander Orlando, FL; OICC, CBU-401, Great Lakes IL
NUSC Code 131 New London, CT; Code EA123 (R.S. Munn), New London CT; Code SB 331 (Brown), Newport RI; Code TA131 (G. De la Cruz), New London CT
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PMTC Code 4253-3, Point Mugu, CA; Pat. Counsel, Point Mugu CA
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