AD-783 394

DESIGN, DEVELOPMENT, AND LABORATORY TESTING OF A CONCEPTUAL HELICOPTER-TRANSPORTED CONTAINER HANDLING DEVICE

F. Costa, et al

Boeing Vertol Company

Prepared for:

Army Air Mobility Research and Development Laboratory

May 1974

DISTRIBUTED BY:

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EUSTIS DIRECTORATE POSITION STATEMENT

The conclusions and recommendations contained in this report are generally concurred in by this Directorate.

Additional limited flight demonstrations are planned to determine further design refinements identified with rotor downwash, ground effects, payload acquisition procedures, aerodynamic characteristics, and other related factors.

Mr. S. G. Riggs, Jr., Military Operations Technology Division, served as Project Engineer for this effort.

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1. REPORT NUMBER: USAAMRDL-TR-74-40	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER: AD-783 394	
4. TITLE (and Subtitle): DESIGN, DEVELOPMENT, AND LABORATORY TESTING OF A CONCEPTUAL HELICOPTER-TRANSPORTED CONTAINER HANDLING DEVICE	5. TYPE OF REPORT & PERIOD COVERED: Final report
	6. PERFORMING ORG. REPORT NUMBER: D210-10507-2
7. AUTHOR(s): F. Costa, R. Seebol, W. Nutley, G. Wilson	8. CONTRACT OR GRANT NUMBER(s): Contract DAAJ02-72-C-0083
9. PERFORMING ORGANIZATION NAME AND ADDRESS: The Boeing Vertol Company, A Division of The Boeing Company, Philadelphia, Pennsylvania 19142	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: Task 1F161104AA3303
11. CONTROLLING OFFICE NAME AND ADDRESS: Eustis Directorate, U. S. Army Air Mobility R&D Laboratory, Fort Eustis, Va. 23604	12. REPORT DATE: May 1974
	13. NUMBER OF PAGES: 137
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Helicopters
Cargo
Materials Handling Vehicles
Containers

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report covers research, developmental, and experimental work required to design, fabricate, and demonstrate a container handling device for acquiring, transporting, and delivering standard 8x8x20-foot cargo containers by designated Army helicopters without the aid of ground personnel.

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A new approach to container handling devices has evolved for the helicopter application. A three-tier built-up aluminum "X" frame structure is used to reduce weight to about 40 percent of equivalent commercial equipment while reacting, in addition to static loads, the aerodynamic and maneuver loads associated with the helicopter mission. Conventional twist locks are employed to latch the device to the container. Locking side and end self-alignment guides are used to provide positive self-centering over a free-standing container. These guides retract inside the 8x20-foot planform to permit device entry into a 20-foot containership cell. Power and control of the device are provided from the transporting helicopter.

A weight range of 1,000 to 1,200 pounds has been demonstrated for a single-purpose helicopter-transported container handling device. The structural integrity and inherent self-alignment capability of the device designed under this program have been verified by laboratory demonstrations. Evaluation of the device under actual flight test conditions, which was not a part of the current program, should be performed to confirm the design and laboratory findings.

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INTRODUCTION

BACKGROUND

Increased emphasis is being placed on transporting military cargo in standard containers. Commercial users have developed equipment for handling containers in loading, unloading, transporting, and interchange between surface transportation modes. A critical portion of the delivery of containers to support military operations is the transport of containers as helicopter external payloads. The major part of the planned heavy lift helicopter's mission is to pick up and deliver containers both from ship to shore and between ground locations. Full advantage of the helicopter's productivity cannot be exploited unless means for rapid pickup and release of the load can be provided. External transport of containers by helicopters has been demonstrated using container handling devices designed for commercial surface activities; however, these devices are unsuitable for aircraft use due to their high weight and bulk and general incompatibility with helicopters and aerodynamic factors.

This document describes the design, fabrication, and demonstration of an experimental container handling device for transporting standard 8x8x20-foot U.S. Army MILVAN and commercial ANSI/ISO containers by CH-47, CH-54, and HLH helicopters without the aid of ground handling personnel.

STATEMENT OF THE PROBLEM

The container handling device is an interface subsystem linking two complex and widely different systems. On the one hand are three helicopters -- the CH-47, CH-54 and HLH -- which differ greatly in size; weight; external cargo lifting capacity; hover precision; hover, approach, and departure wind considerations; onboard power sources; type of external cargo systems; inclusion or absence of external load winching provisions; fixed or swivelling cargo hooks; etc. On the other hand are the containers, which have evolved in the commercial field with its technology, tolerances, and rough handling techniques. For the most part, they do not possess onboard power sources, and they must be picked up in open areas or while stacked below decks on containerships in vertical guide rails. Containers must be considered as invariants with no possibility of modification to facilitate the handling device functions, since most of them are privately owned ANSI/ISO configured and dispersed throughout the world.

Major technical challenges lie in three areas of this problem. First, the most desirable configuration would be compatible with both single-point and tandem dual hook helicopter external cargo systems. Second, the problems of device rotation under the influence of rotor downwash and flight aerodynamics are significant obstacles for the single-point hook configuration. Third, an alignment system has to be developed for the device to quickly and accurately position the twist locks over the container corner fittings while the transporting helicopter is hovering with an offset commensurate with its hover precision capabilities.

PROGRAM SCOPE

The effort was divided into three phases.

Phase I - Operational Analysis, Design Configuration Study, and Trade-Off Analysis

Phase II - Detail Design, Fabrication, and Laboratory Test Plan Preparation

Phase III - Laboratory Test and Design Update

PHASE I
OPERATIONAL ANALYSIS, DESIGN LAYOUTS, AND TRADE-OFF STUDY

OPERATIONAL ANALYSIS

The details of the Phase I effort are presented in Appendix I. The following is a brief summary of the findings and conclusions of Phase I.

The operations analysis identified all the detail functions which must be accomplished in the preparation and performance of the total helicopter missions involving acquisition, transport, and delivery of containers. These functions were reviewed during the initial container device design layout phase and later during the detail design phase to insure that all design decisions considered not only the direct functions of the device itself but also its impact on the total mission. An example of this process is the use of an open framework structure for the device rather than an enclosed semimonocoque arrangement to provide a stable device, without the container attached, for the cruise to lift area and steep descent portions of the helicopter mission.

Time-line analysis, using the offloading of 1,000 containers from an offshore containership in 2 days, established a substantial savings in mission time. This was translated into a design objective of automating as many device functions as possible and of weighing heavily the desirability of all possible time-saving features.

Device Weight

The effect of container handling device weight on 10-year system cost was analyzed and found to be essentially an exponential function. At a 1,000-pound weight, the device has a 10-year system cost of $20,000; while at 5,000 pounds, the cost grows to $340,000. The reasoning behind the maximum device weight of 1320 pounds specified in the contract is apparent from this analysis. The desirability of providing a device that weighs significantly less than 1320 pounds is also indicated.

Overall Dimensions

Design constraints for the container handling device were found to be dictated primarily by the specifications and tolerances of the U.S. Army MILVAN and American National Standards Institute/International Standards Organization (ANSI/ISO) containers. In addition, the requirement to acquire these containers from containership cells below deck was a major factor. The containers have both upper and lower corner fittings. Each fitting has a side and end opening as well as either a top or a bottom opening, depending on its location. The helicopter-transported container handling device can use only the top openings in the four upper corner fittings because these are the only locations that are accessible when the container is inside a containership cell.

Strength Criteria

Strength criteria for the device were based on the capacity of the transporting helicopters. The tandem dual cargo hook system in the heavy lift helicopter has a capacity of 28 tons with a limit load factor of 2.5g's. Uneven loading of the forward and aft lifting points, resulting from asymmetric container center-of-gravity locations, can be either 60/40 or 40/60. This criterion was used in addition to an allowable cable inclination angle of 30° from the vertical to account for aerodynamic drag and a fixed 2780-pound aerodynamic download from rotor downwash. The resulting limit load at each of the four device corners, for the tandem dual hook mode, is 57,800 pounds.

The CH-47 Chinook and CH-54 Tarhe helicopters have single-point cargo handling systems. A maximum capacity of 12.5 tons with a limit load factor of 2.3g's was assumed for the single-point mode of the container device used with either of these helicopters.

Positioning Criteria

The top openings in the container corner fittings are roughly 2-1/2 inches wide and 5 inches long. Diagonally opposite corner fittings on the 20-foot containers are roughly 23 feet apart. To engage the four top corner fittings, the container handling device must be positioned within longitudinal, lateral, and azimuth precisions of ±2.5 inches, ±1.3 inches and ±0.05 degree, respectively, relative to the container.

The hover precisions of the three transporting helicopters are estimated to be:

Model	Hover Precision Over a Spot
CH-47	±2-3 feet
CH-54	±1-2 feet
HLH	± 4 inches

None of these helicopters is capable of positioning the container device accurately enough for unassisted engagement of the container corner fittings. The container device must therefore be equipped with a self-centering system capable of providing the required improvement in alignment accuracy.

The system must either be located inside the 8x20-foot planform of the container or be retractable to permit entry into 8x20-foot containership cells.

Material Selection

Before initial design layouts could be prepared for the container device, the primary structural material had to be selected because the configuration of the device depends on the mechanical properties, structural shapes, and methods of assembly of the prime material.

A comparison was made of the tensile and compressive strengths and moduli, fracture toughness, and lead time requirements for availability of structural shapes of the following materials:

Steel
Aluminum
Boron/Epoxy
Graphite/Epoxy
S-Glass/Epoxy
E-Glass/Epoxy
PRD-49-1/Epoxy

It was concluded that aluminum alloy of the 6061 type was the best compromise for this program based on ready availability of plate and sheet stock, strength and stiffness to weight criteria, weldability, and corrosion resistance.

PRELIMINARY DESIGN LAYOUTS

Layouts were prepared for four potential configurations for the container handling device:

1. Rectangular fixed length
2. "X" frame fixed length
3. Telescoping adjustable length
4. Two-element cooperative

The rectangular fixed-length device uses conventional longitudinal and lateral elements, plus diagonal braces to support the corner twist locks and self-centering system, and to react the crushing loads produced by lifting and helicopter transport. It is designed to carry only the 20-foot-length container.

The "X" frame fixed-length device is similar to the rectangular unit except that it uses main structural elements that are in the same vertical plane as the legs of a four-leg bridle sling, which is required to connect the device to either of the two single-cargo-hook helicopters (CH-47 and CH-54).

The telescoping adjustable-length device has two extendable elements which allow it to adjust to accept containers of 20-, 24-, 27-, 35- and 40-foot lengths.

The two-element cooperative device uses one element which is preattached to the container at the lifting site and a second element which is carried by the helicopter. Each of the elements has a mating system which is compatible with the hover precision of the three transporting helicopters, thus solving the alignment problem. The disadvantages of this concept are in the logistics and attachment of the element to the container.

TRADE-OFF STUDY

A weighted parameter trade-off study was performed to compare the relative merits of the four potential device configurations. Parameters included in the evaluations were:

- Weight
- Mission time
- Simplicity
- Cost
- Height
- Power requirements
- Positioning
- Adjustability
- Reliability
- Maintainability
- Logistics

Figures of merit were established for each of the configurations:

Configuration	Figure of Merit
Rectangular fixed length	81
"X" frame fixed length	130
Adjustable length	19
Two-element cooperative	94

Since the "X" frame fixed-length configuration had the highest figure of merit, this design was recommended for expansion into a detail design. Primary factors in the decision which favored the "X" frame configuration were low weight, good reliability, and potential for low overall height.

PHASE II - DETAIL DESIGN AND FABRICATION

STRUCTURAL DESIGN CRITERIA

The Phase II effort began with the establishment of criteria on which the detail design layouts would be based. These included:

1. 6061-0 aluminum sheet stock would be bent into channels and angles, which would be welded into subassemblies and then heat-treated for most structural members. This would be done to avoid the lead times inherent with extruded shapes and the high cost of fully built-up structures.

2. Where closed sections would be required for compressive or buckling strength, they would be built up using the bent-up channels closed by a welded-on plate.

3. A minimum structure thickness of 0.10 inch would be used for tolerance to rough handling whenever stress analyses indicated that a thinner guage could be used.

4. Machined fittings would be made from 4-inch-thick 7075-T6 aluminum plate stock to avoid the requirement for special billets.

5. The basic "X" frame would be divided into five sections (four outer welded sections and a center welded section) to keep overall sizes for heat treatment within the limits of locally available processing ovens and tanks. The sections would be joined together by mechanical fasteners at a series of manufacturing splices.

SYSTEMS DESIGN CRITERIA

Two types of operating subsystems were decided upon for the container device: corner twist locks, and retractable side and end alignment guides. Design criteria for these systems included:

1. Power source for the subsystems would be 115/208-volt, 3-phase, 400-cycle, A-C current, which is available on-board each of the three transporting helicopters.

2. A low-pressure, 750-psi, self-contained hydraulic system would be mounted on the container device to drive a single twist lock cylinder and push-pull rod system and six alignment guide cylinders. A 400-cycle, 2-h.p. electric motor would be used to drive the hydraulic pump.

3. The operating subsystems would be controlled by an operator in the helicopter, via a control box and umbilical cord. Each subsystem would be as automated as possible to minimize operator tasks.

4. Control of the hydraulic cylinders would be by 28-volt D-C solenoid valves. This power source is available on each of the transporting helicopters.

5. Off-the-shelf commercial hydraulic and electrical components would be employed in the interest of economy and to avoid long delivery times. No military specification qualifications were required on these experimental conceptual container devices.

CONTAINER DEVICE DESIGN

Detail structural designs for the container device were developed through an evolutionary process. A designer analyzed the structural requirements and prepared detail subassembly drawings. Stress analyses were then performed to verify structural integrity and to identify underdesigned and overdesigned areas. The designs were then refined, where possible and time permitting, to optimize the structure.

A weights engineer, in conjunction with the designer and stress engineer, established weight targets for the major elements of the device to meet the contract weight objective of 1,320 pounds. As each subassembly design drawing was completed, weight was calculated and compared to the appropriate target weight. If an overweight condition was indicated, the design was reviewed and either modified or completely redone to reduce the weight.

Designs were reviewed next with the fabrication subcontractor. Program timing was considered very tight; therefore, designs were released to the shop only after raw material availability was confirmed. Some designs were altered based on material availability.

A system of phased design releases to the shop was adopted to allow the design effort to overlap with the manufacturing effort. Machined fittings were released first. Welded and heat-treated structural assemblies were next. Mechanically fastened assemblies, followed by subsystem installations and details, completed the process.

One primary structural component, the device twist lock, was purchased from the manufacturer of a commercial container handling device. ANSI/ISO standards define dimensions for the twist locks. Since they are single-load-path elements of fixed dimensions, their strength is dictated by material and heat-treat. The commercial twist locks are forged 4,000 series steel parts with a 125,000-psi to 145,000-psi heat-treat. The commercial supplier indicated a willingness to supply twist locks, modified slightly to our specification at nominal cost. It was decided to purchase these parts rather than to fabricate them.

A record was kept of the progression of the container device detail design in the form of two-view sketches and isometric drawings. The initial device configuration prior to the Phase I trade-off study is shown in Figure 1. This configuration was a rectangular framework with four retractable corner guides. The estimated weight was 1,550 pounds.

Figure 2 shows the device configuration which received the highest figure of merit in the Phase I trade-off study. The configuration is an "X" frame with side and end self-alignment guides. The estimated weight was 1,200 pounds.

Before the decision was made to use a welded subassembly type structure, the configuration shown in Figure 3 was considered. Here, a fully built-up rivetted construction is used with 65-inch-long side guides to provide ±30 inches of longitudinal and lateral tolerance in aligning with the container. A lattice type longitudinal drag beam is used between the two forged dual-mode hookup points. Individual hookup points are provided on the four outer "X" frame sections for attachment of a four-leg bridle sling for single-point lifting. The estimated weight was 1,400 pounds.

The use of a hybrid welded subassembly type structure with a detachable rivetted drag beam is shown in Figure 4. In this configuration the side and end guides were shortened to roughly 30 inches, which provides a ±15-inch alignment tolerance. The end guides are forked to provide clearance for engaging the full swivelling HLH cargo hooks in the dual-mode hookup shackles. The dual-mode shackles have been changed from forgings to built-up side plate structures. The crossbar which the HLH cargo hook contacts is made from Carpenter Custom 455 steel, the same material which is used in the HLH cargo hook, to provide optimum compatibility. The drag beam is a closed box section consisting of two extruded side channels and sheet top and bottom surfaces. A center splice is used because extrusions were only available in 10-foot lengths. The drag beam is field removable to save weight for the single-point lifting mode, where a 200-pound wire rope sling must be used.

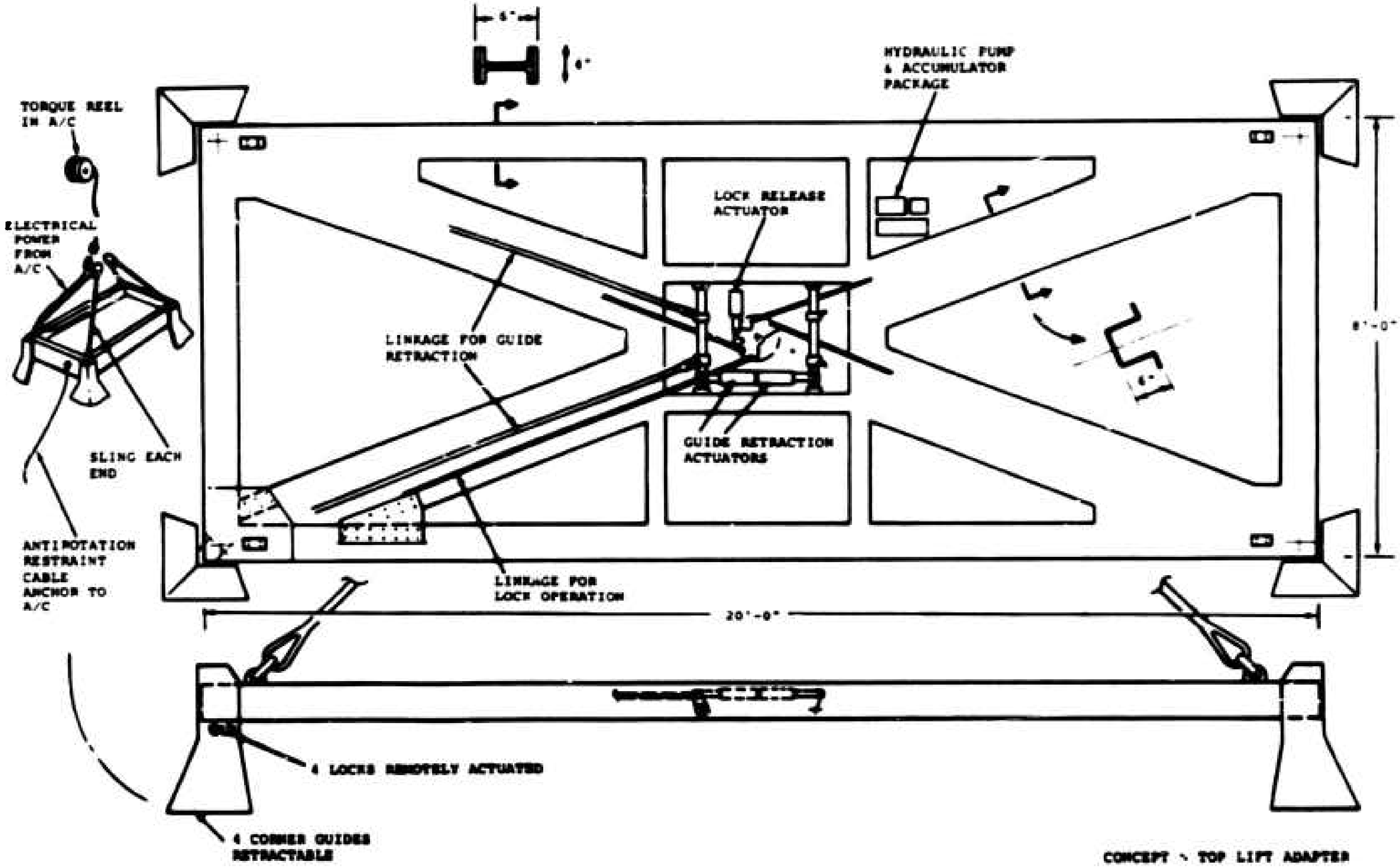

Figure 1. Schematic of Proposed Helicopter-Transported Container Handling Device.

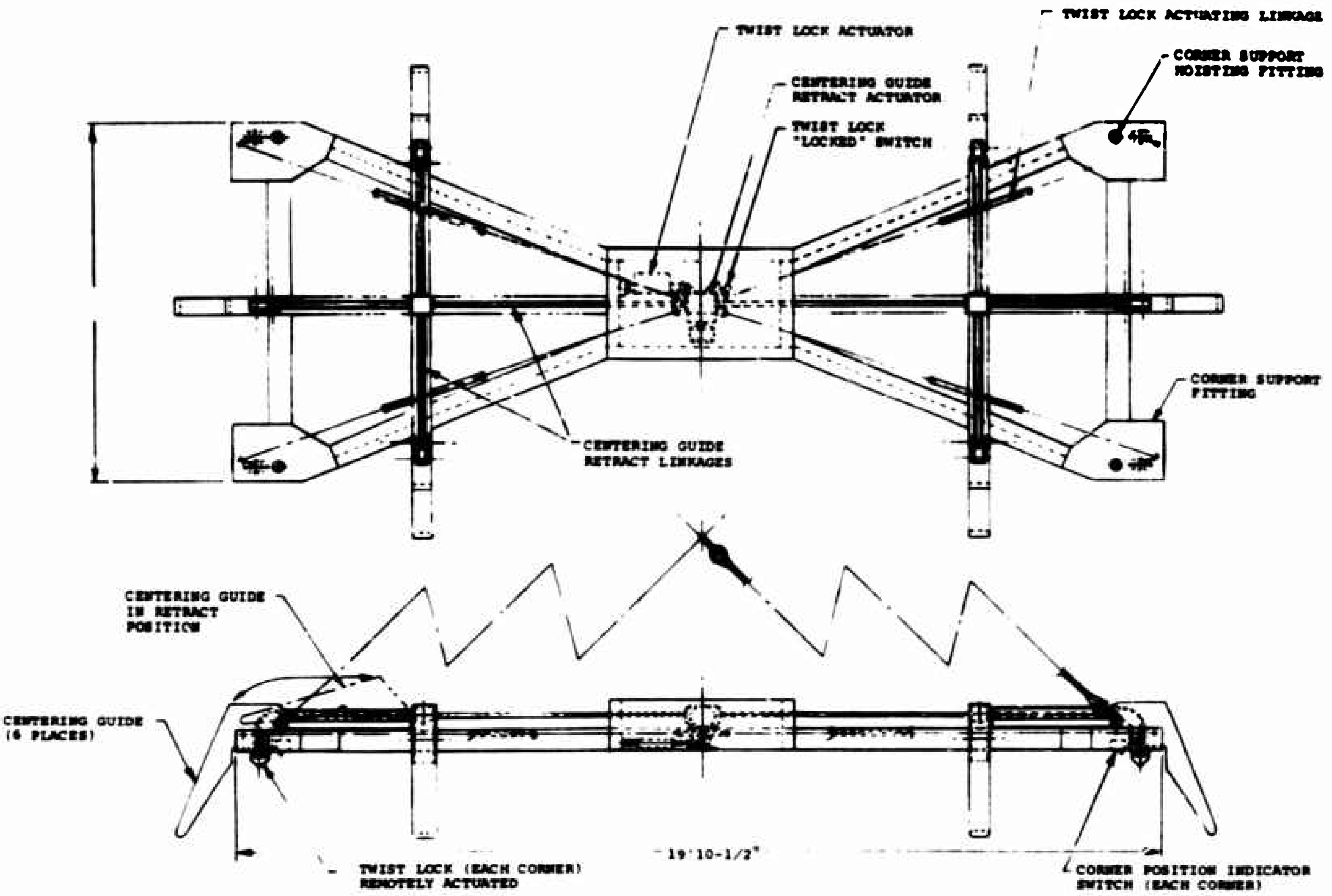

Figure 2. "X" Frame Container Handling Device Configuration.

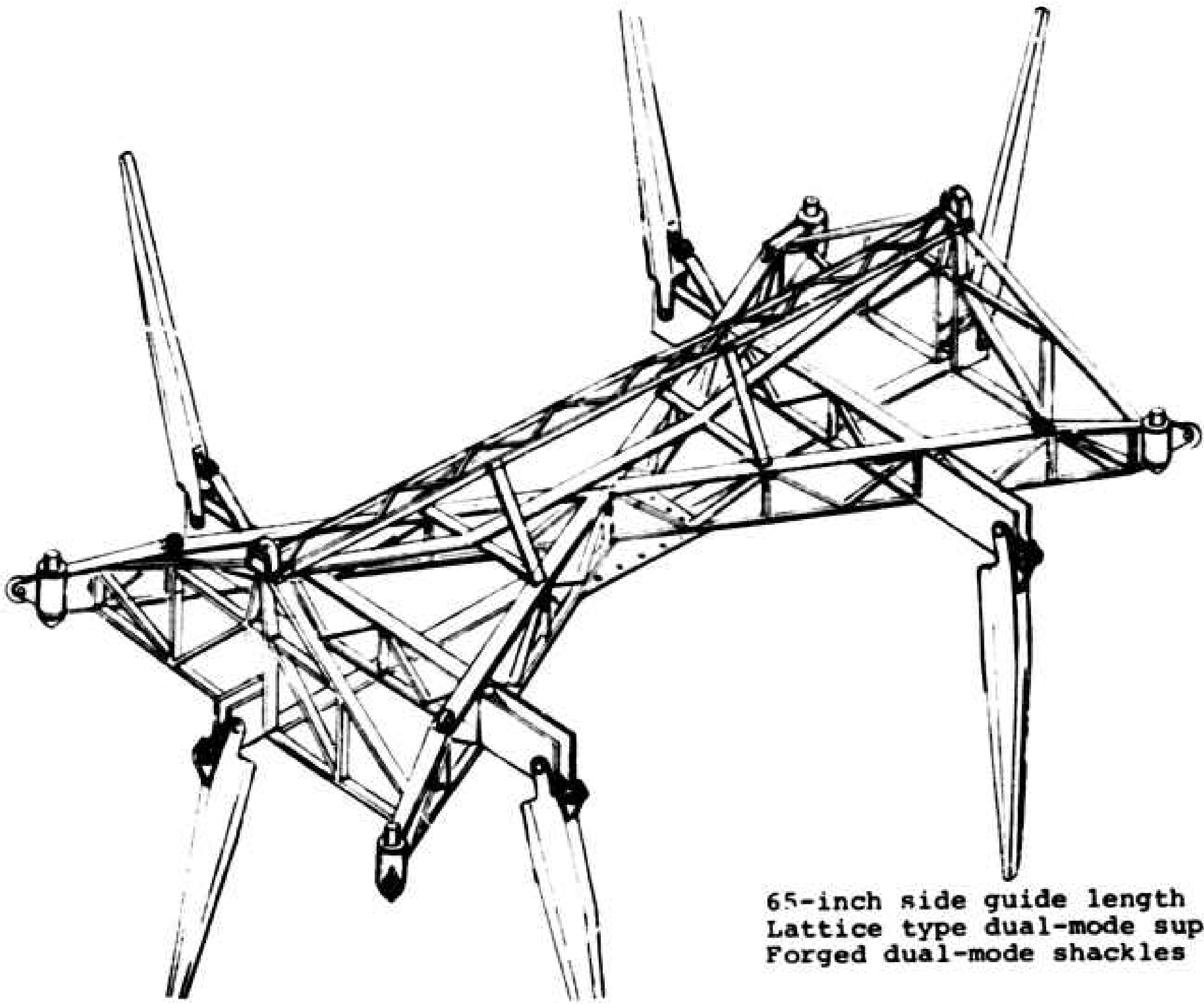

Figure 3. Fully Built-Up (Rivetted) Container Handling Device Configuration.

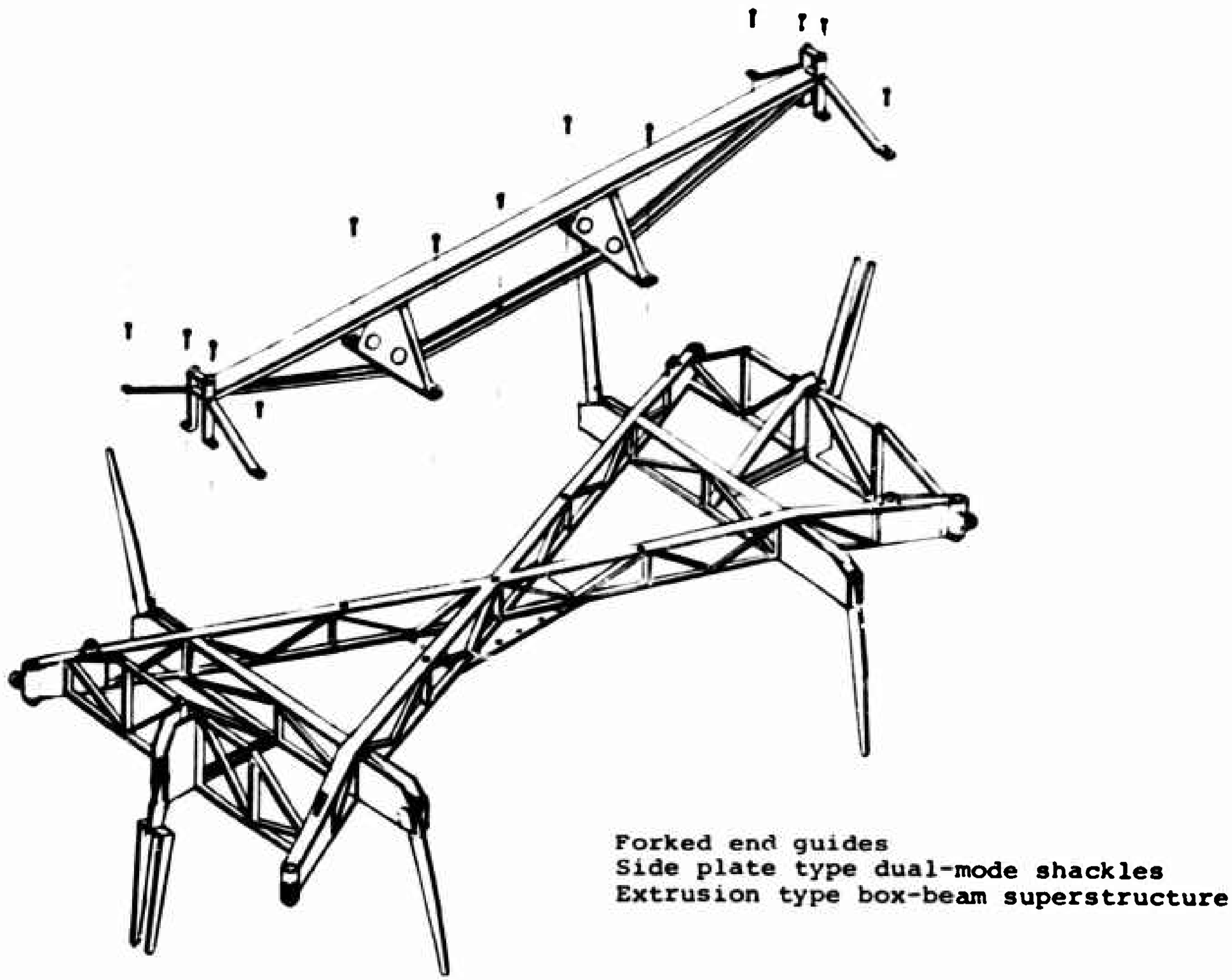

Figure 4. Hybrid Welded Container Handling Device Configuration.

Figure 5 shows the container device configuration which went into fabrication. It contains all of the features shown in Figure 4 and described above and also reflects additional structural refinements. The HLH cargo couplings and the outline of the container are shown for reference only. The push-pull rod system which controls the four corner twist lock pins is partially shown, but none of the side/end guide actuating mechanism or the hydraulic system components are indicated. Figure 6 shows the device configured for the single-point lifting mode with the drag beam removed and the bridle sling in place.

A list of the engineering drawings and sketches which describe the detail design for the helicopter-transported container handling device is presented in Table I. Figure 7 shows the nomenclature for most of the major structural elements in the device. The detailed stress analysis for the container handling device is provided as Appendix II.

A photograph of one of the two container devices fabricated under this contract is shown in Figure 8.

OPERATING SCENARIO

Tandem Dual Hook Mode (HLH)

The device is positioned under the helicopter cargo winches with the ball-shaped hydraulic reservoir closest to the cockpit. The drag beam is in place and the wire rope sling is removed. The helicopter cargo couplings are lowered and manually engaged in the dual-mode pickup shackles. The helicopter control box (see Figure 9) is positioned in the load controlling crewman (LCC) station and plugged into the 115/208-volt 400-cycle A-C and 28-volt D-C electrical systems using the HLH cable. The umbilical cord is connected to the control box, routed under the helicopter fuselage to a point between the two winches, and then down to the device, where it is plugged into the electrical power connector located close to the center of the "X". Hydraulic fluid level is checked visually on the sight glass attached to the ball-shaped hydraulic reservoir and topped off if necessary.

The hydraulic pressure switch on the control box is moved to the 'on' position and may remain in this position for the duration of the mission. When the hydraulic system pressure reaches 750 psi, a pressure switch automatically turns the motor/pump off. When the hydraulic system pressure drops below 650 psi, either through normal actuation or by internal leakage in the hydraulic solenoid valves, the motor/pump automatically runs until the pressure again reaches 750 psi. Running of the motor causes a flicker in the green hydraulic pressure light on the control box.

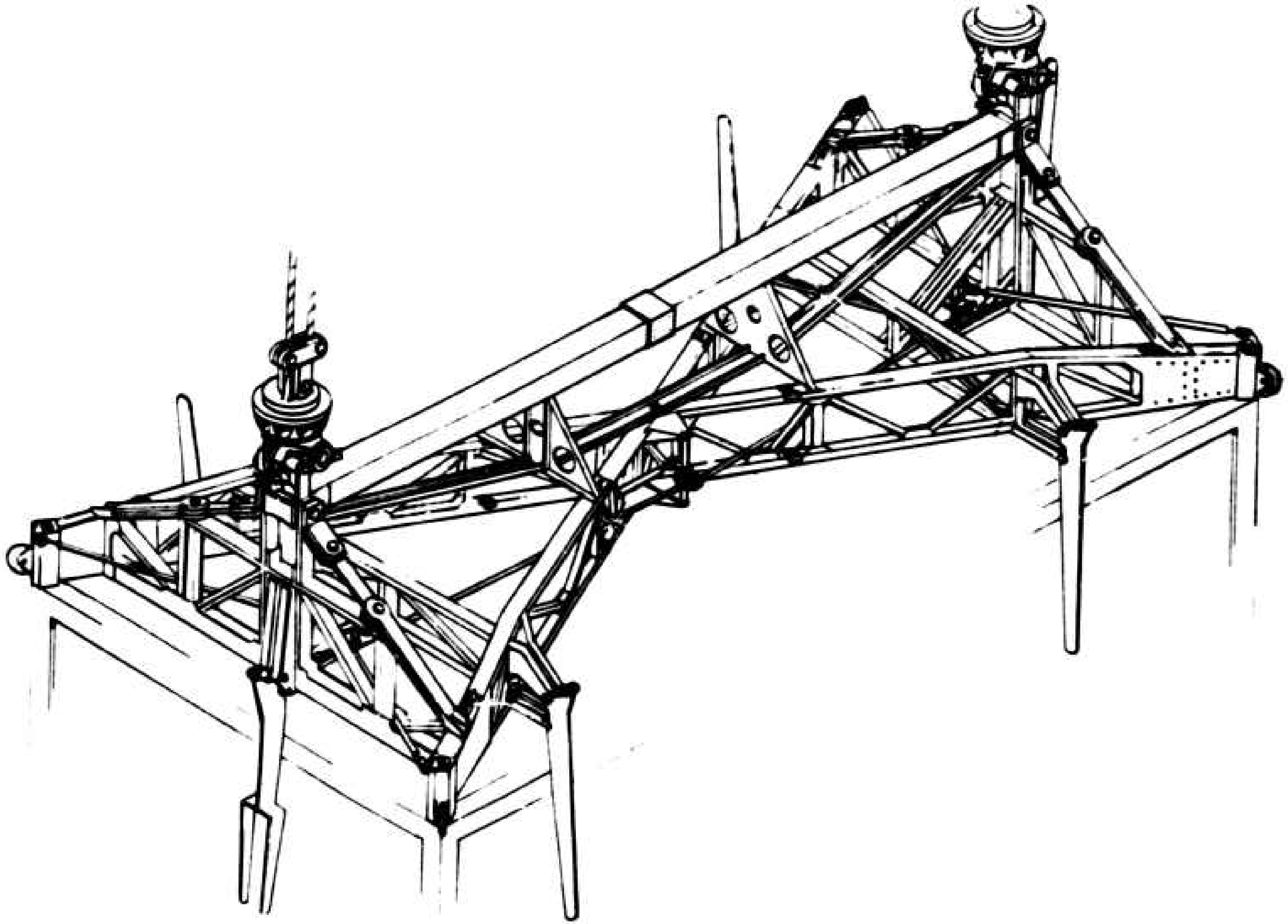

Figure 5. Final Container Handling Device Configuration.

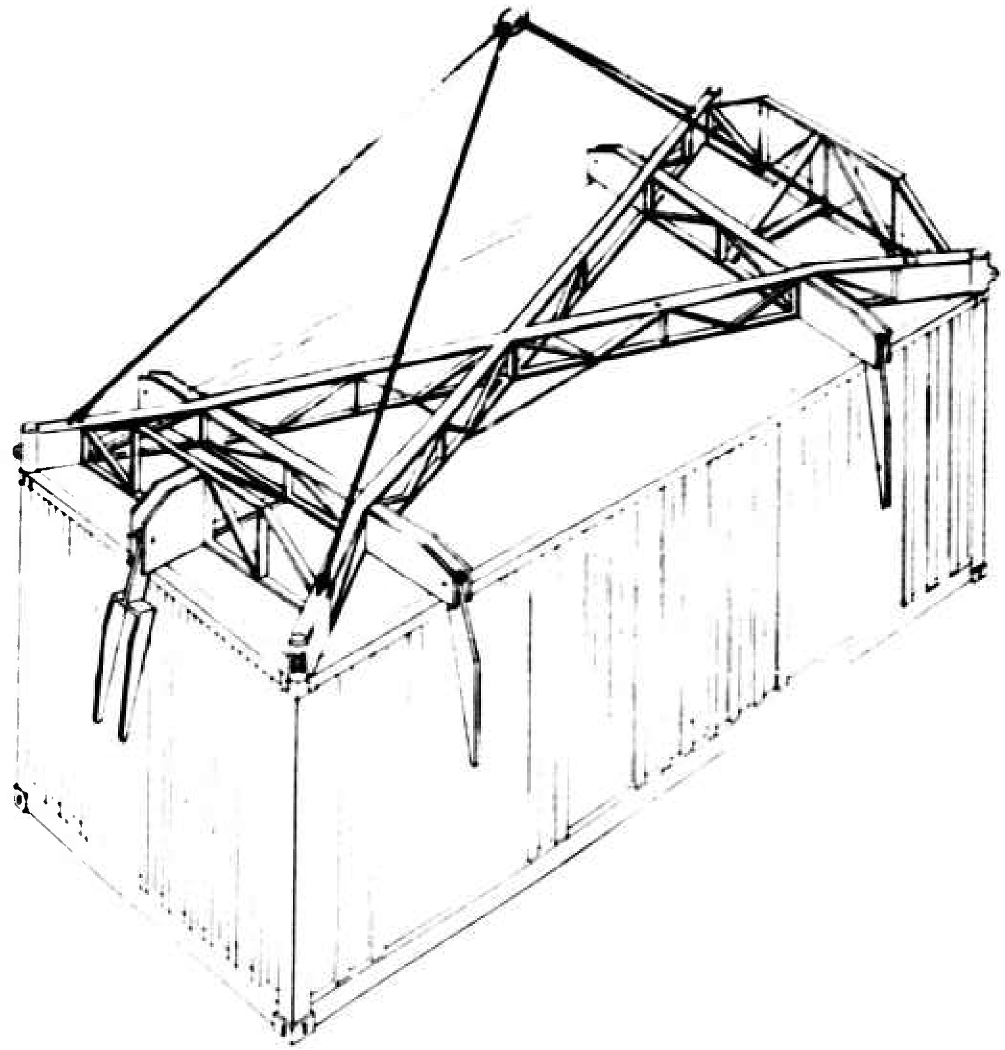

Figure 6. Single-Point Container Handling Device Mode.

TABLE I. LIST OF ENGINEERING DRAWINGS AND SKETCHES

Drawing Title	Dwg. No.	Rev.
Housing Cargo Carrying Device Twist Lock	SK24888	B
Bulkhead Cargo Carrying Device Box Beam	SK24893	B
Center Section - Container Handling Device	SK24908	C
Outer Section Container Handling Device	SK24911	B
Shackle Cargo Handling Device	SK24912	B
Guide Container Handling Device	SK24924	B
Dual Mode Beam - Container Handling Device	SK24934	B
Pin Twistlock - Container Handling Device	SK24938	A
Drag Beam Container Handling Device	SK24955	A
Guide Support Lateral Truss Container Handling Device	SK24957	B
Upper Clevis Details - Container Handling Device	SK24962	-
Details Container Handling Device	SK24965	B
Support Structure End Guide Container Handling Device	SK24967	B
Configurations Container Handling Device	SK24992	-
Mechanical Control System - Cargo Handling Device	SK24993	B
Center Section Truss Container Handling Device	SK25160	B
Electric Wiring Diagram Container Handling Device	SK26134	-
Container Device Hydraulic System	SK26138	-
End Guide Full Retraction Linkage	SK26139	-
Container Device Helicopter Control Box	SK26145	-
Tank Assembly Hydraulic Fluid	114H4600	K
Switch Pressure Hydraulic Fluid	114HS112	H

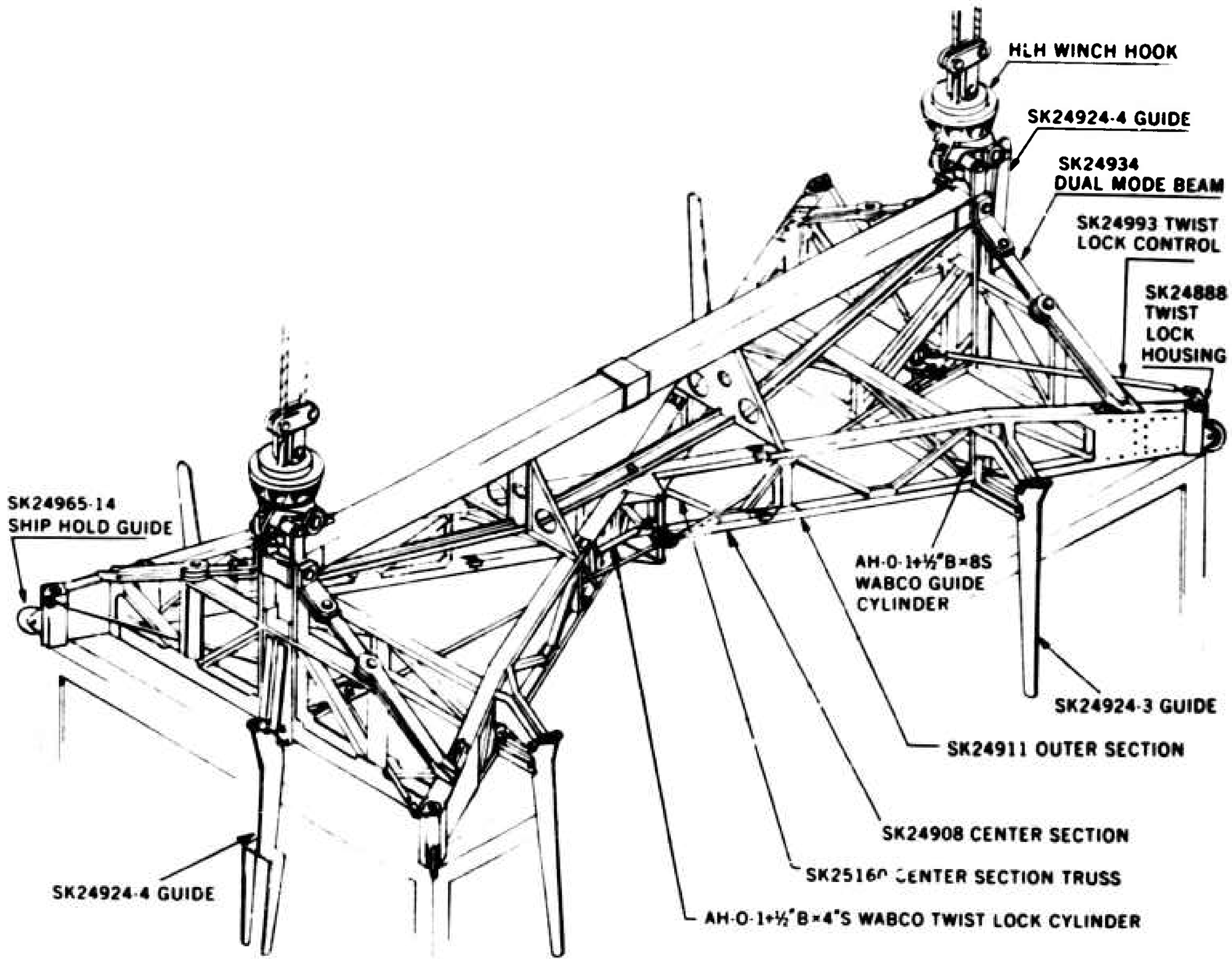

Figure 7. Nomenclature - Major Container Device Structural Elements.

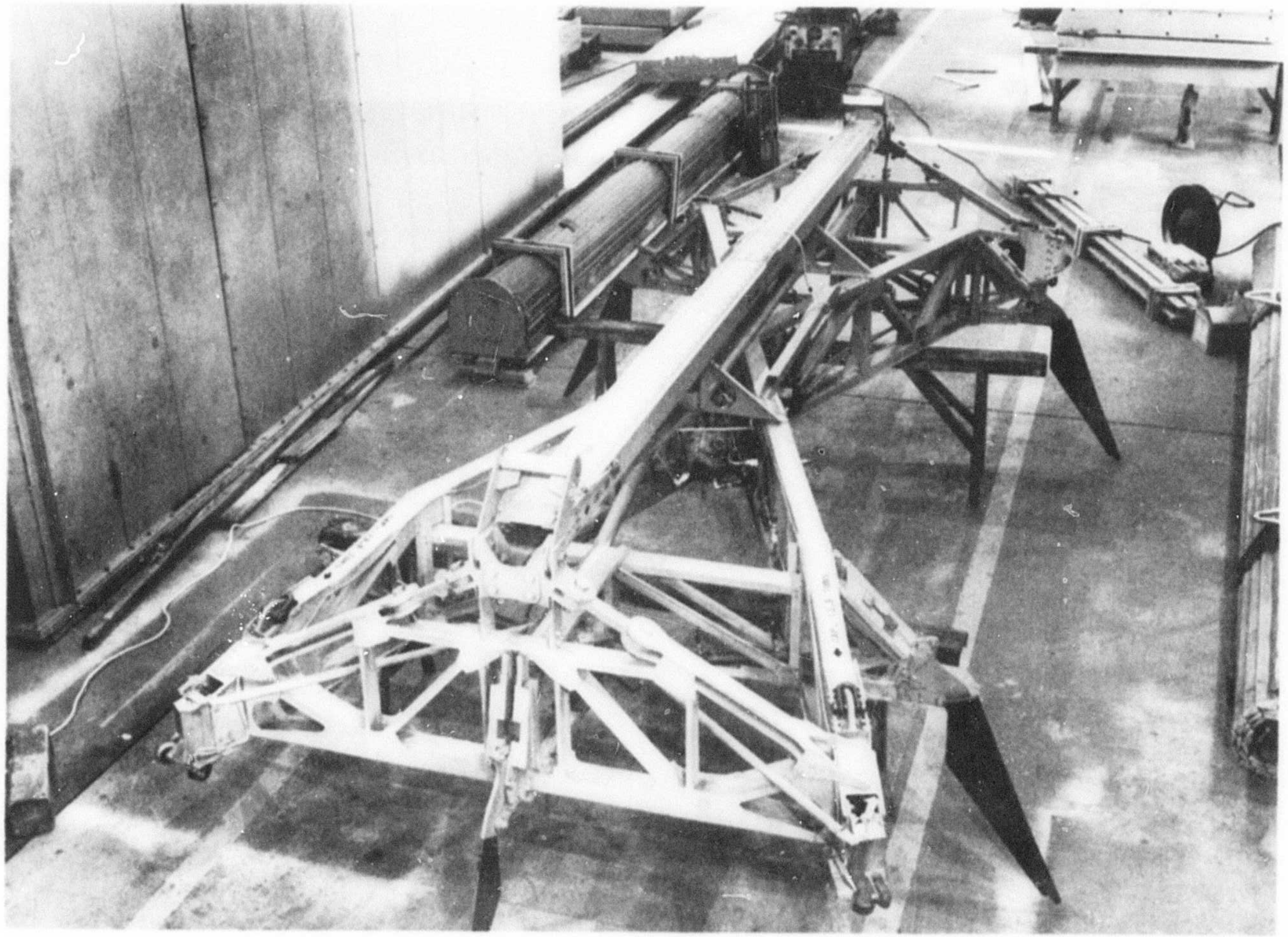

Figure 8. Helicopter-Transported Container Handling Device SK24992-1.

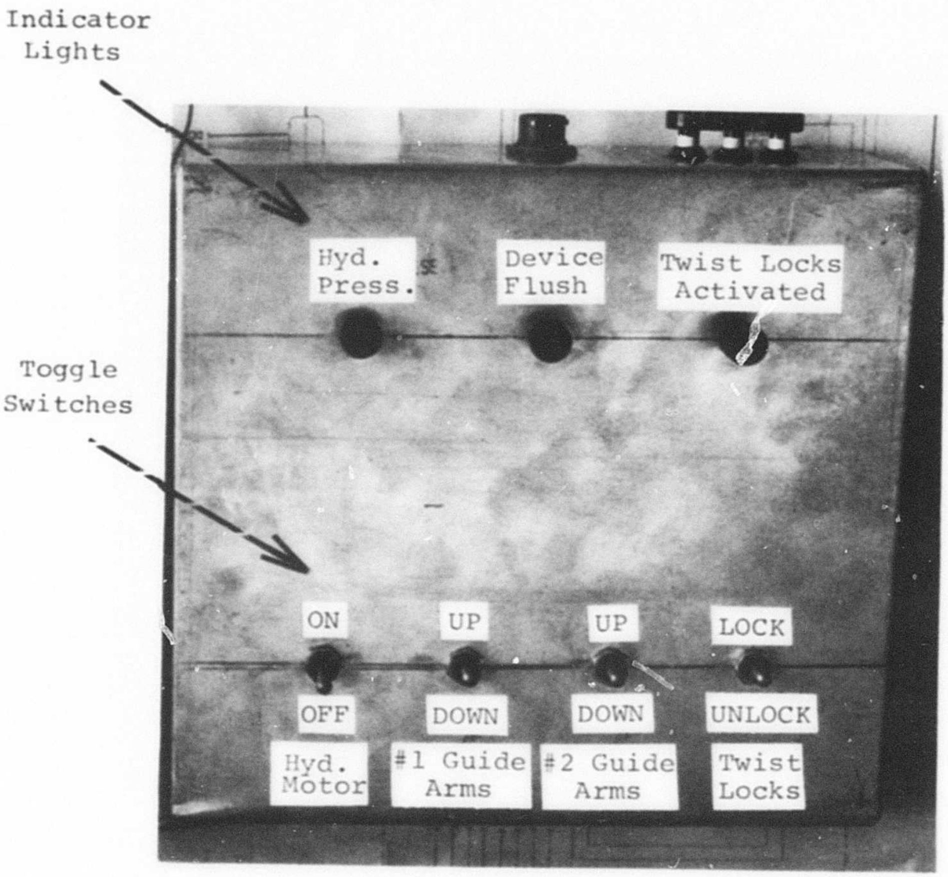

Figure 9. Helicopter Control Box.

When sufficient ground clearance is available, the two sets of side/end guides may be functionally checked. Each set consists of the pair of guides on one 20-foot side and one of the two end guides. This arrangement was selected to permit a quartering approach to a free container in addition to the vertical descent with all six guides down. Each guide has an integral mechanical lock which engages automatically and keeps the guide in a down and locked position when it strikes the sides of the container during alignment. The helicopter-borne control box has two guide switches, each color coded to match the three guides it controls. Two guide positions are available: up, which retracts the guides inside an 8 x 20 planform; and down, which is the locked position used for aligning with a free container. Individual flow control valves are not used; therefore, the three guides move in random sequence between the two command positions. Guide position is determined either visually or by noting the control box switch position.

The twist lock pins are controlled by a push-pull rod system which is driven by a single, centrally located hydraulic cylinder. The system is controlled by a switch on the helicopter control panel with two momentary positions: locked and unlocked. The twist lock system can be functionally checked only when four corner microswitches located adjacent to the twist lock pins are closed simultaneously. This can be accomplished either by temporarily taping the switches closed or by placing the device in position on top of a container. When the four microswitches are closed, a green light illuminates on the control panel. The light is labelled "device flush" and indicates that the device is in correct position on the container and ready for twist lock actuation. This electrical interlock prevents the twist lock pins from being moved from the unlocked position when the device is free of a container and thus always maintains the pins in the correct position to enter the corner fittings of a container. The four corner microswitches also insure that the container is not damaged to a point where only three twist locks will engage the container. The twist lock switch is held in the locked position until a green light on the control panel labelled "twist locks activated" illuminates. Twist lock position may also be verified visually by observing the position of DAYGLO colored arrows attached directly to the top of each twist lock pin shaft. When the arrows are aligned with the long (20 ft) side of the container, the twist locks are in the unlocked position. When the arrows are aligned with the short (8 ft) side of the container, the twist locks are locked.

A free-standing container is acquired as follows. The helicopter transports the empty device to the pickup site and transitions into hover. Either a vertical descent or a quartering approach is made to the container with the appropriate alignment guides in the down and locked position.

When the container has been trapped by the guides, the helicopter descends quickly to complete final alignment and entry of the twist lock pins into the container corner fittings. When the green device flush light comes on, the twist locks are actuated to the locked position and the container is ready for lifting and transport.

Inadvertent opening of the twist locks in flight is prevented in three ways. Hydraulic pressure is not required to keep the twist locks in position. During flight, friction between the twist lock pins and the container corner fittings is sufficient to hold the lock. Second, the twist lock switch on the control box is a guarded momentary switch which prevents accidental bumping. Third, a hydraulic pressure reducer is installed in the twist lock unlock circuit. It limits the unlock force to 150 pounds, which is insufficient to overcome the friction between the twist lock pins and the container corner fittings. Thus, even a deliberate command for the twist locks to open in flight will not cause them to unlock. In-flight emergency load jettison is accomplished through the normal systems provided on each of the transporting helicopters for this purpose.

Normal position for the side and end guides is down and locked. The guides are retracted when acquiring or depositing a container in close proximity to other containers, when the device is lowered into a 20-foot containership cell, and when the device is being placed on the ground for storage.

To release a container from the device, the container must be placed on the ground. The container device then is lowered approximately one inch until it is resting on the container. The twist lock switch is held in the unlocked position for 1 to 2 seconds. The device can then be lifted clear of the container.

Single-Point Mode (CH-47 and CH-54)

The only feasible means of effectively transporting a container with the automation device is to assure a stabilized flight pattern and the elimination of cargo rotation. This problem has not been resolved.

PHASE III - LABORATORY DEMONSTRATION, ENGINEERING DRAWING UPDATING, AND HLH COMPATIBILITY TESTING

LABORATORY TEST PROGRAM

The two container devices were laboratory tested. Detailed test data and results are contained in Appendix III. Succeeding paragraphs summarize the test findings.

A major contractual requirement was to produce a device which weighed no more than 1,320 pounds. The reasoning behind such a requirement was discussed earlier under the Phase I effort. Following completion of fabrication and prior to start of the other laboratory tests, the first device (serial number 1) was weighed in the dual-hook-mode configuration using an aircraft weighing kit. The load cell was located in series with a bridle sling and an overhead trolley crane, which was used to lift the device clear of the ground for weighing. The as-weighed data and the additions and deletions required to adjust the weight to the delivered condition are shown below.

Container device weight (S/N 1)	1,165 lb
- lab test 60-cycle electric motor	-42 lb
+ production 400-cycle electric motor	+19 lb
+ helicopter control box & umbilical cord	+50 lb
Delivered weight	1,192 lb

The three types of testing conducted to demonstrate proper functioning and structural integrity of the container device are listed below. Numbers in parentheses indicate the devices subjected to each test.

1. Self-alignment demonstrations from the extremes of position error specified for the device. (1 and 2)

2. Normal latching and unlatching demonstrations with a U.S. Army MILVAN container. (1 and 2)

3. Load testing of the device in the vertical direction using a ballasted U.S. Army MILVAN container to simulate design load plus a small maneuver load factor. (1)

Self-alignment demonstrations were made in succession from offsets of 1-foot longitudinally, 1-foot laterally, and 10 degrees of azimuth, relative to the principal axes of the MILVAN container. Demonstrations were also made from random combinations of offset within the limits of 1 - foot longitudinally and laterally and 10 degrees of azimuth. All required demonstrations were successfully completed. In a few instances the self-alignment sequence ended with the device tilted or cocked on top of the container, usually with two of the four twist lock pins off the side of the box. It was found that when the device was lowered vertically by the crane with an estimated velocity of at least 30 feet per minute (FPM), self-alignment was satisfactorily accomplished. At lower velocities, one of the guides contacted the container first and the device started to pivot about this contact point instead of sliding along the ramp surface in a level attitude.

Normal latching and unlatching with the U.S. Army MILVAN were demonstrated in a sequence that involved:

1. Placing the device twist lock pins into the container corner fittings.

2. Remotely actuating the twist locks to the locked position.

3. Lifting an empty container clear of the ground via the container device.

4. Setting the container back on the ground and resting the device on the container.

5. Remotely actuating the twist locks to the unlocked position.

6. Lifting the device clear of the container.

All normal latching and unlatching demonstrations performed in accordance with the above procedure were successfully completed. During one unlatching demonstration the twist locks were inadvertently commanded to the unlocked position when only one end of the container was fully resting on the ground. Full unlock hydraulic pressure was reacted by the friction at the two twist locks still supporting some container weight. Hollow twist lock shaft extensions which had been designed as safety valves in the twist lock mechanical system failed, leaving the device and container in a partially engaged position. It was decided to change the design philosophy in this area. This is discussed in detail later in this section. The hollow twist lock shaft extensions were removed and replaced with solid shafts, and a hydraulic pressure reducer was installed to protect the mechanical system from overloads.

Vertical load testing consisted of ten lifting cycles of the container device in the dual hook mode configuration while carrying a MILVAN container ballasted to a combined container and ballast weight of 67,200 pounds. This weight is the design capacity of the device (28 tons or 56,000 pounds) times a 1.2G maneuver load factor (56,000 x 1.2 = 67,200). The load was held suspended by the container device for 5 minutes on each lift cycle. Visual inspections of the container device were made following each cycle. No indications of actual or impending structural damage were found during any of the inspections. The container device successfully completed the structural integrity demonstration.

ENGINEERING PRINT UPDATING

The changes noted below were incorporated on the container device design drawings based on the finding and conclusions of the laboratory demonstration tests.

SIDE PLATES ON SELF-ALIGNMENT GUIDES

The side and end self-alignment guides are constructed from flat sheet stock. This was done because the proper ramp angle for the guides and the length of the vertical step at the upper end of the ramp could not be definitely established prior to the laboratory tests. It was decided to provide basic guides which could be easily modified by the addition of side plates, if required. The vertical step at the upper end of the guides was initially set at 2 inches. Preliminary self-alignment checks indicated that the depth of the step should be increased. Side plates were added to provide a 7-inch vertical step. All self-alignment demonstrations were conducted with these side plates installed.

SOLID TWIST LOCK SHAFT EXTENSIONS

Hollow twist lock shaft extensions were initially incorporated on the container device as a safety valve in the mechanical twist lock push/pull rod system. In the event of an overload condition, these shafts would fail before damage was incurred elsewhere. The extensions are accessible and easy to inspect and replace. During the laboratory testing, a twist lock command was inadvertently given with some container weight on two twist locks, and the hollow extensions failed. The design philosophy was reviewed, and it was decided that a more desirable approach would be to limit the maximum possible force in the mechanical system and to always maintain the capability to disengage the device when the container was on the ground. Therefore, the hollow shaft extensions were replaced with solid assemblies, and a force-limiting pressure reducer was incorporated.

HYDRAULIC PRESSURE REDUCER

A pressure reducer set to 150 psi was added to the unlock side of the twist lock hydraulic cylinder circuit. This device limits the maximum possible unlock force in the mechanical twist lock push/pull rod system. The purpose of this device is to protect the mechanical system from failure as a result of inadvertent twist lock actuation while maintaining the capability to also permit twist lock opening when the correct conditions exist.

CONTROL BOX CIRCUIT BREAKER AND SWITCHES

Some popping of the control box 5-ampere A-C circuit breakers was experienced. The electrical system was reviewed, and it was determined that these breakers had a marginal capacity during motor restarting with residual hydraulic pressure. Since the electrical wiring had adequate load-carrying capacity, the control box circuit breakers were changed to 10-ampere units.

The side and end guide control switches originally were the two-position momentary type with spring centering. It was found that the commercial solenoid valves used to control the guides have a normal internal leakage which causes the hydraulic pressure in the guide cylinders to drop. After the guides were placed in the up position, they slowly began to return to the down and locked position under the force of gravity. The electrical switches were changed to a momentary down, spring centered, up detent switch. This allows the hydraulic system pressure switch which senses the servo valve leakage to also maintain the guide pressure and position automatically.

HLH COMPATIBILITY TESTING

The second container handling device (serial number 2) was used in performing cargo handling system testing on the heavy lift helicopter (HLH) cargo handling system test rig. This was done to evaluate the compatibility of the device with full-scale HLH hardware prior to the fabrication and first flight of the completed helicopter. Physical and functional compatibility were evaluated by introducing the device into the test rig demonstration scenario. The test rig, which is shown in Figure 10, is a 70-foot-high tower on which the tandem dual hook winch system for the HLH is mounted. The initial rig test program involved hoisting and lowering of a ballasted 28-ton MILVAN container and demonstrations of the various cargo hook release systems. The container device was used as the interface subsystem between the helicopter cargo hooks and the container. Over four hundred and fifty 28-ton hoisting and lowering cycles were performed with the container device. The device was lifted without the container and

Figure 10. Heavy Lift Helicopter - Integrated Cargo Handling System Test Rig.

lowered for self-alignment and normal latching and unlatching sequences using the helicopter control box. Figures 11 and 12 show the container, device, and HLH cargo hooks and cables during the program. These tests showed excellent compatibility of the device with the HLH.

Figure 11. Container Device During HLH Compatibility Testing.

Figure 12. Closeup of HLH Cargo Coupling Attached to Dual-Mode Shackle.

CONCLUSIONS

- Technology has been developed to support the design and development of helicopter-transported container handling devices at both the conceptual and production levels.

- The container device fabricated under this contract is capable of acquiring the 20-foot standard container only and thus is a single-purpose acquisition device. Many of the design features are also applicable to multipurpose acquisition devices capable of handling more than one container length and noncontainerized loads.

- Within the ground rules of this program, the optimum configuration for the helicopter-transported container handling device includes:

  1. An aluminum alloy multi-tier space frame structure.

  2. Four operable corner twist locks for container engagement and latching.

  3. Six operable self-alignment and self-locking guides, comprised of four side guides and two end guides. These guides are retractable inside an 8x20-foot planform for device entry into a containership cell.

  4. Self-contained low-pressure hydraulic system to power the guides and twist locks.

  5. Remote helicopter-borne control panel and umbilical cord to transmit electrical power and control commands from the helicopter to the container device.

  6. Field-removable dual-mode superstructure to reduce weight when a four-legged wire rope bridle sling is used.

- Structural integrity, normal latching and disengagement, and inherent self-alignment capability of the device fabricated under this program have been satisfactorily demonstrated in the laboratory.

- The weight range for a helicopter-transported container handling device has been demonstrated to be 1,000 to 1,200 pounds.

RECOMMENDATIONS

- Flight testing of the helicopter-transported container handling device should be performed to confirm the design and laboratory test findings under actual operational conditions. Specifically, the following should be evaluated:

    1. Length of side and end self-alignment guides which dictate the maximum self-capture capability of the device.

    2. Concept of two sets of three self-alignment guides and the quartering approach to a free container.

    3. The desirability of individual controls for each of the six self-alignment guides versus the increased complexity required in the helicopter control box.

    4. Tolerance of the self-aligning and latching systems to non-level device attitudes.

    5. Desirability of either slower or faster actuation times of the guide and twist lock systems.

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APPENDIX I

OPERATIONAL ANALYSIS, DESIGN CONFIGURATION, AND TRADE-OFF ANALYSIS

1.0 Introduction

The commercial containerized cargo industry employs a series of standard size containers with common corner fittings for restraint and lifting. The containers are designed to be adaptable to several modes of transport. One method of transferring containers between transport modes is to employ a piece of equipment alternately called a lifting frame, spreader frame, or top lift adapter.

Commercial top lift adapters are designed to be semiautomatic container handling devices. A rigid I-beam structure is provided to prevent compressive loads imposed during lifting from crushing the containers. Retractable corner guides are sometimes provided to aid in final positioning of the adapter on top of the container. The guides are retracted when the device is lowered inside containership cell guides. Remotely actuated twist locks are located in each corner to latch the container to the adapter for lifting, without the aid of hookup personnel.

Commercial adapters are used in conjunction with gantry cranes, boom cranes, straddle cranes and mobile container transporters called straddle carriers. Adapter weight is not a critical factor in any of the commercial applications. Commercial adapters are constructed of structural steel and weigh from 1.5 tons for a manual fixed-length unit to 6 to 7 tons for adjustable-length units with retractable corner guides and self-leveling systems.

A major part of the planned heavy lift helicopter utilization is to pick up and deliver commercial containers both from ship to shore and between ground locations. Full advantage of helicopter productivity cannot be exploited unless means for rapid pickup and release of containers can be provided. Demonstrations of helicopter external transport of containers have been performed using commercial container handling devices. These devices have been found to be unsuitable for helicopter use due to their high weight and general incompatibility with helicopters. The purpose of this program is to establish and demonstrate a design for a container handling device specifically tailored for use by Army helicopters.

The Phase I program includes:

a) A definition of the purposes for the device in the helicopter external cargo mission.
b) An operational analysis of the generalized helicopter mission to define all functions which involve the container handling device.
c) Definition of the design criteria for a helicopter device to transport the ANSI 8x8x20-foot container.
d) A survey of commercial approaches to container handling device design.
e) Preliminary design layouts for handling devices which will satisfy the operational analysis.
f) A weighted parameter trade-off study to select the best approach for the helicopter-transported device.
g) Recommendation of the preliminary design approach which should be expanded into a detailed design under Phase II of this program.

2.0 Discussion

2.1 Purposes for the Container Handling Device

The helicopter transported container handling device serves three main purposes:

a) It acts as a spreader bar to react compressive loads, in the plane of the top surface of the container, induced by lifting. This is necessary since containers built in accordance with Reference 1 are designed only for lifting loads applied perpendicular to the plane of the top surface.

b) The assembly serves to support and locate corner twist locks which mate with corner fittings on the containers. These twist locks provide a remote means for latching the container to the device for helicopter transport, thus eliminating hookup personnel and enhancing rapid hookup and release.

c) The assembly serves to support retractable tapered guides which are required to position the adapter within the accuracy required for twist lock engagement while the helicopter holds hover position to a lesser accuracy. This enhances rapid hookup of free-standing containers.

2.2 Operational Analysis

2.2.1 General

The first step in the operational analysis was to identify the functions of the container handling device. These functional requirements are expressed by means of functional flow diagrams which show specifically what must be accomplished by the total system. From the standpoint of the total system, the objective is to move the greatest amount (weight) of cargo from ship to shore in the shortest period of time. Thus, to minimize the cost of the operation, the cycle time must be minimized; also, since helicopters are payload limited, the weight of the device must be minimized. By addressing detailed operational functions during the design of different configurations, the major total system objectives can be attained.

The second step in the operational analysis was to display representative time lines for each time critical function, thus providing a baseline for time studies. Time is a primary consideration in the trade-off studies.

The third step was to define design constraints for the handling device, such as cell clearance, flared entry, guide slope, superstructure clearance, etc. It is desirable that the final design meet all the constraints. However, some of the constraints do not directly affect a particular design solution. (For example, the maximum container weight of 67,300 lb for the 40-foot container is not applicable to the specific design of a 20-foot handling device which is considered prime in this contract.)

2.2.2 Functional Requirements

The desired and required operational functions are displayed as Figures 1 through 18. These functions have been expanded to a significant detailed level so that design solutions to satisfy each function can be traded off. As a result of these trade-offs, the most cost effective design can be selected based on cost, time to complete the function, reliability, maintainability, etc. No design features are expressed by any of the functions. The functions merely express the requirements which the design features must satisfy. The functions have also been expanded to form a time baseline, which is discussed in a subsequent paragraph. The value of particular designs can then be assessed on the basis of their impact on generalized mission time.

2.2.3 Required and Desired Functions

All operational functions for each of the container designs were considered. Only the functions shown in the heavy boxes in Figure 13 have been expanded, since these functions directly affect the container handling device. All functions are required except those designated with an asterisk in the lower right-hand corner. These functions are desired but are not required.

The functional analysis is intended to be all-inclusive. Thus, certain functions are not desirable but are included to account for the different possibilities. For example, functions 1.2.1(Prepare container rigging) and 4.0(Wait for lift area clearance) are not desirable but have been included in the analysis for completeness.

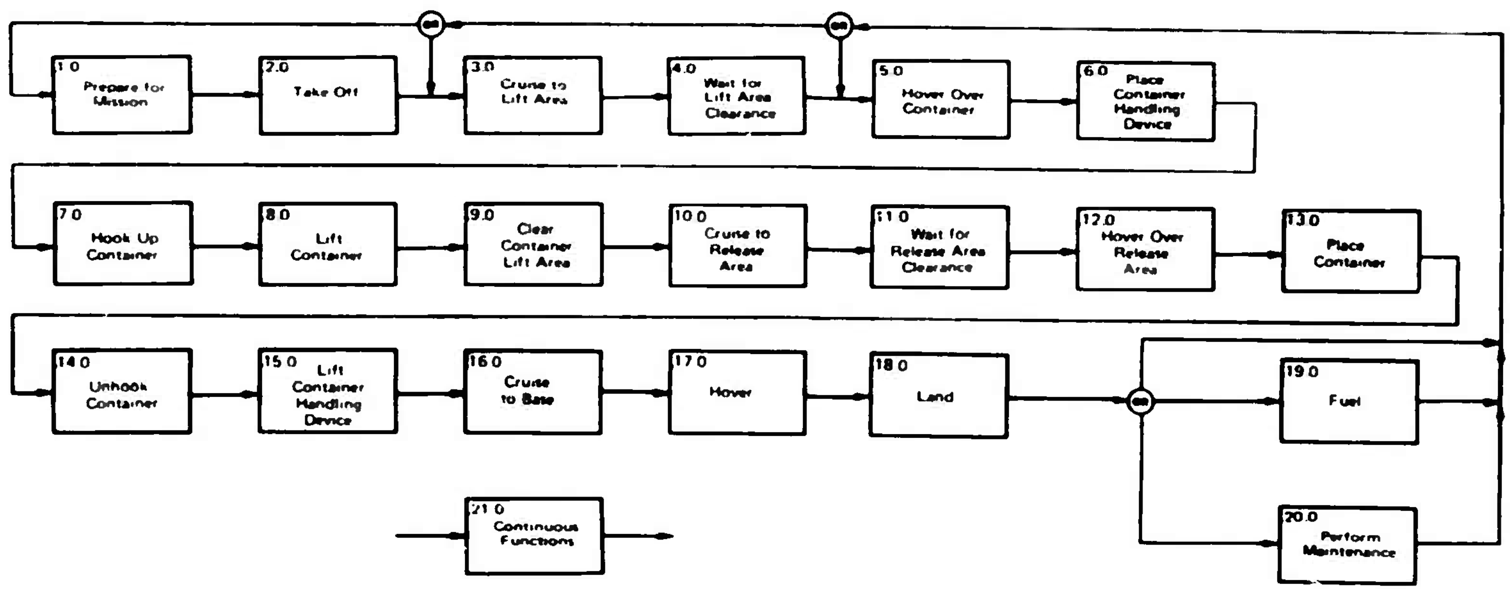
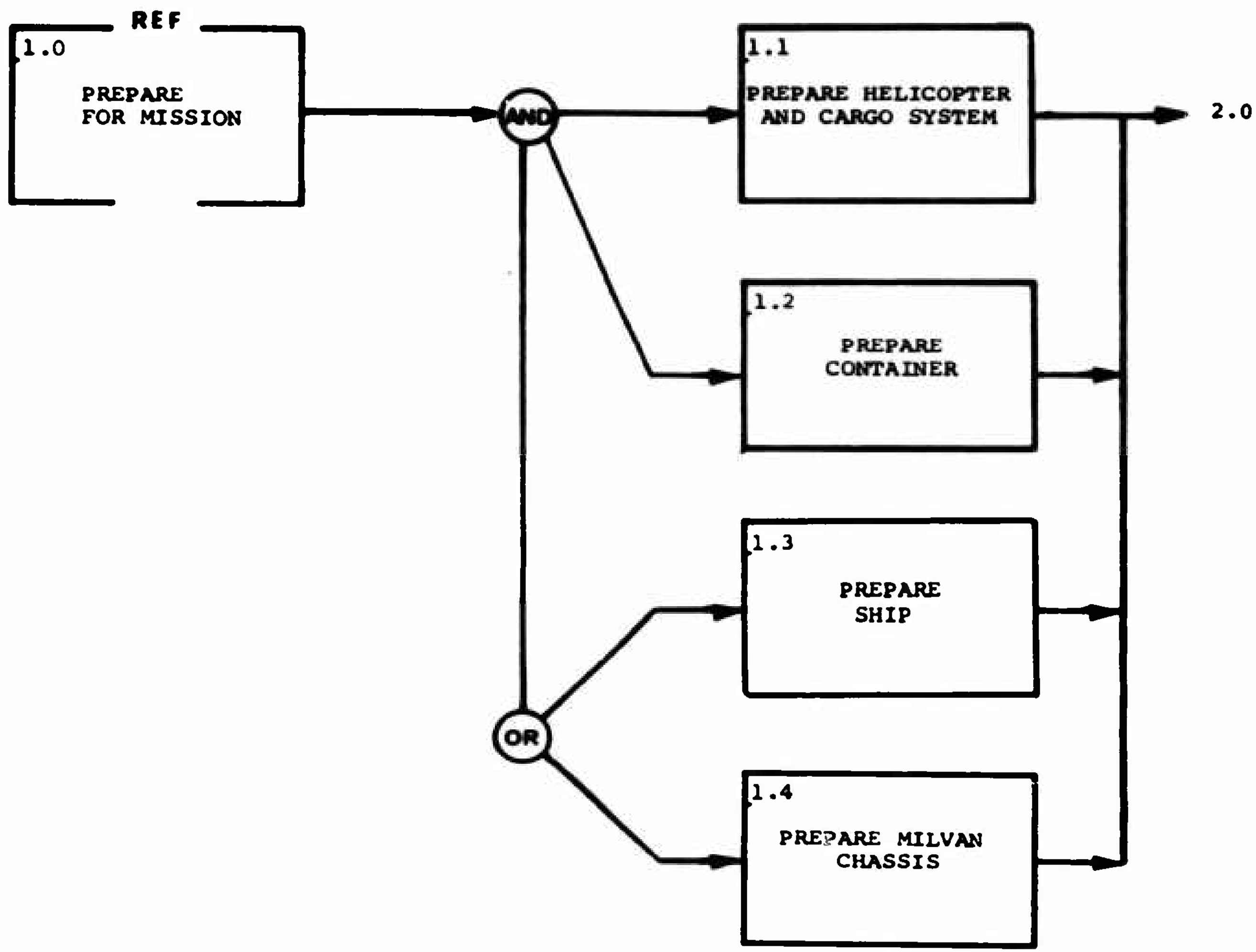


Figure 13. Functional Flow Diagram of Container Transport Mission.



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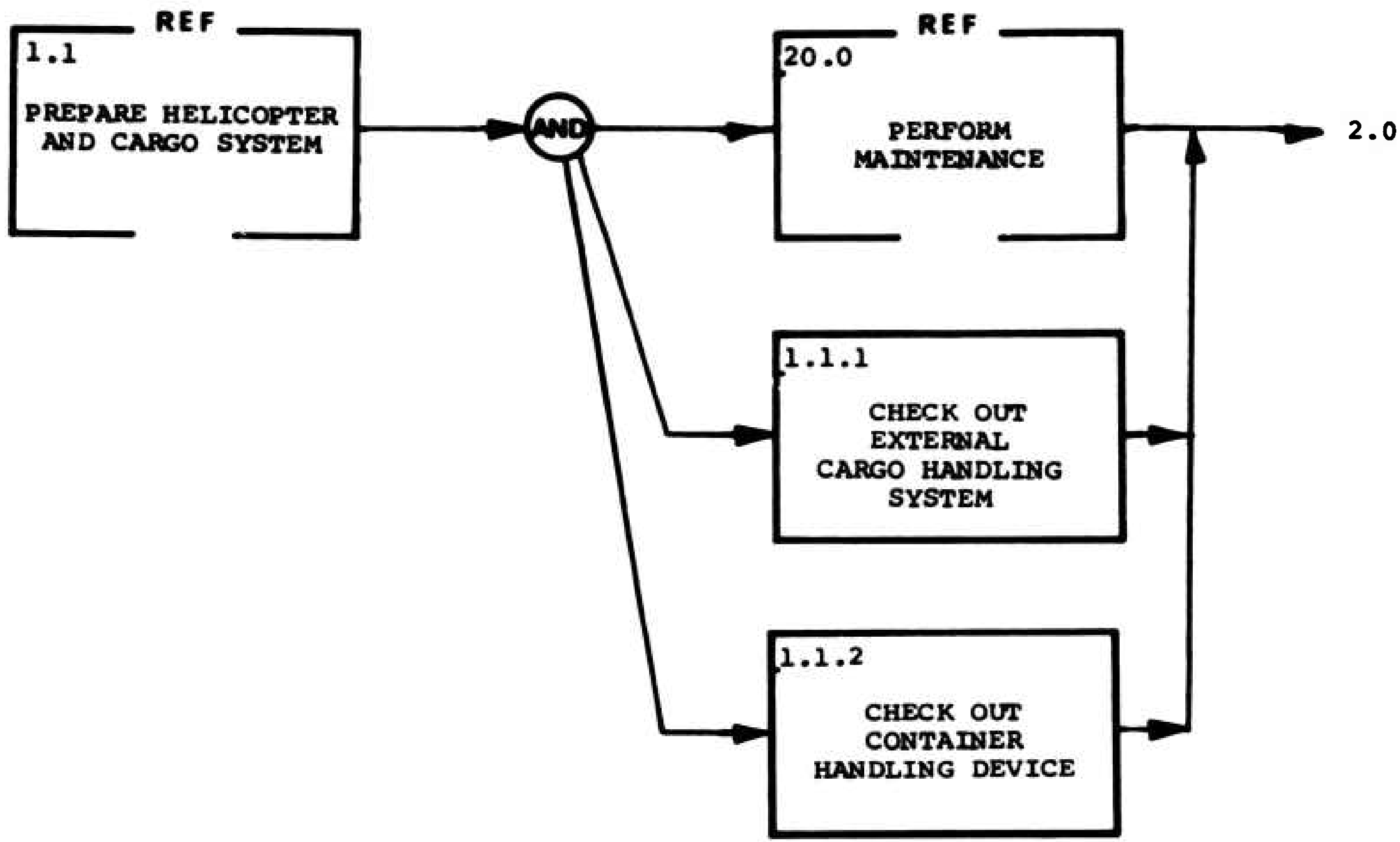

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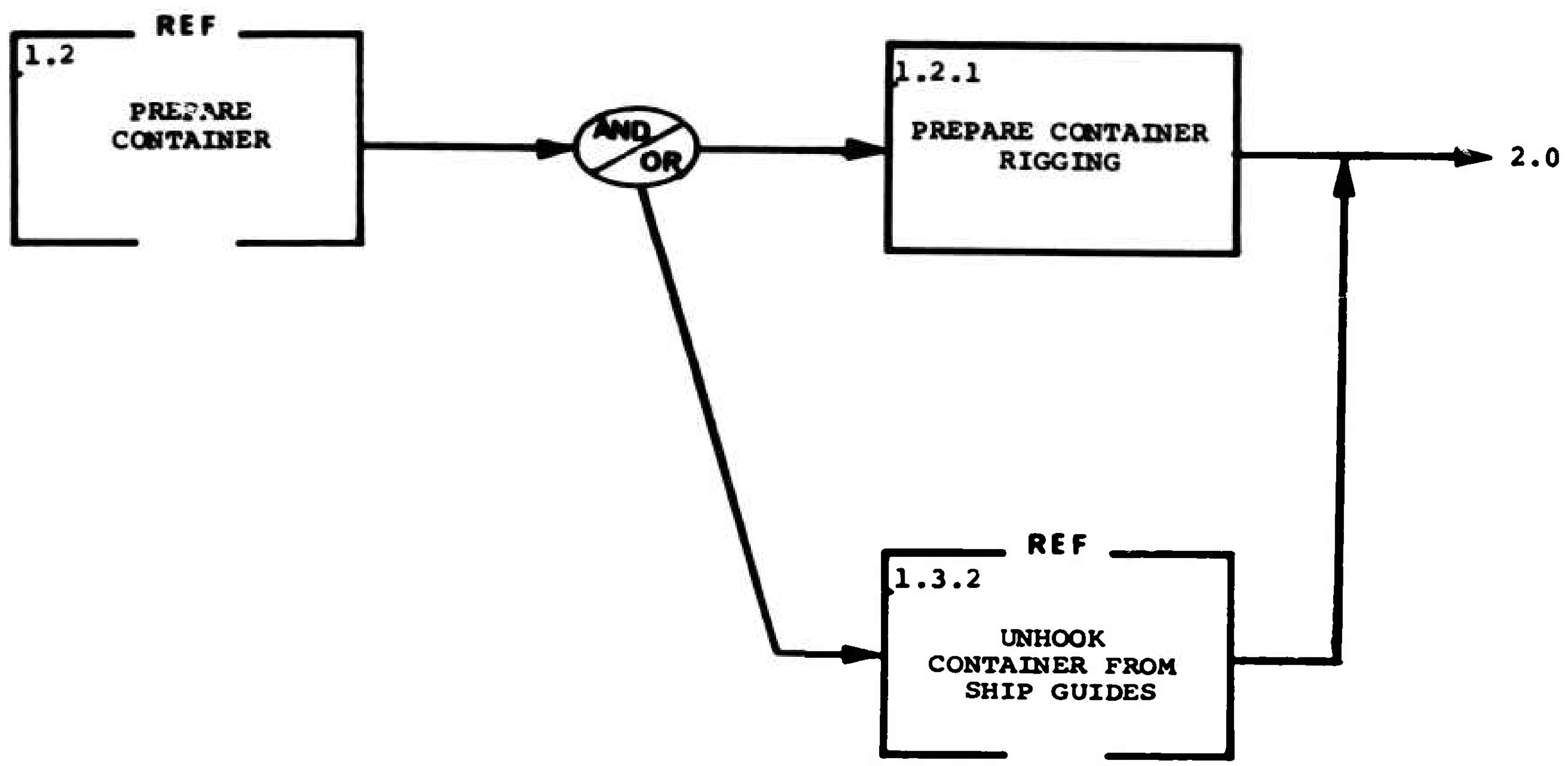

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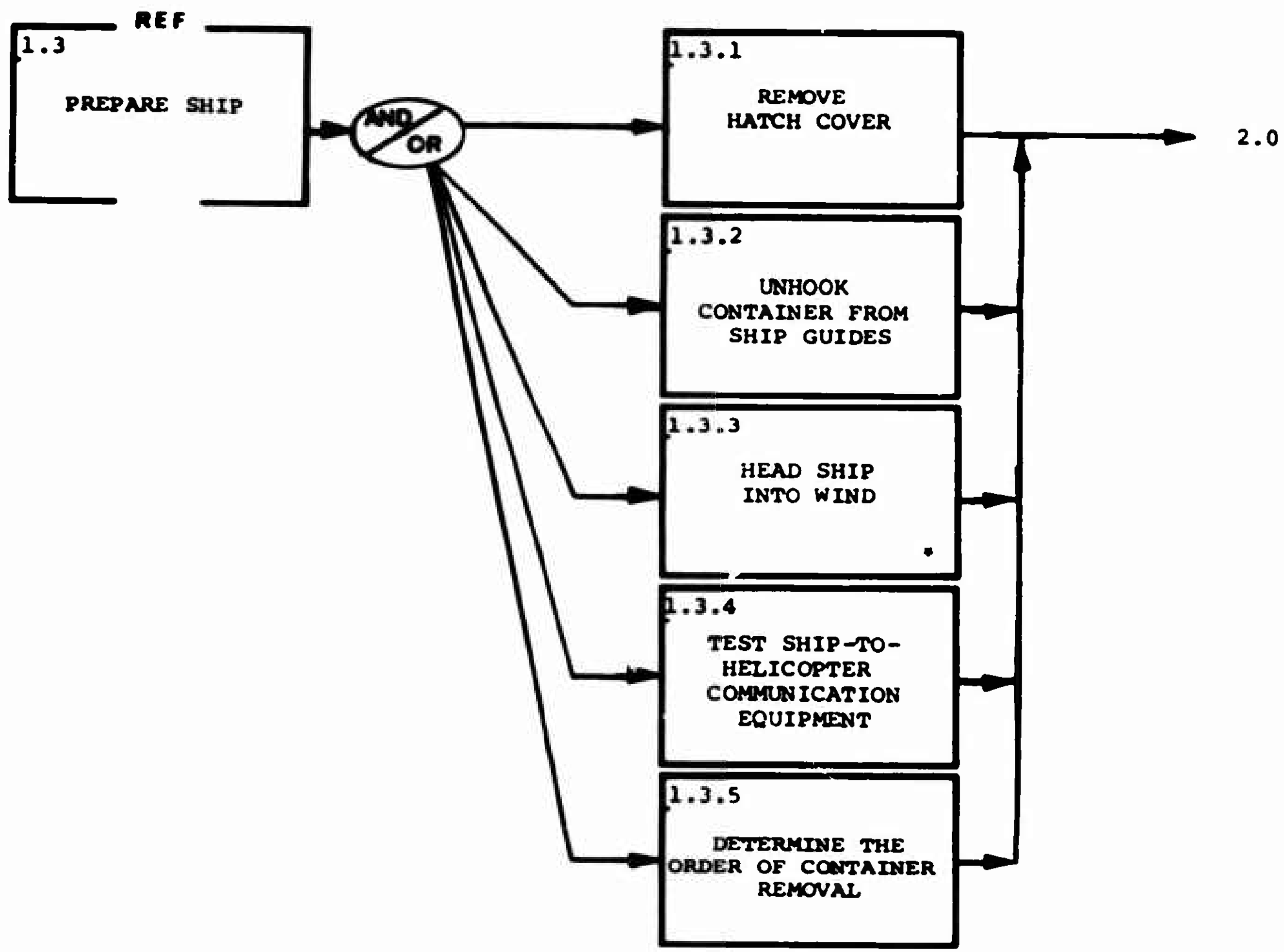

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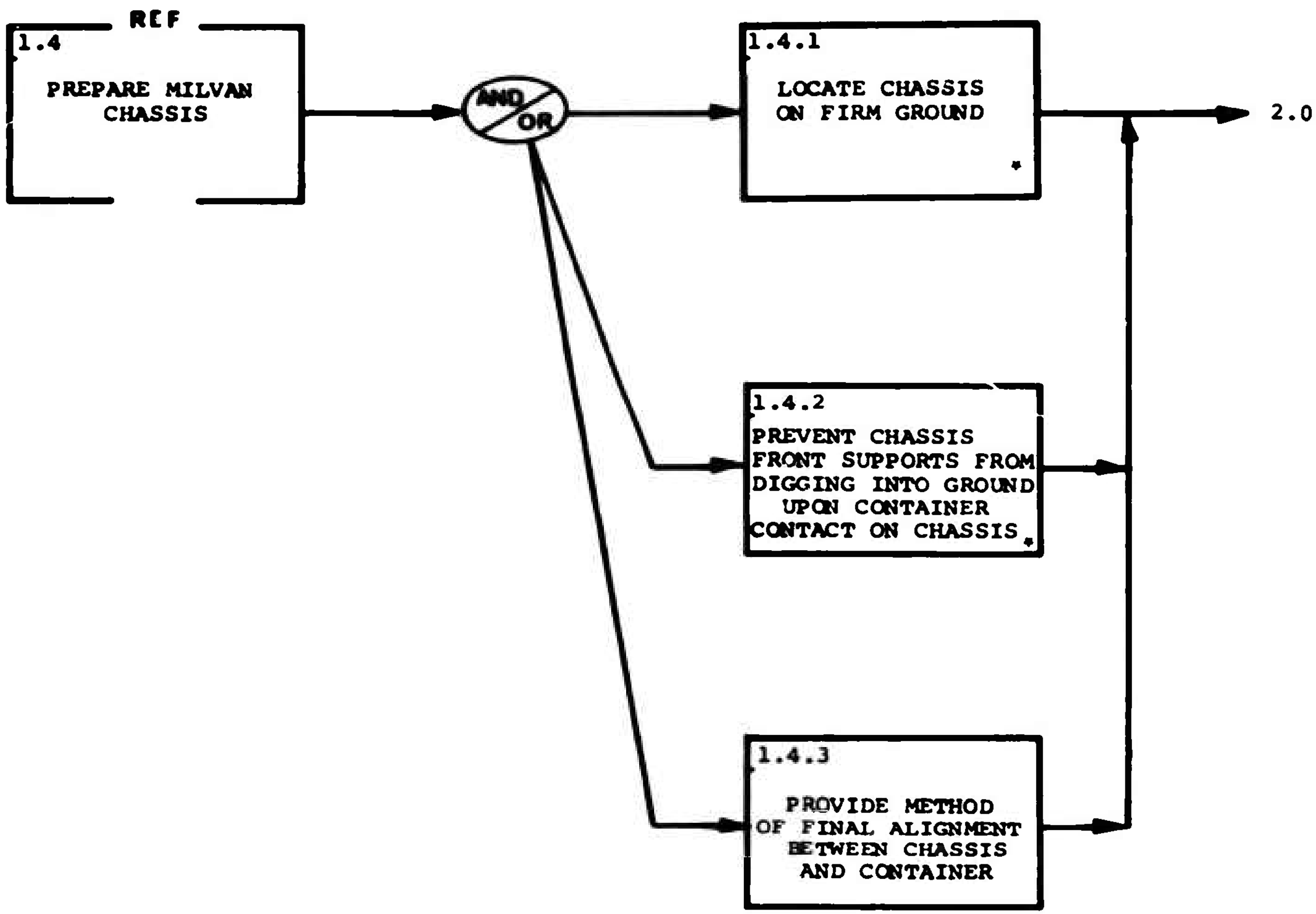

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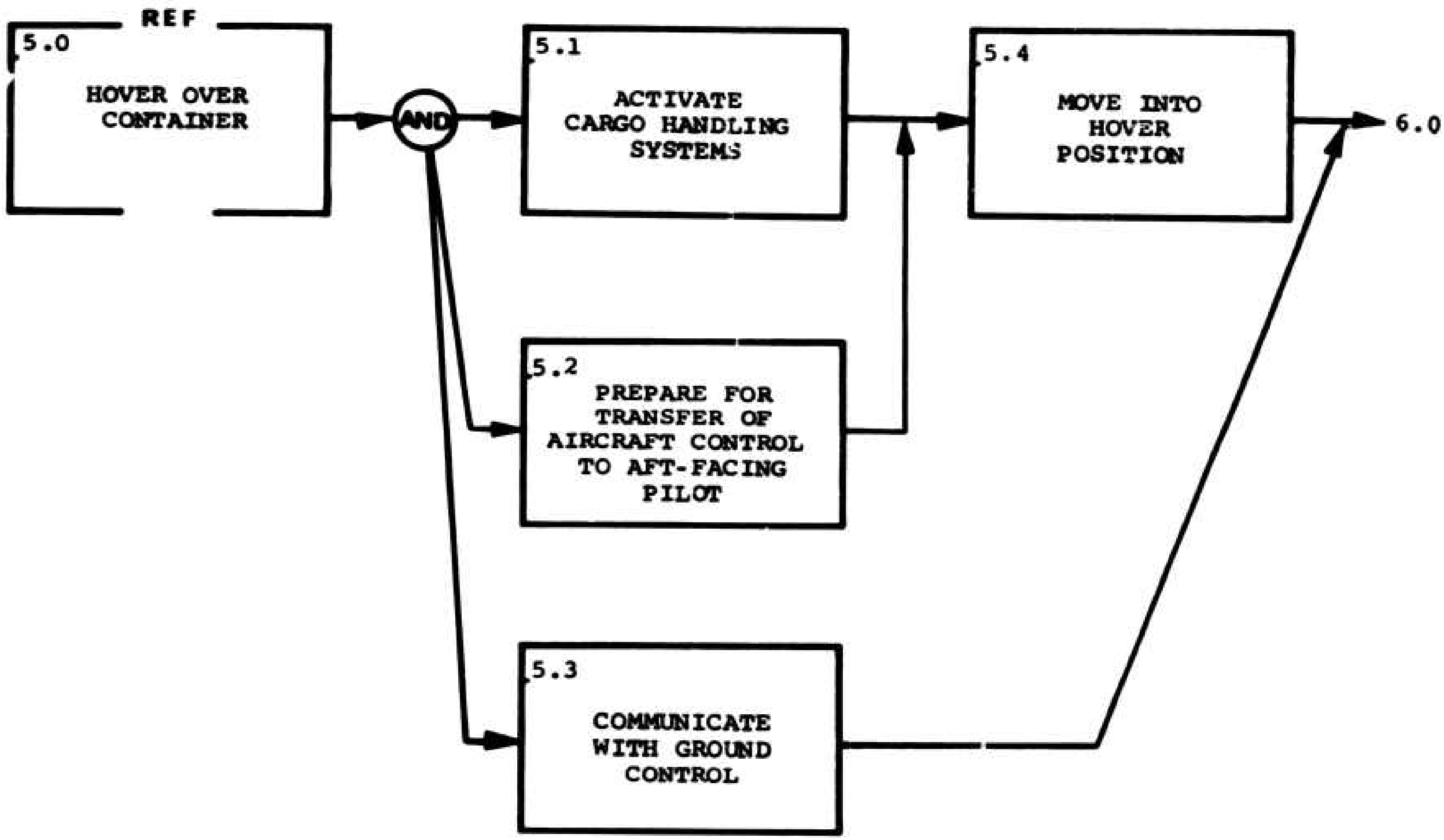

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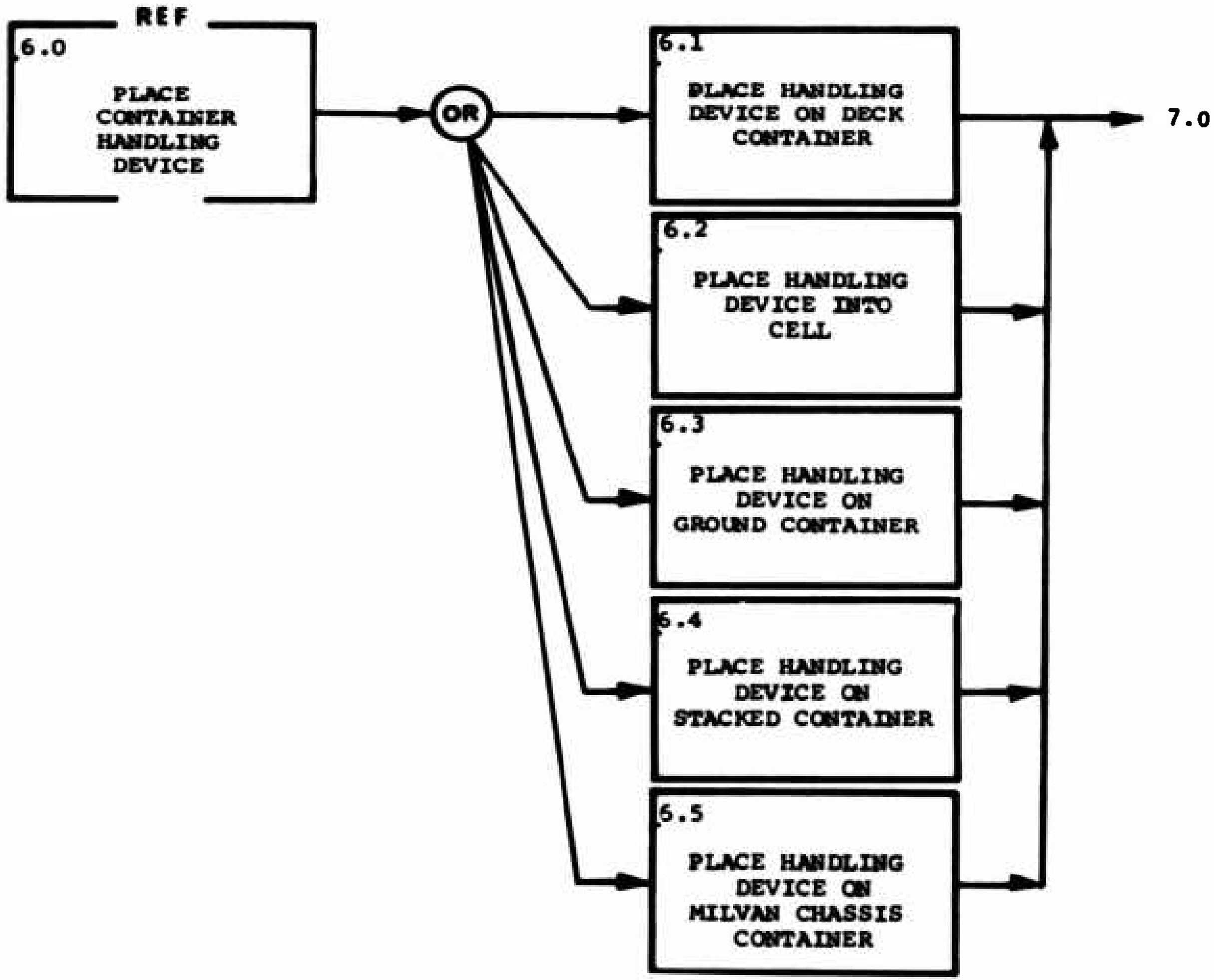

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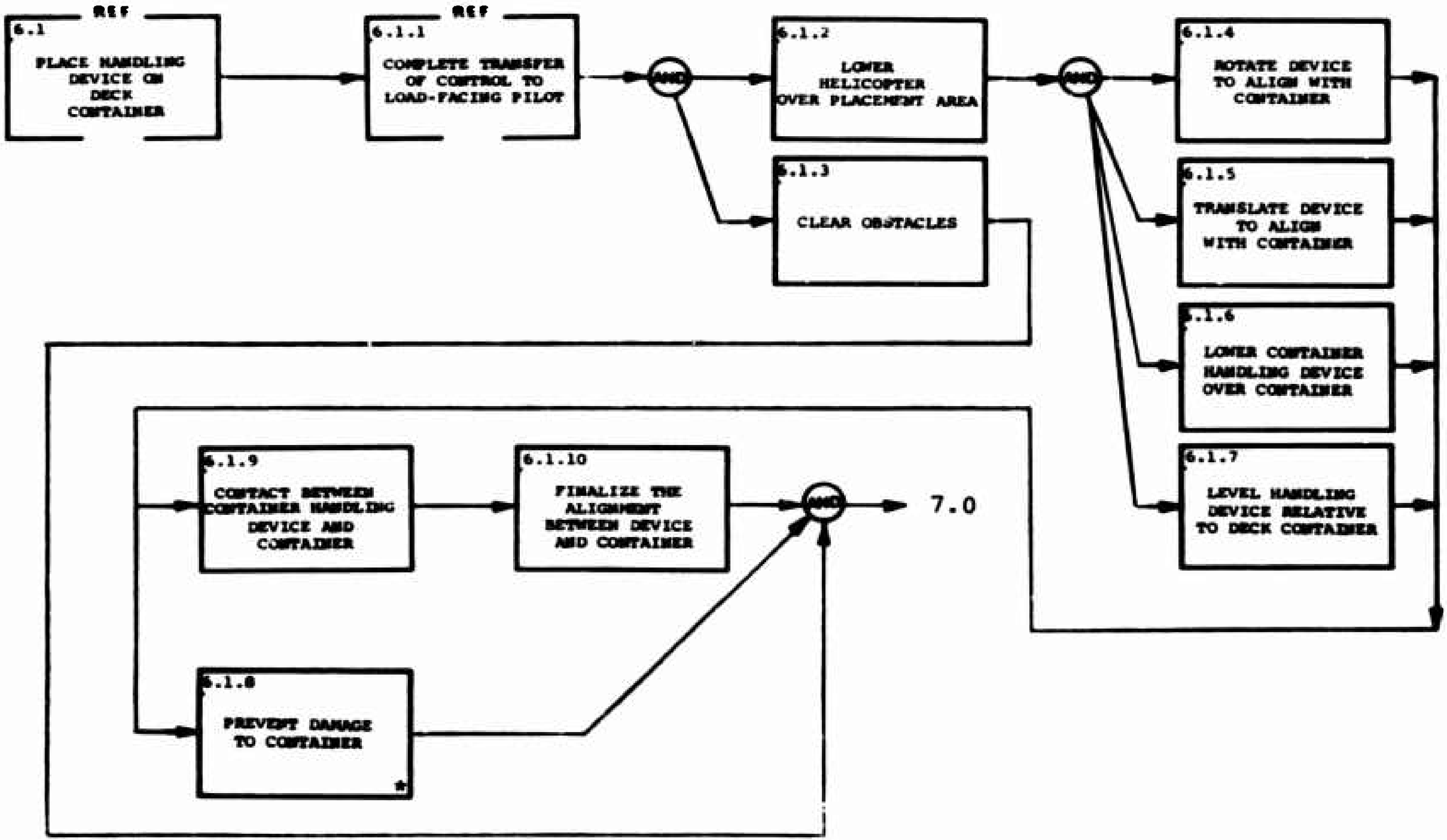

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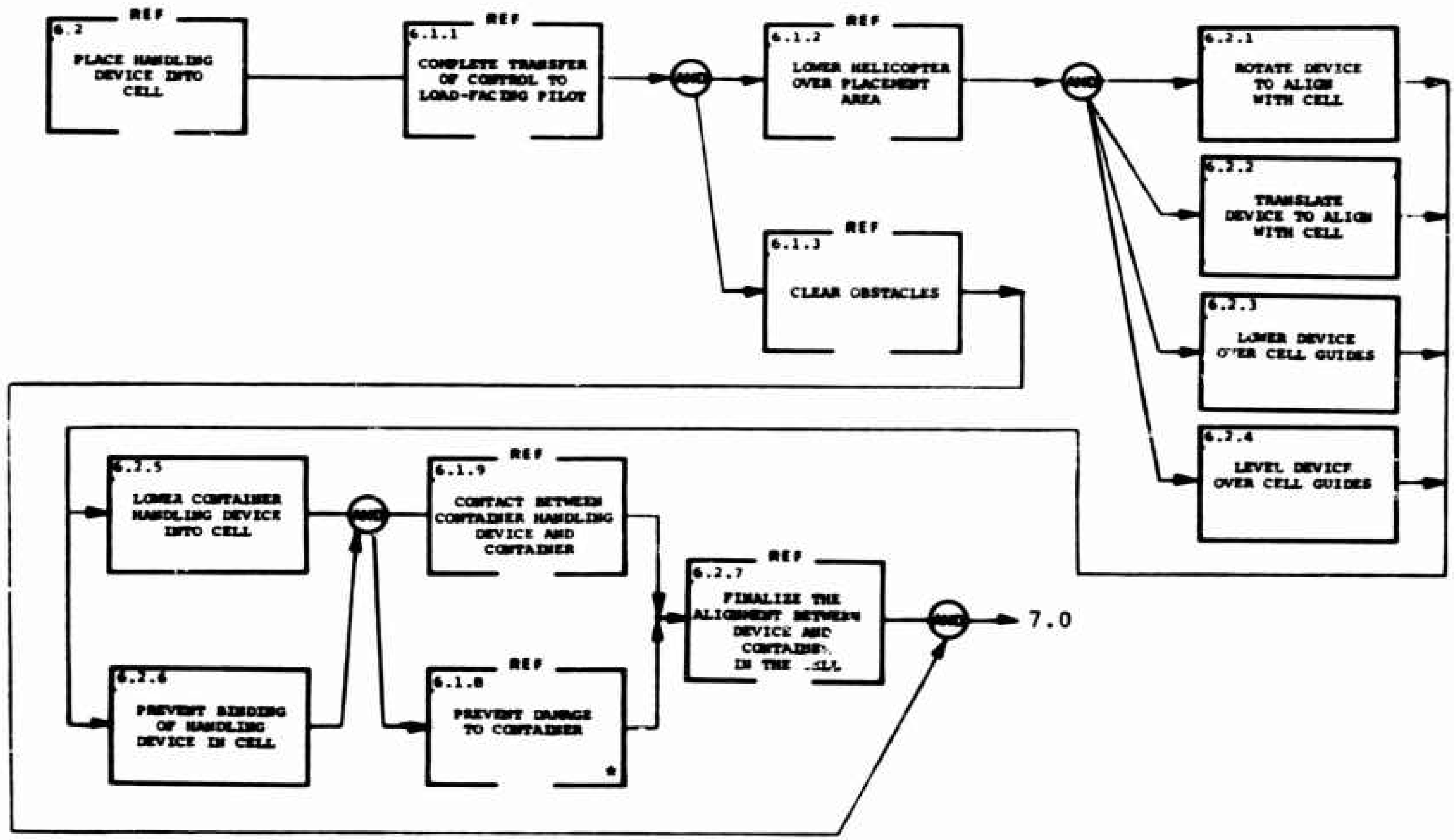

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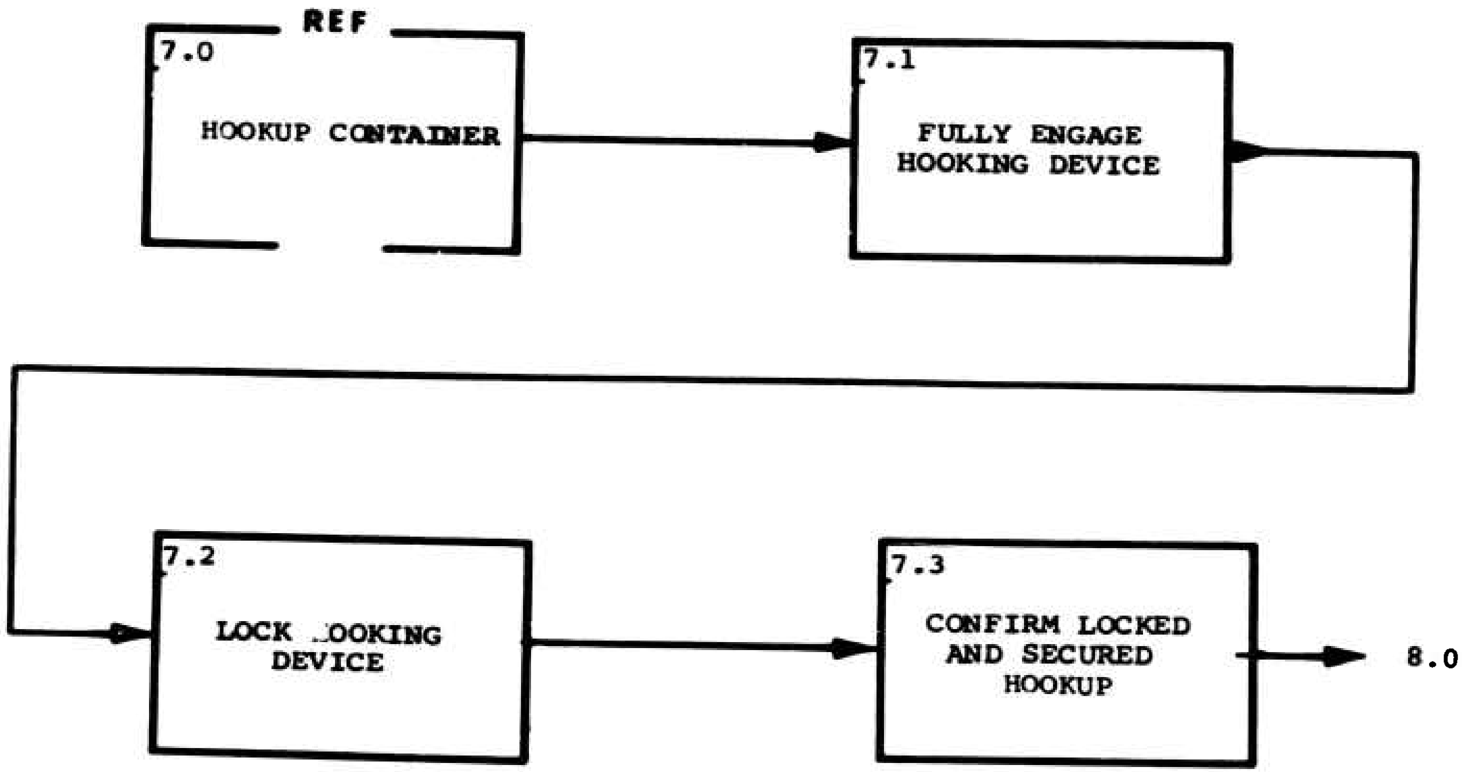

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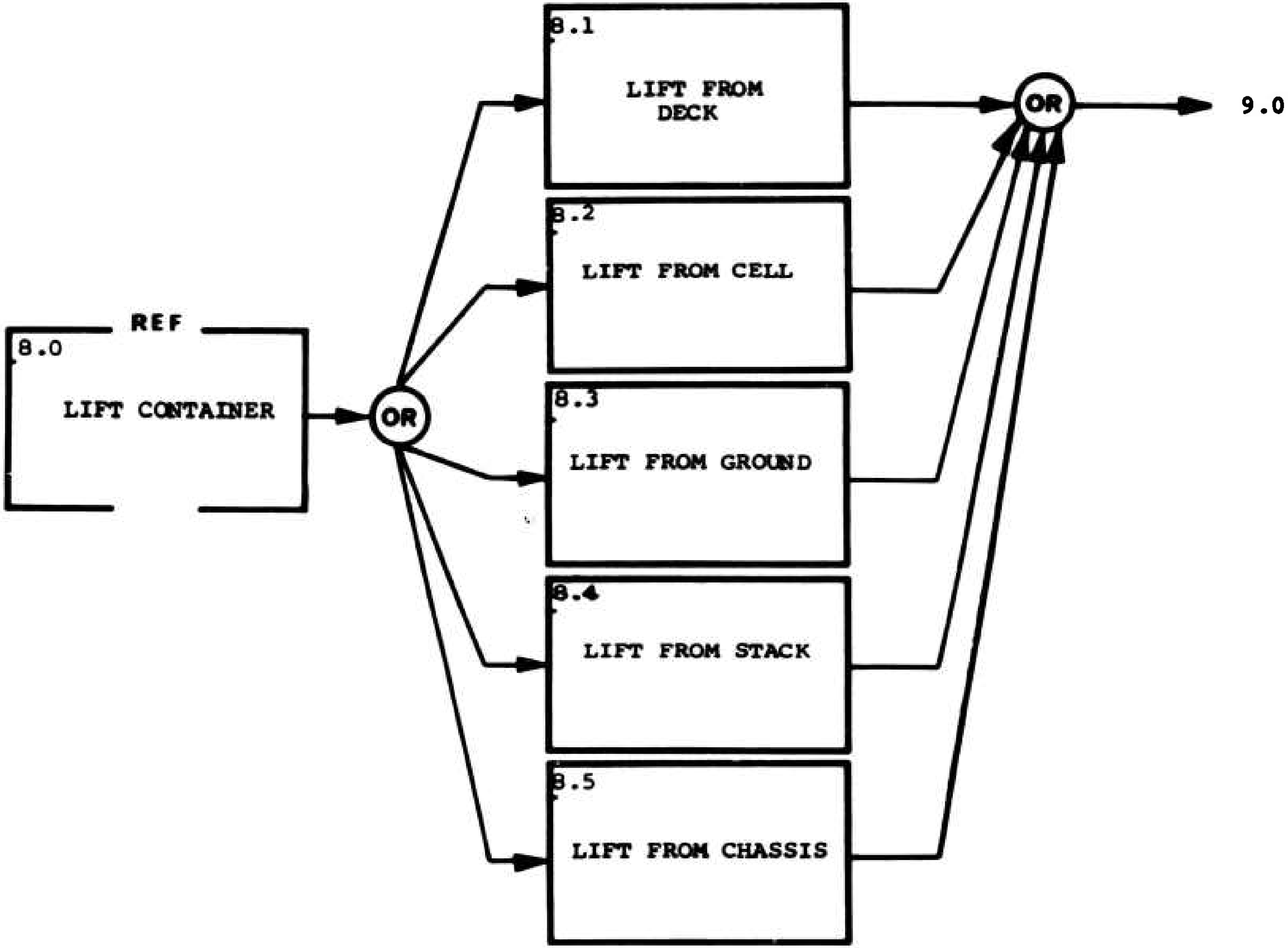

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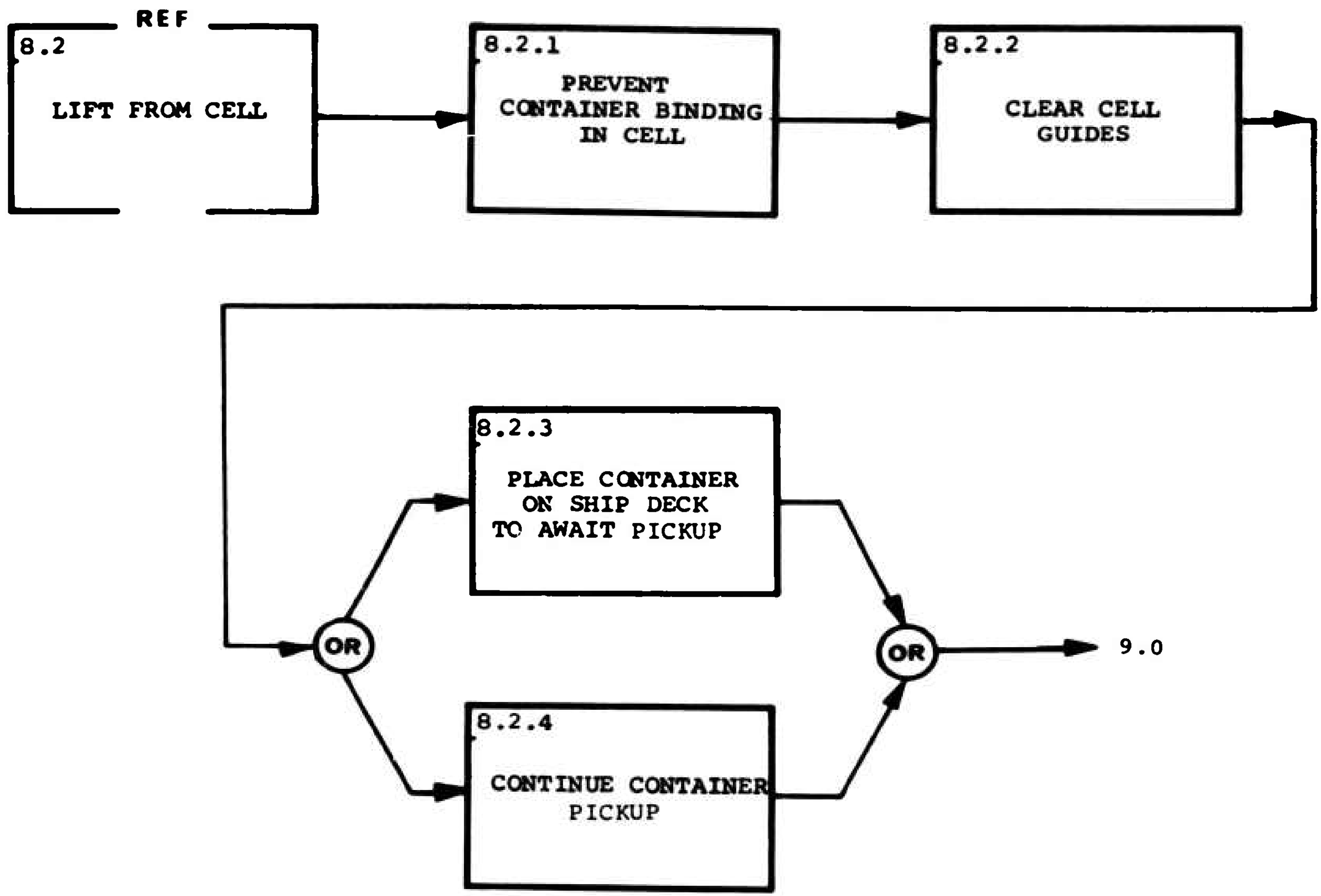

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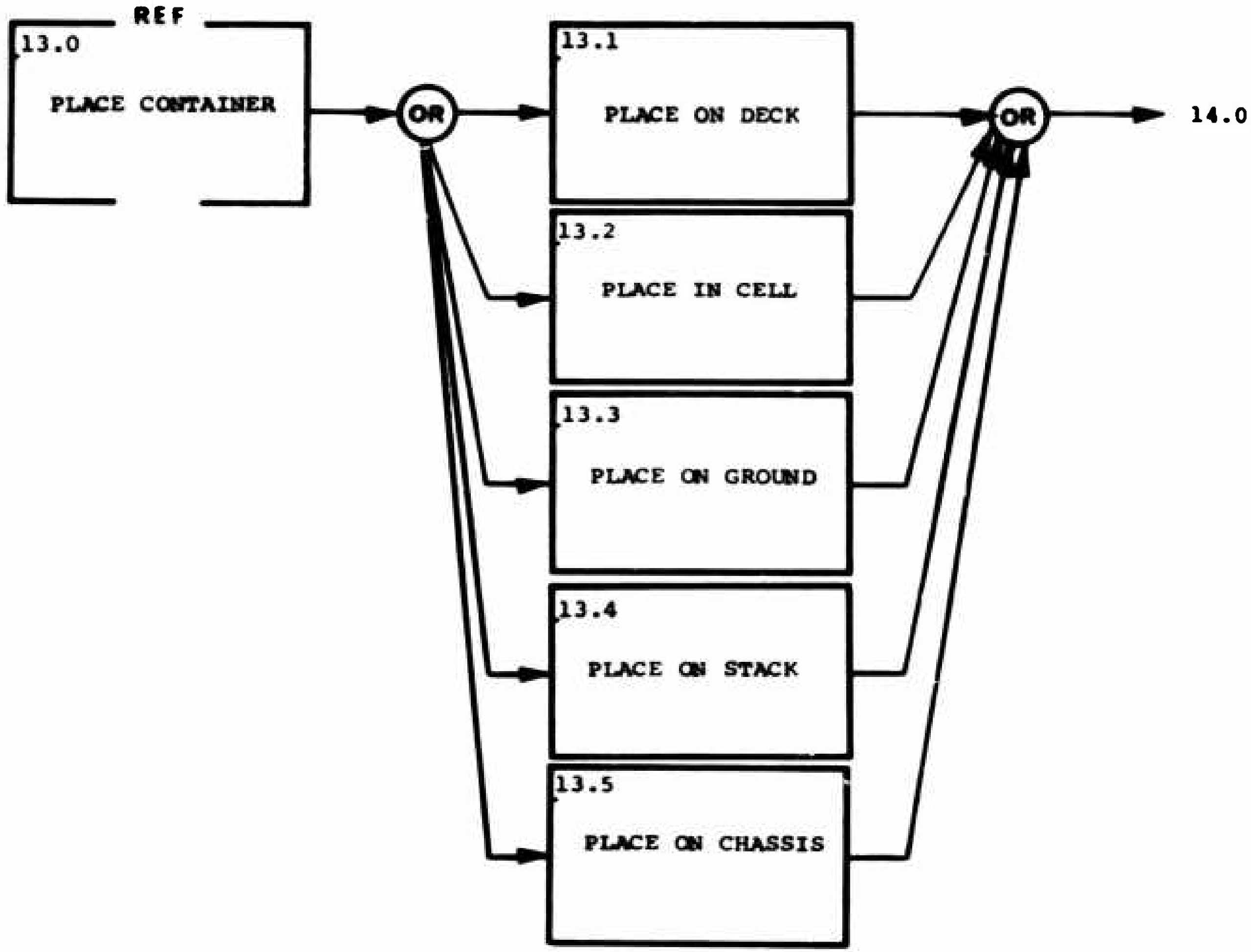

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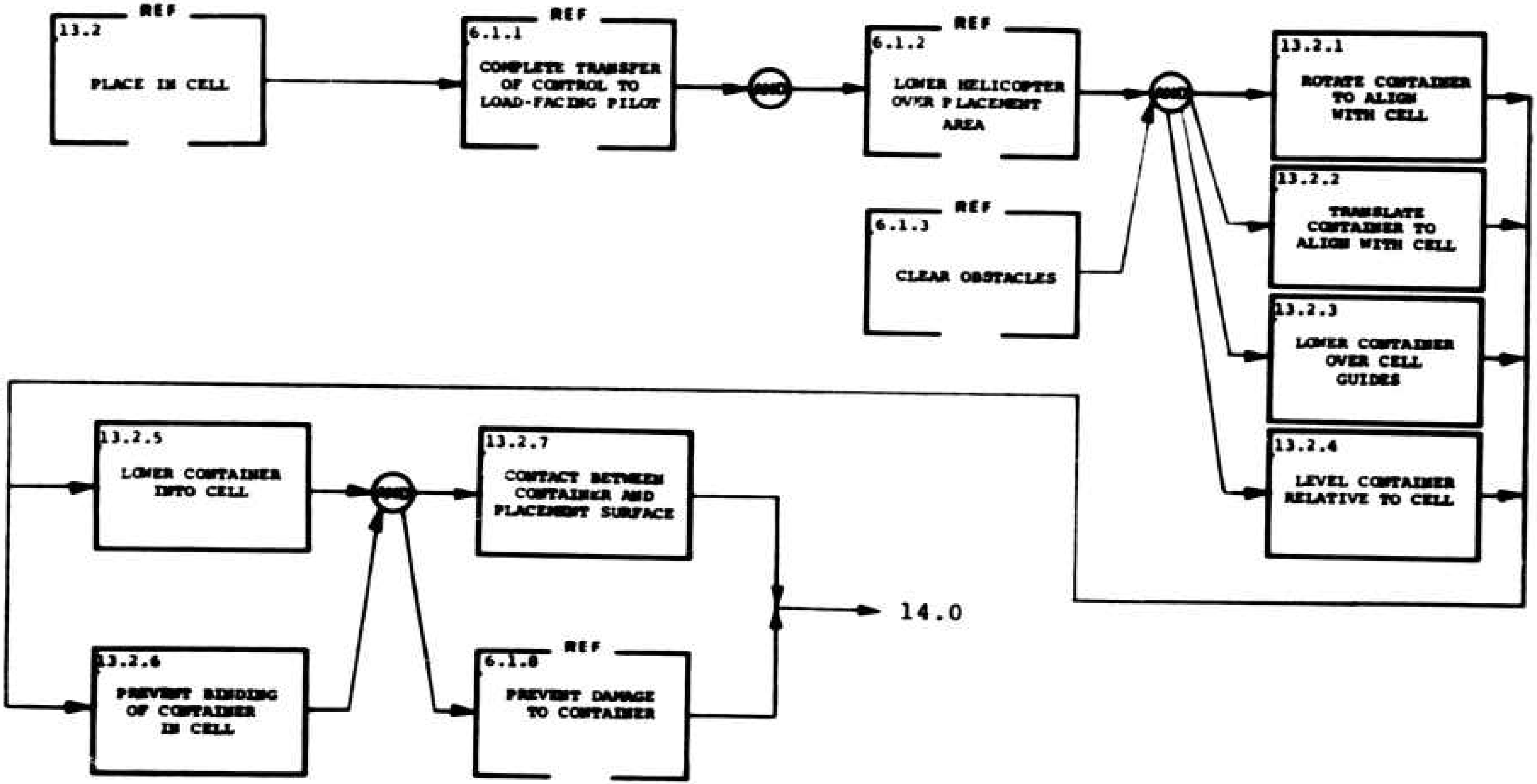

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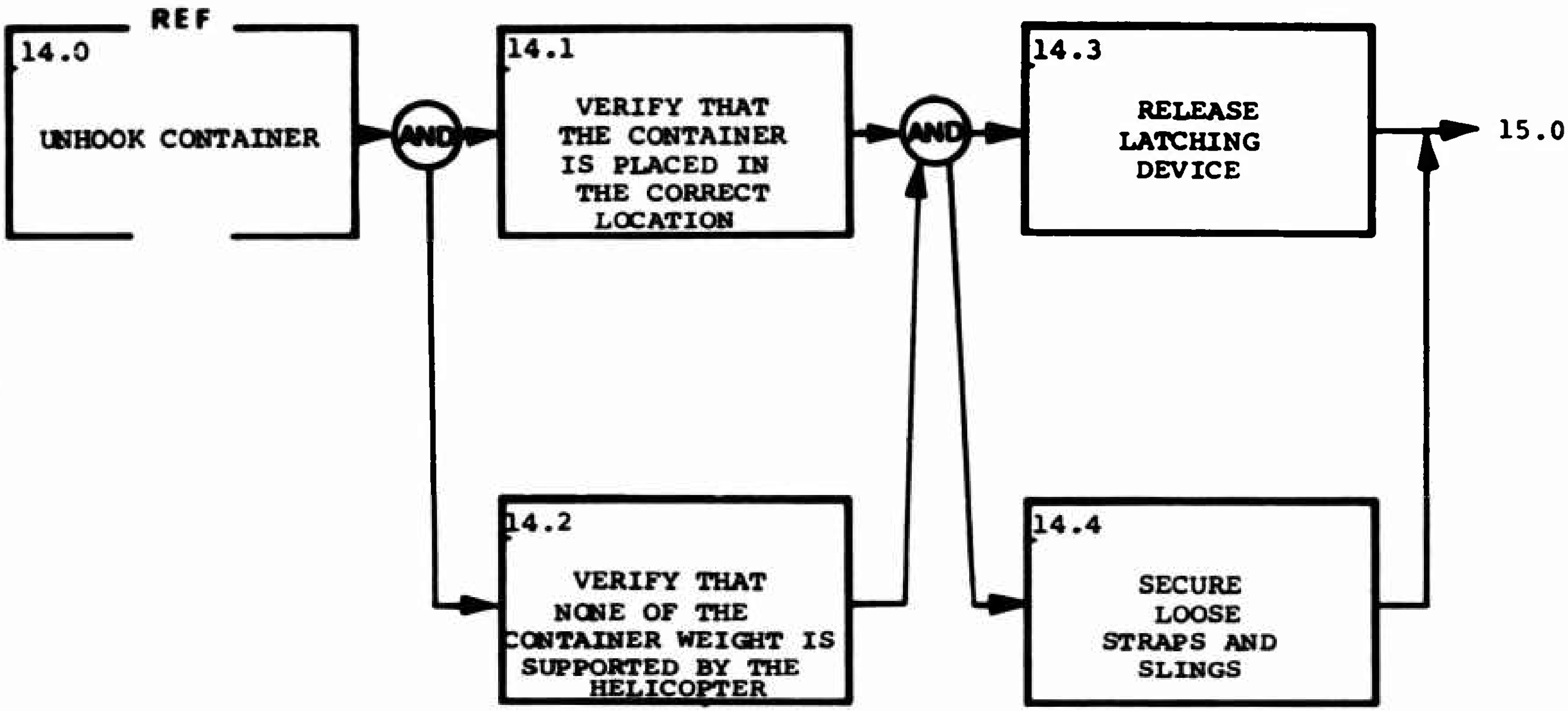

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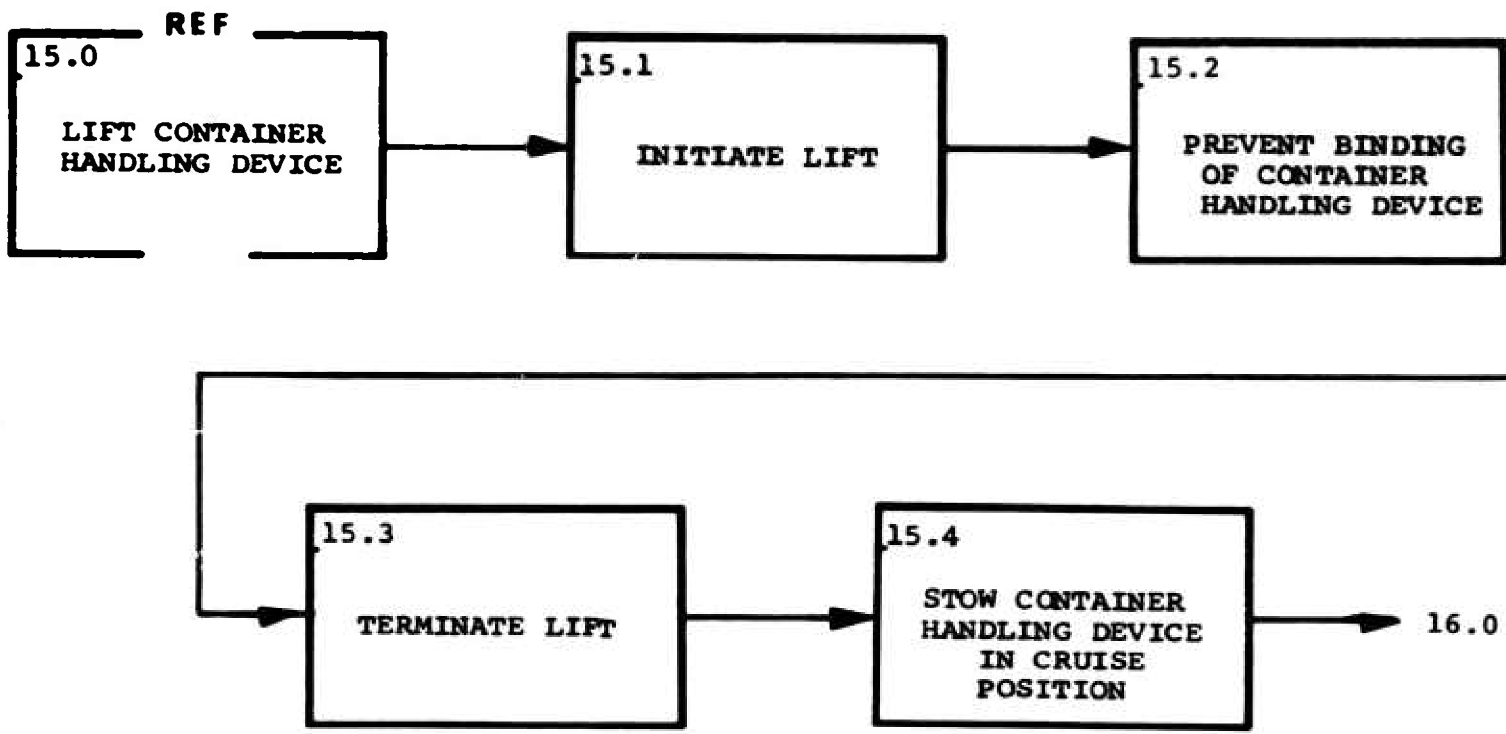

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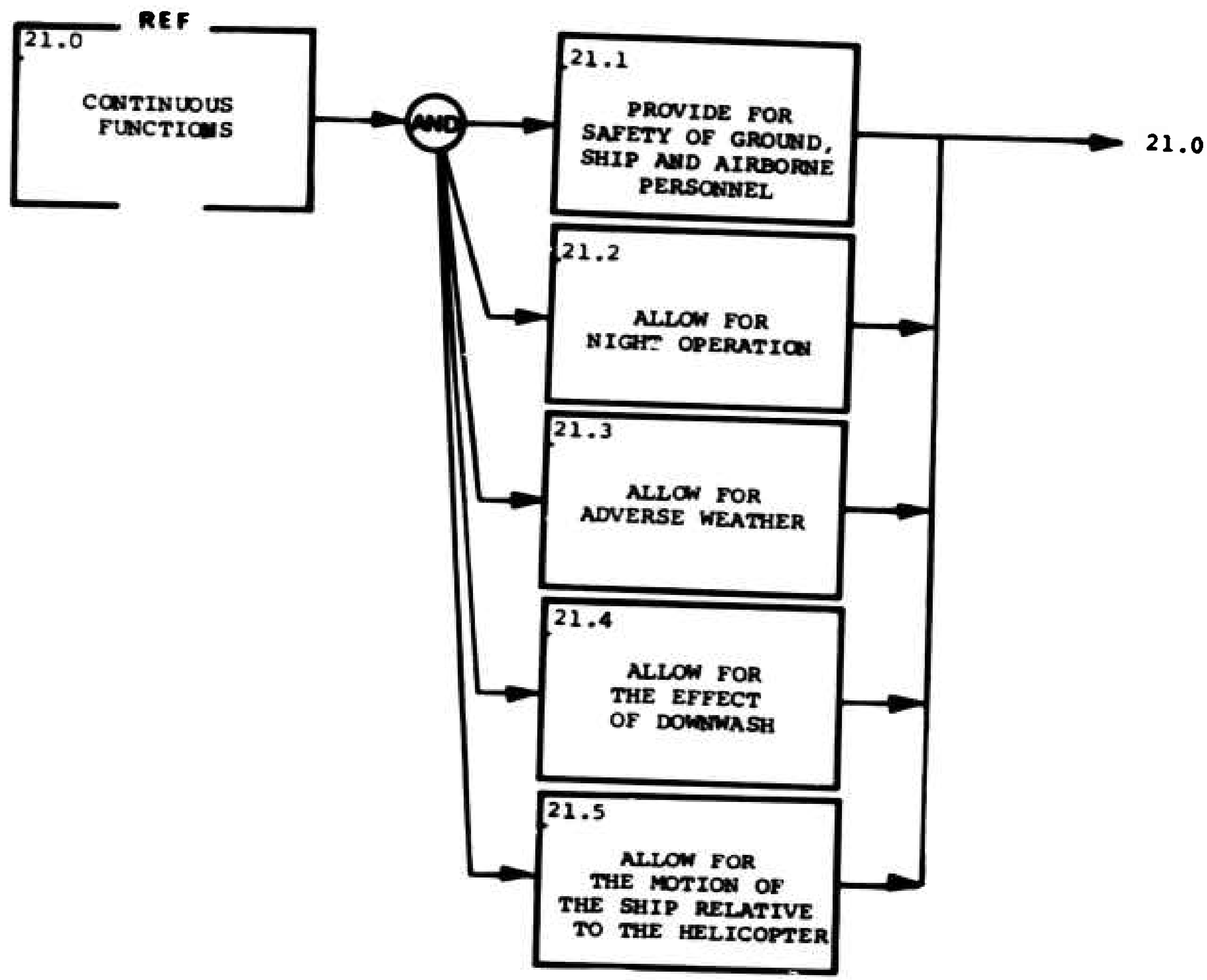

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2.2.4 Time-Line Analysis

A number of time-critical functions have been defined on a time-line basis in Figures 14 through 17. Consider a typical mission involving the container handling device.

Mission: Containership Unloading

Radius: 5 Miles (Ship to Depot Distance)

Cruise to Lift Area Time	= 169 sec	
Accelerate (.1q) to 140 kt	76 sec	8,678 ft
Cruise @ 140 kt	41 sec	9,550 ft
Decelerate (.1g)	52 sec	10,142 ft
Cruise to Release Area Time	= 210 sec	
Accelerate (.1q) to 120 kt	66 sec	6,386 ft
Cruise @ 120 kt	90 sec	11,842 ft
Decelerate (.1g)	54 sec	10,142 ft

A typical helicopter cycle would take 12 minutes based on the analysis shown in Figure 14. If it is required that 1,000 containers be off-loaded in 2 days, 10 helicopters would be needed. (Utilization per helicopter = 10 hours per day.) In order to reduce the number of helicopters to 9 and save $6.3 million flyaway cost and $20 million life-cycle cost, 1.2 minutes per mission cycle must be saved. The value for each second saved in the mission is $87,000. This means that incorporation of time-saving features in the container handling device can easily be justified on the basis of mission cost.

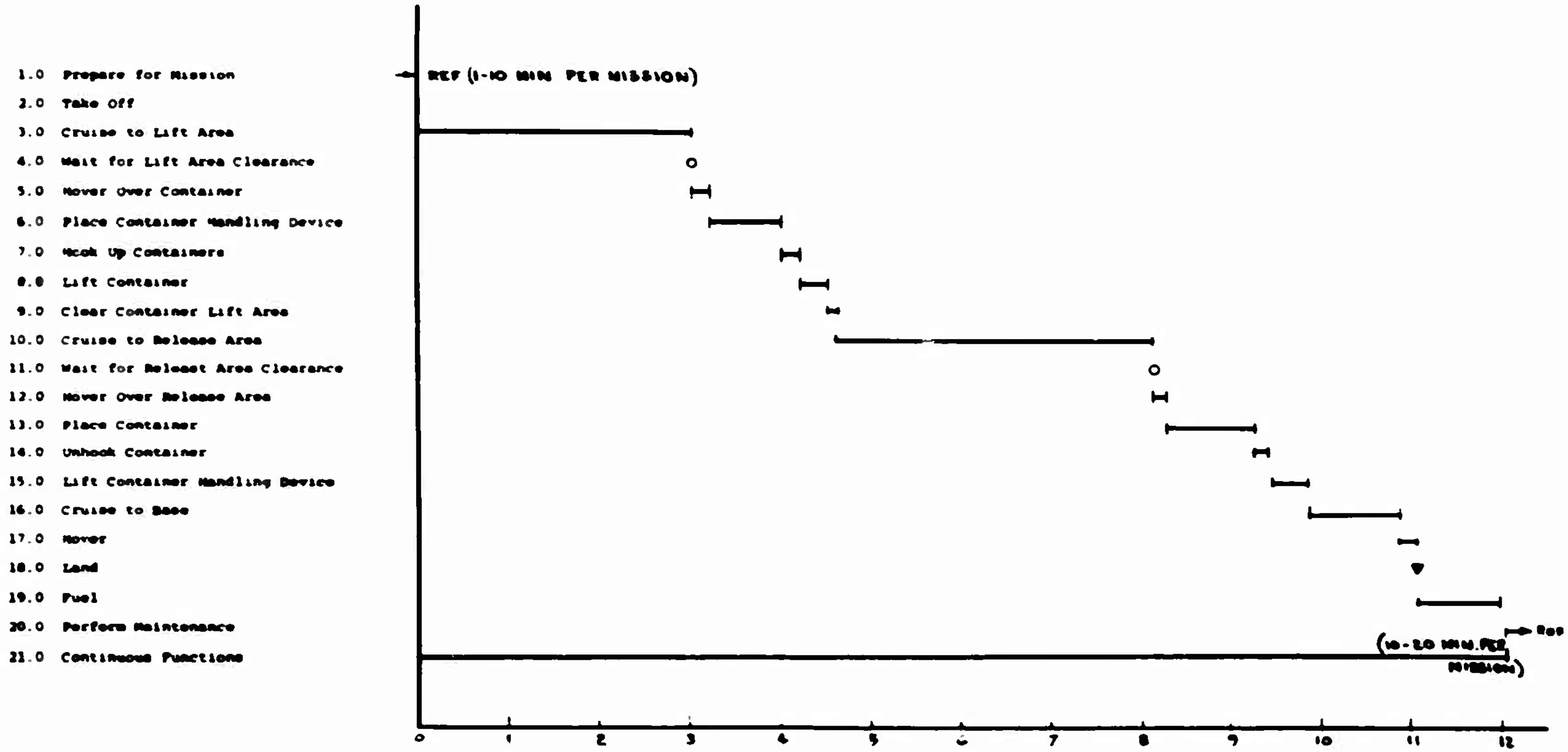


Figure 14. Time-line Analysis.

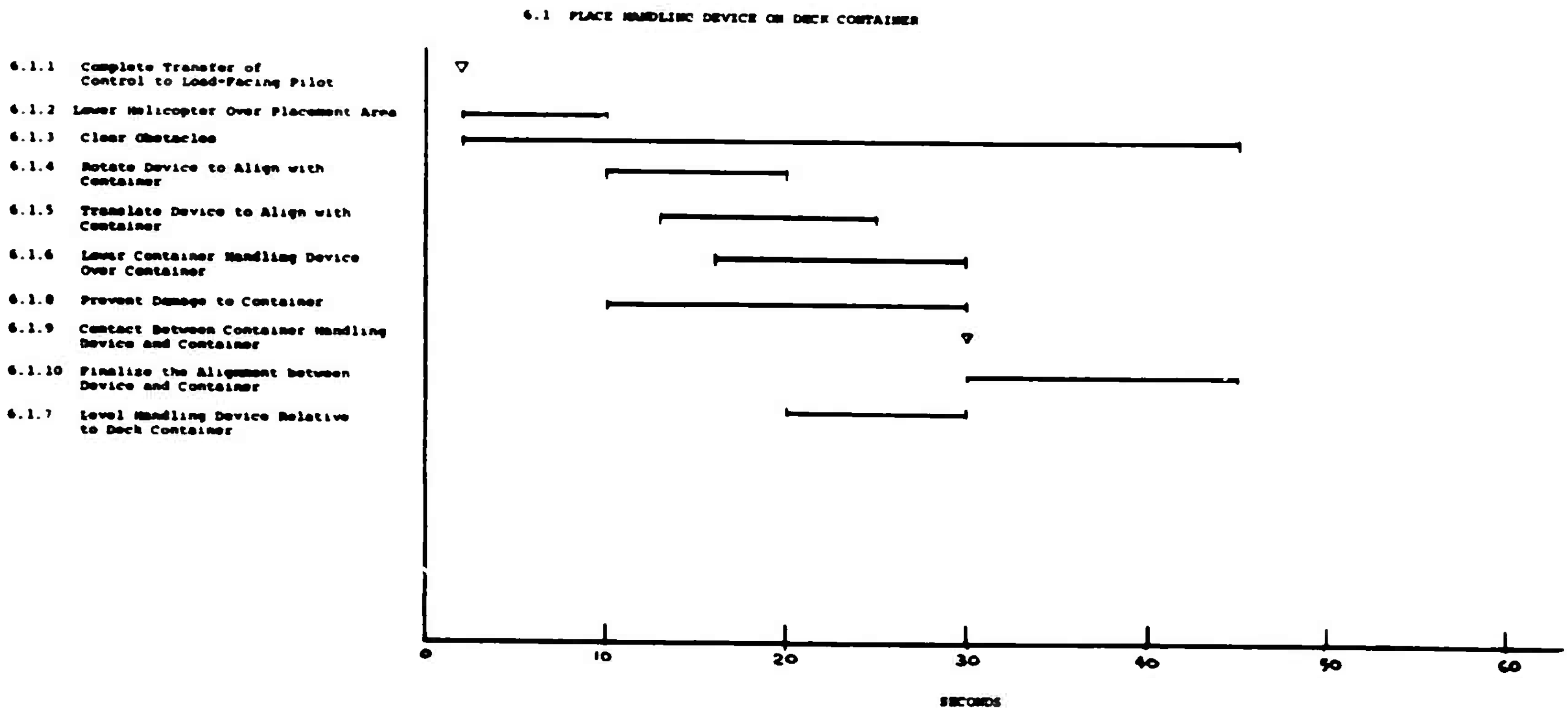


Figure 15. Time-line,Place Handling Device on Deck Container.

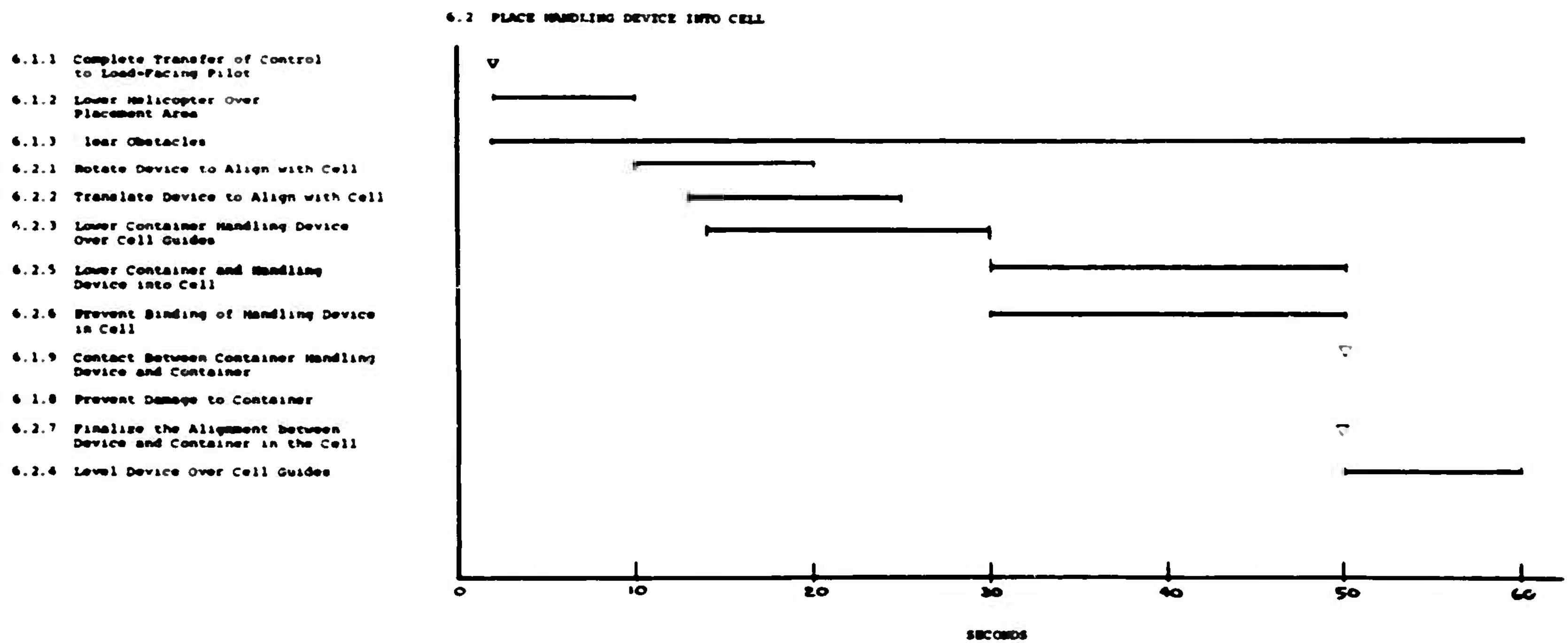


Figure 16. Time-line,Place Handling Device into Cell.

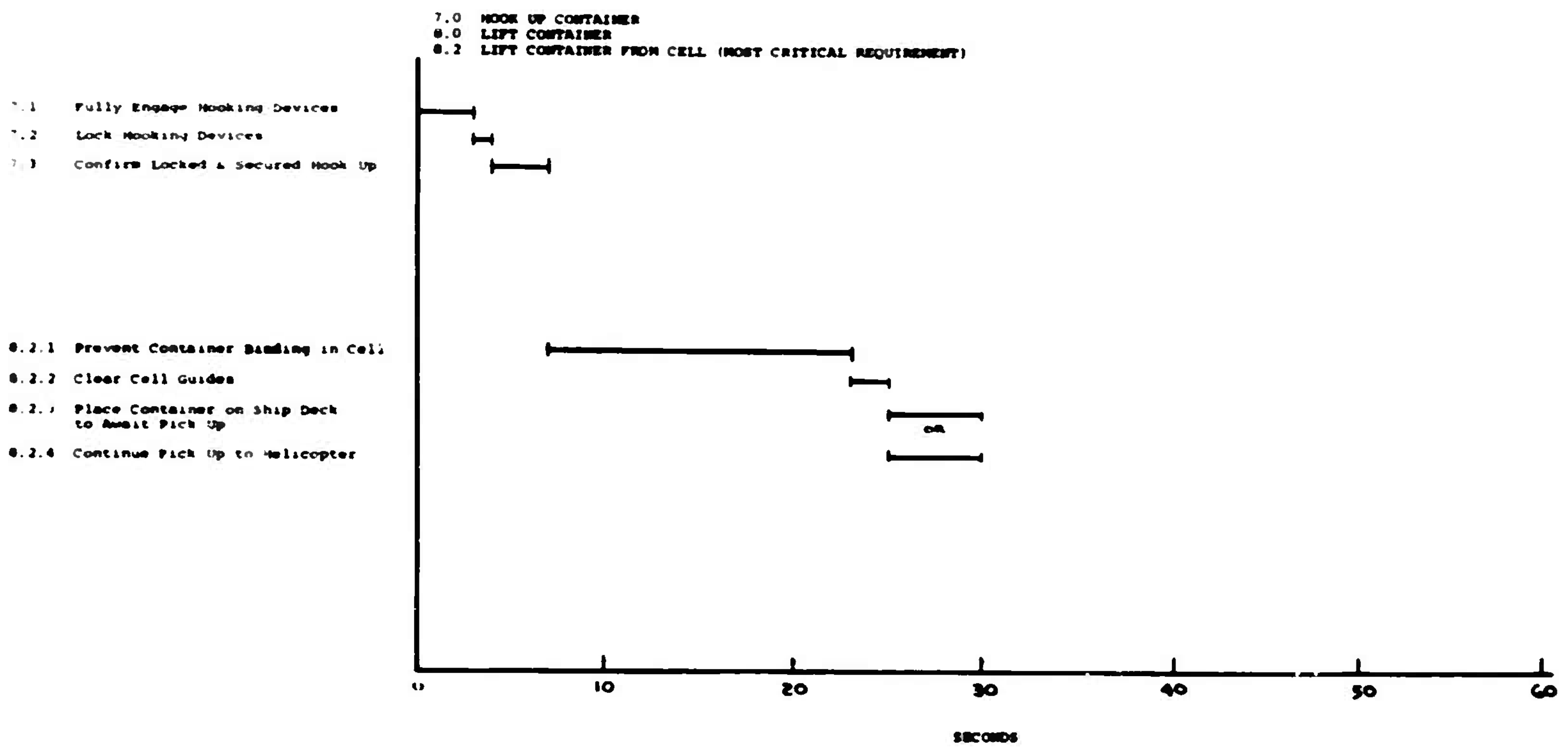


Figure 17. Time-line,Hookup and Lift Container.

2.3 Design Constraints

Design constraints for the helicopter device are those interfaces, standardized requirements, and natural phenomena which limit or control some aspect of design. Certain design constraints are not considered as required in the context of this program but have been included as desired goals in order to present as complete a picture as possible.

Container Dimensions - The prototype cargo handling device must be compatible with the 8x8x20-foot standard and MILVAN containers. Additionally, it is desirable that the production device be compatible with container lengths of 20, 24, 27, 30, 35, and 40 feet. A recent survey of the commercial container population presented in Reference 2 is shown in Table II.

Container Manufacturing Tolerance - Allow for containers to be built to +0 and -3/16 inch on width, -1/4 inch on length (for the 20-ft size) and -3/8 inch for sizes 24 through 40 feet long.

Container Weight - Design the device for the maximum gross weight of the 20-foot container (44,800 lb). However, it is desirable to design for the 40-foot container maximum gross weight (67,300 lb).

Cell Clearance - (Container Guide Corner Angles) - Allow for a containership cell clearance of 1/2 inch all around (from the maximum container dimension).[2]

Flared Entry Guide - The slope offset of the flared entry guides varies from ship to ship. This offset dimension varies from 24 inches on the S.S. Hawaiian Enterprise to 4-1/2 inches on the Container Forwarder.[3,4]

TABLE II. CONTAINER POPULATION IN PRESENT USE

Size	Length (ft)	Height (ft)	Width (ft)	Approximate Quantity
Standard - 20 feet	20	8	8	40,000
Oversize - 20 feet	20	8.5	8	2,500
Matson	24	8.5	8	8,000
Sea-Train	27	9.5	8	2,500
Sea-Land	35	8.5	8	30,000
Standard - 40 feet	40	8	8	4,000
Oversize - 40 feet	40	8.5	8	24,000

Operating Environment - It is desirable that the device be capable of operation under the following conditions:

a) Temperature	-65°F to +160°F
b) Humidity	0 to 100%
c) Sand and Dust	(Per MIL-STD-810B)
d) Sunshine	(Per MIL-STD-810B)
e) Rain	(Per MIL-STD-810B)
f) Salt Fog	(Per MIL-STD-810B)
g) Fungus	(Per MIL-STD-810B)

Ship Analysis Including Superstructure Clearance - At least 150 feet of usable cable will be required in order to clear ship's superstructure and to reach containers at the bottom of the cells. [3]

The basis for this number is summarized below for representative current and future containerships.

SL-7 - The SL-7 ships are currently under construction in European shipyards. These ships will carry 1,085 35-foot and 40-foot containers at speeds up to 33 knots. The design has no shipboard gantry crane. Maximum depth of storage cells is 62 feet below deck, and the maximum height of the forward and aft masts above the deck is 84 feet.

C5-S-73 - The C5-S-73 was the first of the modern containership designs to see service. The cargo capacity is 928 20-foot containers with no shipboard cargo handling gear. Hatch cover weight is 64,500 pounds. Maximum depth of storage cells is 54 feet below deck, and the maximum height above deck is 57 feet for the rear mast.

C6-S-85 - These ships are designed to carry 800 to 1,000 20-foot containers at a maximum speed of 23 knots. Gantry cranes have been eliminated from the original design. Hatch cover weight is 47,500 pounds. Maximum depth of the storage cells is 50 feet below deck. Maximum height above deck is 95 feet for the rear mast.

C7-S-88 - The C7-S-88 class ships have a capacity of 1016 24-foot containers. However, the vessels have a conversion feature to change the cells to fit 20-or 40-foot containers, although this operation would take at least 14 to 30 shipyard days. Hatch cover weight is 51,100 pounds. Maximum depth of the cells is 56 feet below deck, and the forward mast is 78 feet above deck.

2.4 Material

Commercial container handling devices employ low-grade structural steel to the almost complete exclusion of other materials. The use of steel is undoubtedly dictated by:

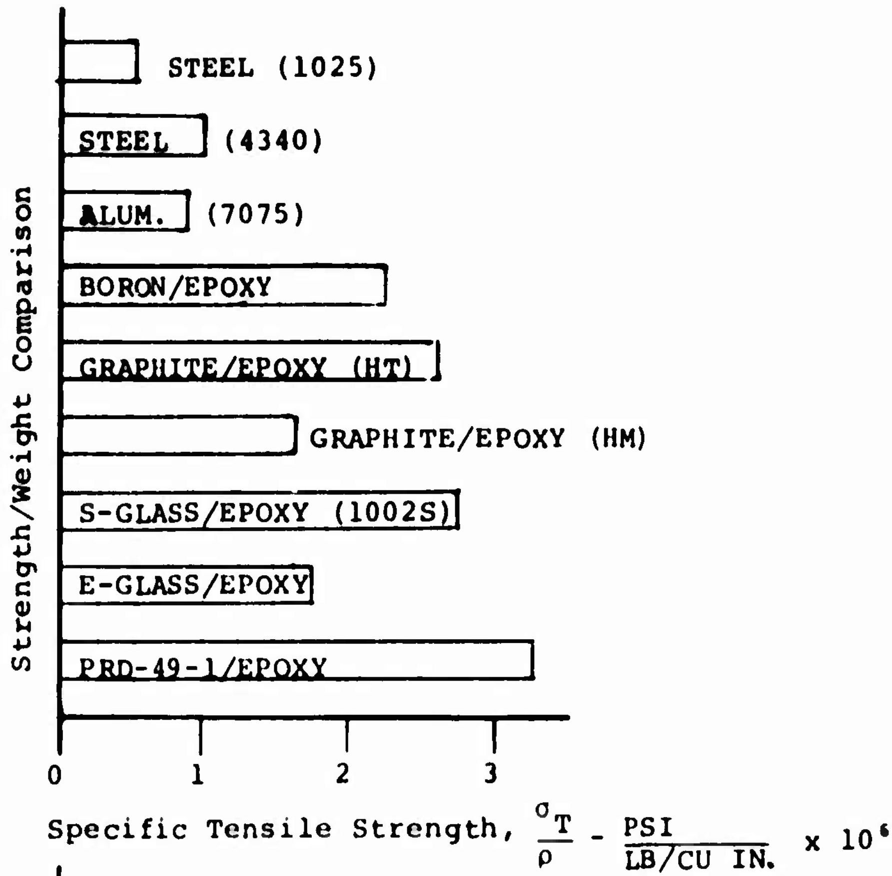
a) Cost
b) Minimal Weight Constraints
c) Experience With This Material
d) Durability

In the helicopter application, the container handling device represents a direct loss of payload. As a result, the most important parameter becomes weight. Size of the device is essentially fixed, as are the maximum capacities of the containers which are lifted. Attainment of low weight must therefore center on material selection.

The search for low-weight structural materials for the aerospace industry has led to the development and application of fiber-reinforced composite materials in primary airframe structures. Currently, a great number of fiber-reinforced composites are available with widely different properties which offer advantages in design optimization. Some of these materials and their properties are shown in Figure 18.

Since a primary function of the device is to act as a spreader bar, the compressive properties are of prime importance. As shown in Figure 19, practically all of the composites have better compressive strength-to-weight ratios than steel or aluminum. In terms of stiffness to weight, the graphite and boron composites definitely excel.

In the commercial container handling device industry, the opinion exists that the loads imposed on the device during operations inside the containership cell guides are a major factor in the device's design. In addition to general rough handling, operations inside the cell guides involve banging into the guides, since only 1/2 to possibly 1 inch clearance exists between the containers and the guides. The impact characteristics of the material are therefore also of importance. Figure 20 shows a comparative index of fracture toughness for several composites and for steel. The graphite and boron composites, which have the best combination of compressive properties, are substantially below steel in fracture toughness. No data has been found as yet on the dynamic loads imposed on container handling devices.



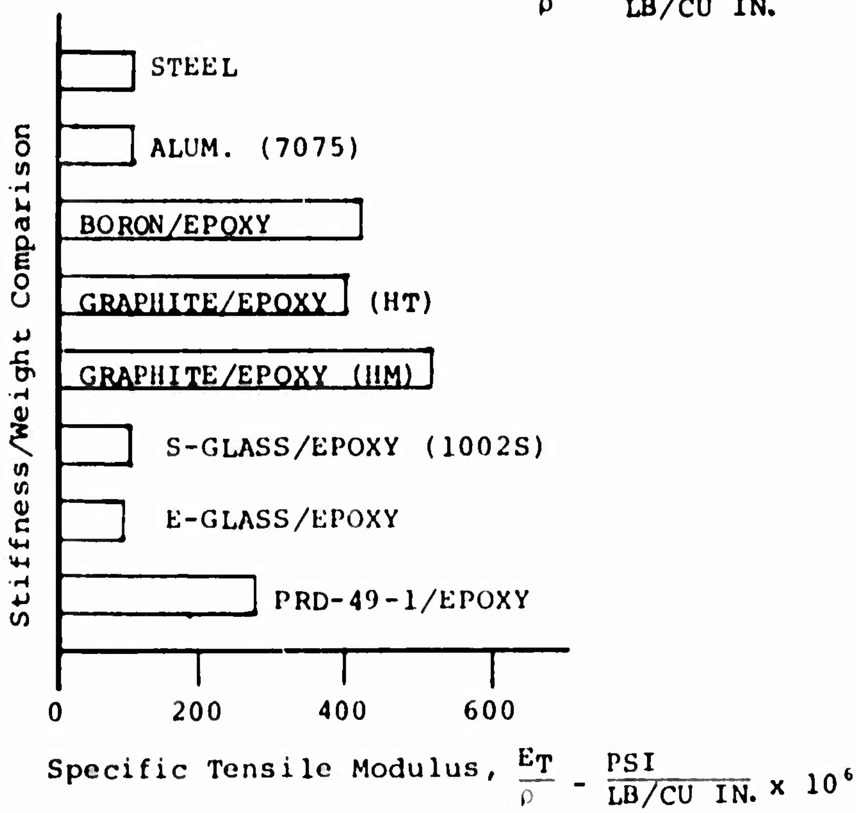


Figure 18. Comparison of Material Tensile Properties.

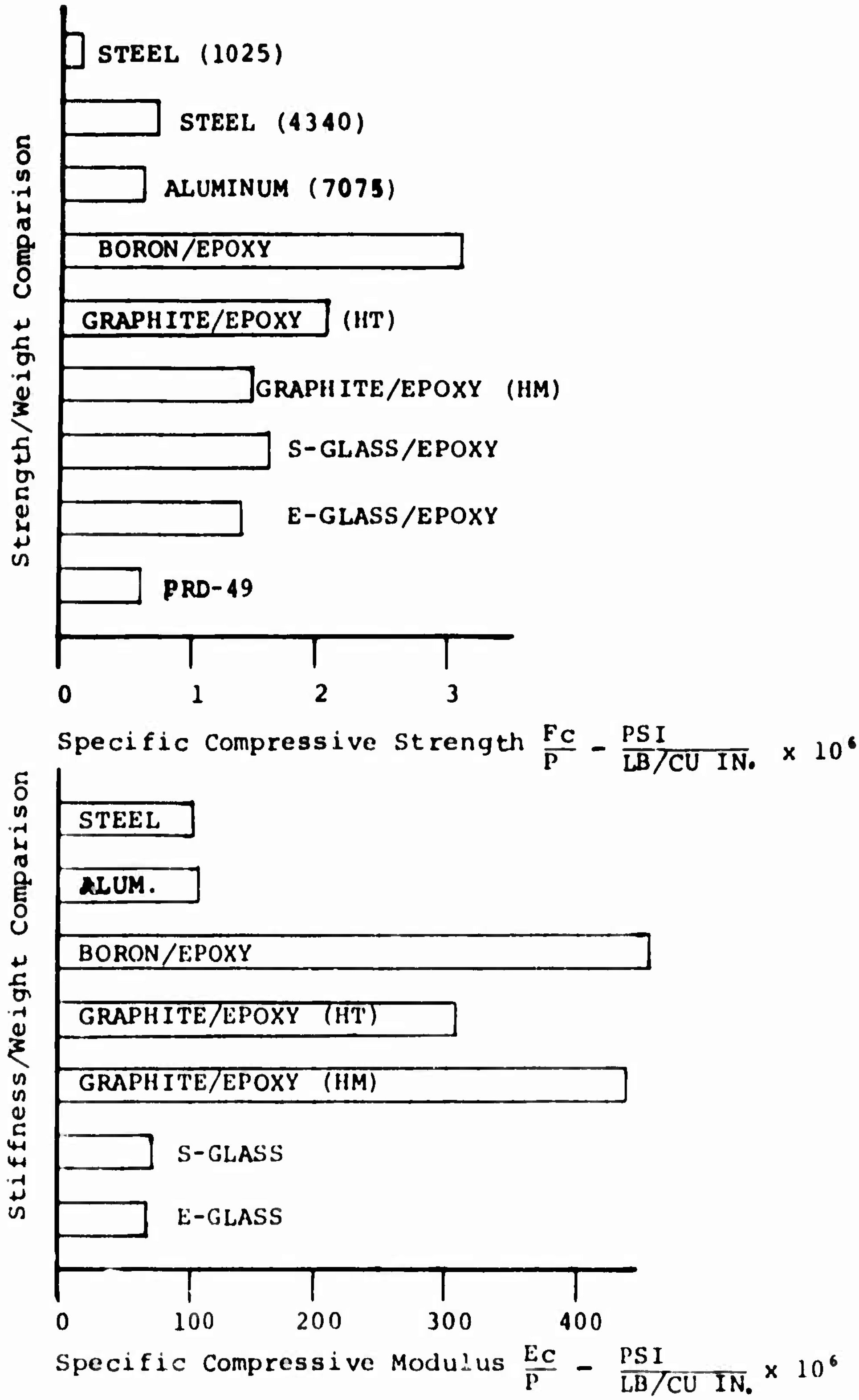


Figure 19. Comparison of Material Compressive Properties.

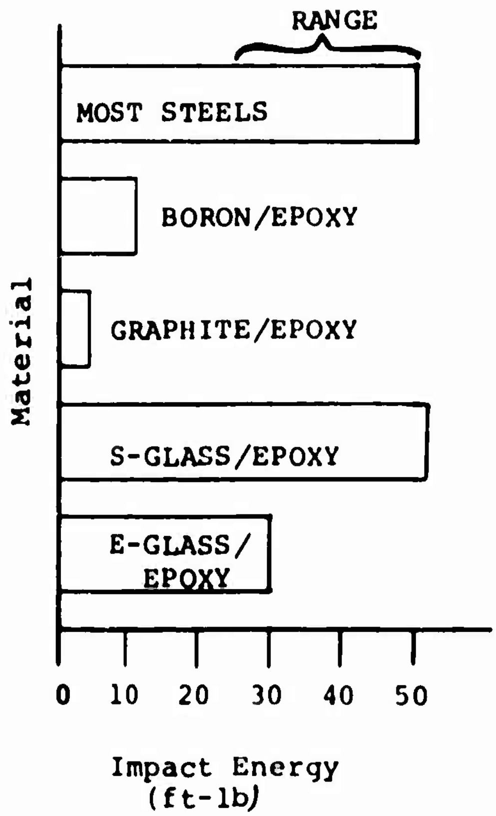


Figure 20. Fracture Toughness (Reference 5).

A compromise is definitely indicated when both compressive strength and high impact resistance are required in a composite material. This can take the form of either a material compromise or a design compromise. A design could be selected which protects compressive members from impact damage either by interior location or by the use of a protective coating, such as polyurethane.

Estimates were obtained on the lead time requirements for fabrication of structural beam shapes in composite materials. Using a two-dimensional weave and a continuous cure process, structural shapes in lengths up to 20 feet will take 3 to 4 months for delivery. This time period is incompatible with the contractual commitment of an 8-month program span.

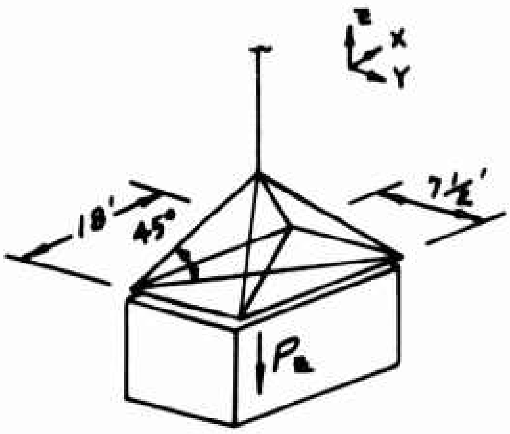
Considering the material compressive properties as shown in Figure 19, there are substantial strength and stiffness-to-weight improvements available from high-strength steel (4340) or aluminum alloy as compared to carbon steel (1025). Of the two, the aluminum holds an edge in corrosion resistance, especially in a marine atmosphere.

The sizing of the main structural members will be based on a combination of bending and axial compressive load conditions. Although unit strength is important in bending, the allowable column strength in this length range is primarily a function of the modulus of elasticity. A somewhat lower strength aluminum alloy with the same modulus as 7075 and weld capability appears to be the best choice.

The use of 6061 aluminum alloy is therefore recommended for the container handling device which will be built under this program. This selection is based on strength and stiffness to weight, commercial availability of structural shapes, weldability of this alloy, and corrosion resistance.

2.5 Preliminary Strength Criteria

Single-Point Suspension - CH-47 and CH-54 A/C only.



Cargo Weight = 25,000 lb

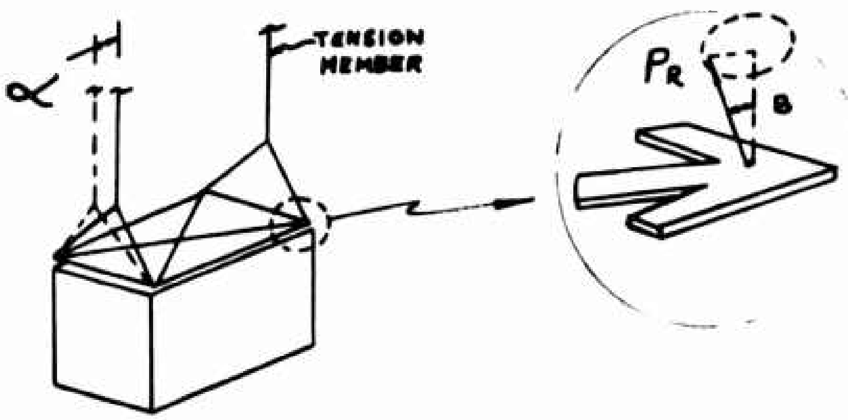
Vertical Load Factor = 2.3 Limit*

*Includes an estimated 15% increase due to dynamic coupling of cargo and A/C.

P_Z = 25,000 x 2.3
= 57,500 lb limit
= 86,200 lb ultimate

Aft Trail (Swing Back) Angle Capability = 30°

Dual-Point Suspension - HLH A/C only.



Payload	=	56,000 lb
Wt of Cable & Coupling	=	700 lb
		56,700 lb
Load Factor	=	2.5 Limit (Increase due to dynamic coupling considered to be negligible)
Aerodynamic Load On Cargo	=	2780 lb limit
Load Distribution	=	60/40 or 40/60
Design Cable Angle (α)	=	30°

Max Load on One Tension Member = 1.15 x .60 x (2.5 x 56000 + 2700)
= 100,000 lb limit
= 150,000 lb ultimate

For preliminary design, 50% of this load will be considered to be the vertical component at each corner of the handling device. The total corner load to be applied at an angle = 30°.

$$\therefore \quad P_R = .5 \times \frac{100,000}{\cos 30^\circ}$$

= 57,800 lb limit
= 86,800 lb ultimate

Note: Symmetrical loads will be considered to act at all four corners simultaneously.

2.6 Effect of Device Weight

The weight of the container handling device must be held to a minimum in order to maximize the helicopter payload. MTMTS data shows that the weight of the 20-foot containers ranges from 4 to 22.5 tons. If, for example, a 22.5-ton load were split, 2 tons for the handling device and 20.5 tons for the container, 10% of the containers could not be lifted. Thus, for a 1000-container-ship, 100 containers would have to be reconfigured to be 110-20.5 ton containers. Thus, as shown in Figure 21, the 2-ton handling device would result in a $200,000 10-year systems cost penalty, over a zero weight handling device. Figure 21 also shows the 10-year system cost penalty for a number of different weight devices. Notice that for the heavy container devices, the penalty is very severe.

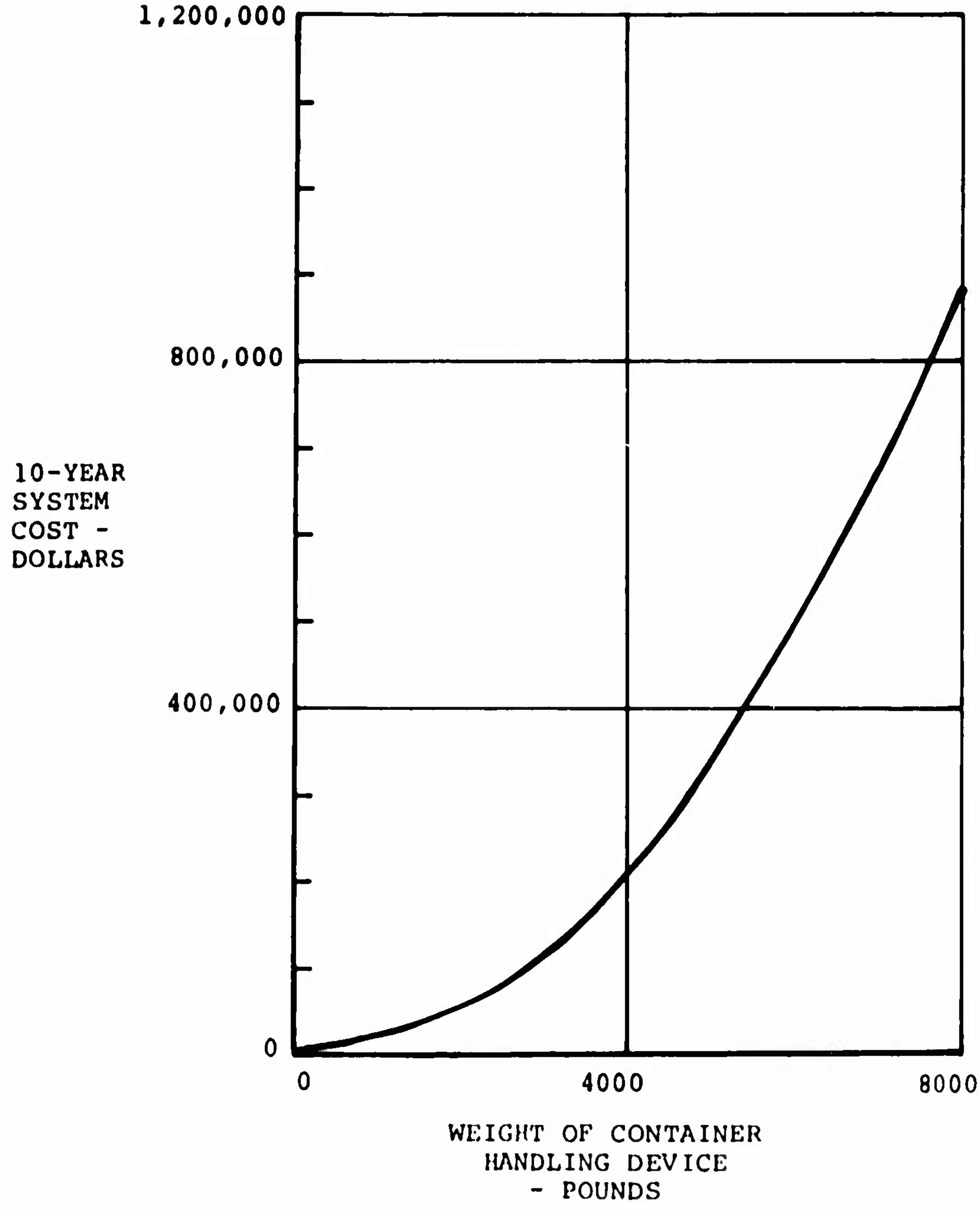


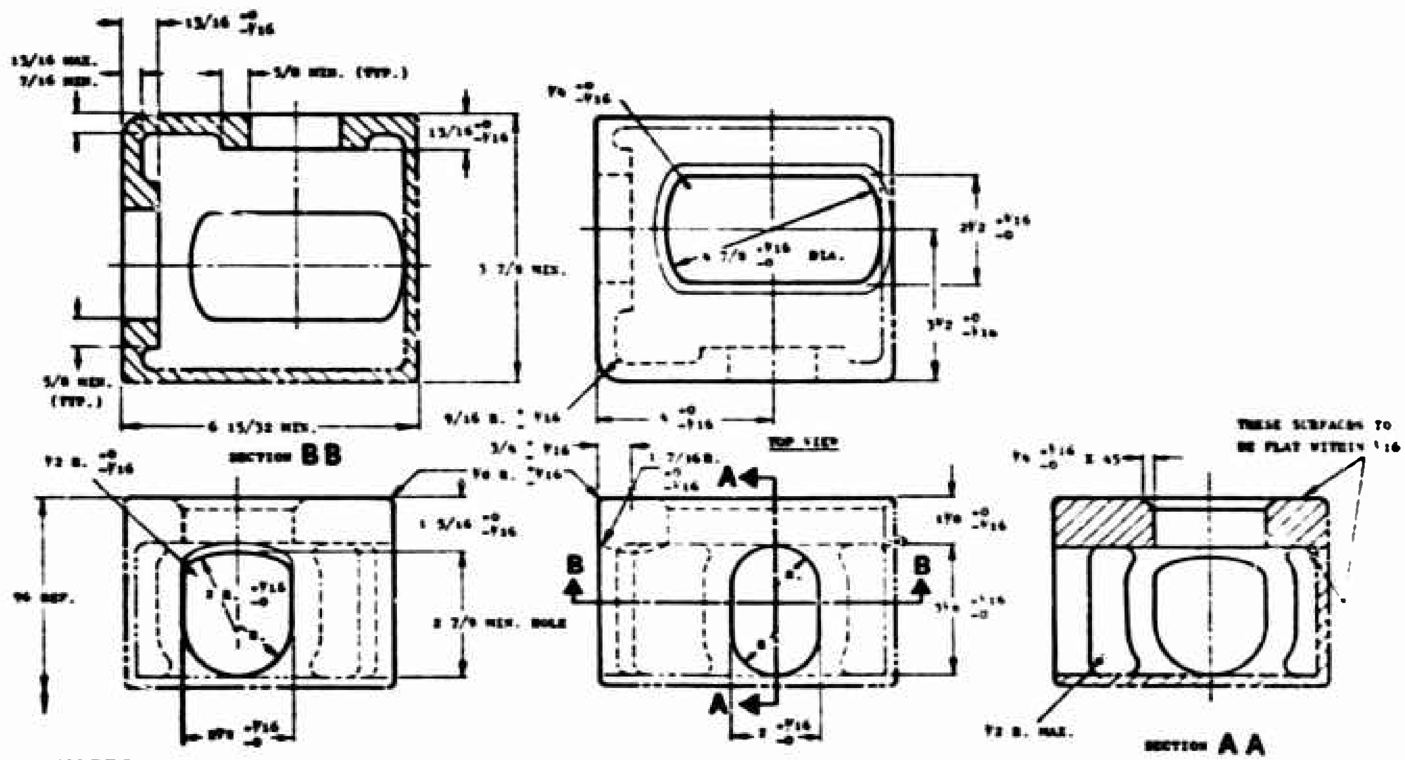
Figure 21. Effect of Container Handling Device Weight on Total 10-Year Systems Cost.

2.7 Latching Criteria

The intended use of the container handling device is to pick up, transport, and deliver standard ANSI (American National Standards Institute) containers. A container is defined in Reference 1 as an article of transport equipment which is: (a) of a permanent character and strong enough for repeated use, (b) designed to facilitate the carriage of goods by two or more modes of transport without intermediate reloading, and (c) equipped with features permitting its ready handling and transfer from one mode of transport to another.

To accomplish requirement (c), containers are equipped with top and bottom corner fittings. The helicopter-transported container handling device will use only the top corner fittings since these are the only ones accessible when the containers are stacked below decks i containership cell guides. Figure 22 shows the standard dimensions for top corner fittings. The opening provided in the top surface of the corner fitting is 4-7/8 + 1/16 - 0 inches diametrically by 2-1/2 + 1/16 - 0 inches between the flat sides.

The top corner fittings are designed to permit the use of three types of lifting fittings: fixed hooks, screw anchor shackles, and twist locks. The fixed hooks and screw anchor shackles are engaged manually and protrude outside the planform of the container as shown in Figure 23. These fittings can be used in all applications except inside containership cell guides where sufficient side clearance does not exist.



NOTES

1. Solid and dotted lines (-----) show surfaces and contours, which must be physically duplicated in the fitting.
2. Phantom lines (—··—) show optional walls, which may be used to develop a boxed shaped fitting.
3. Outside and inside corner radii, where sharp corners are shown, must be 1/8 in. maximum except as noted.
4. Four fittings required per container, 2 R.H. - 2 L.H.

Figure 22. Standard Dimensions for Container Top Corner Fittings.

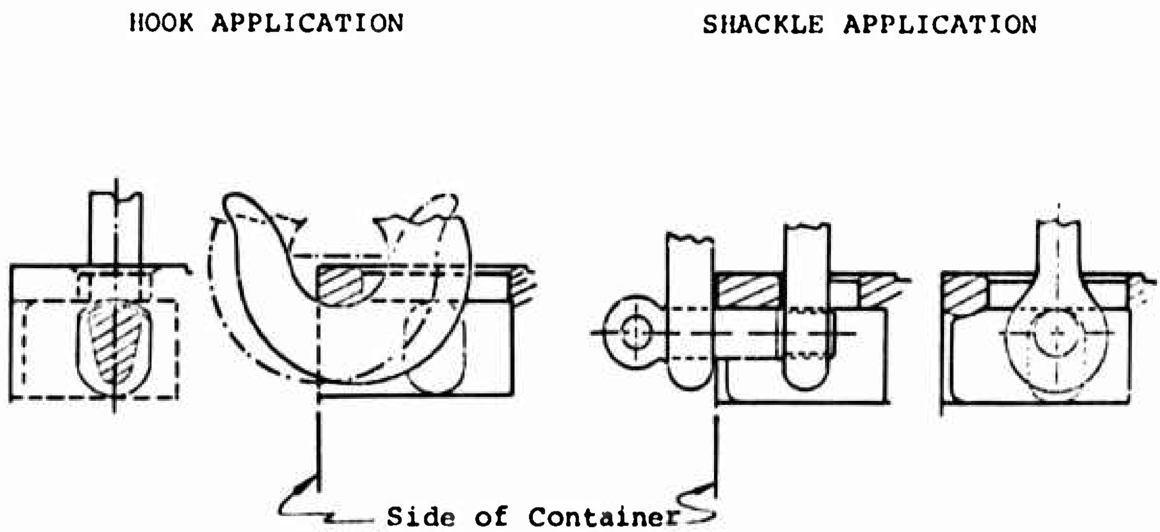


Figure 23. Hook and Shackle Attachments Protruding Beyond Side of Container.

The twist locks can be engaged either manually or automatically and remain completely inside the container planform.

Remotely controlled twist locks will be used on the helicopter-transported container handling to satisfy objectives of: (a) rapid pickup and release of the load, (b) elimination of ground hookup personnel, and (c) compatibility with the containership mode of transport. Standard twist lock dimensions are shown in Figure 24.

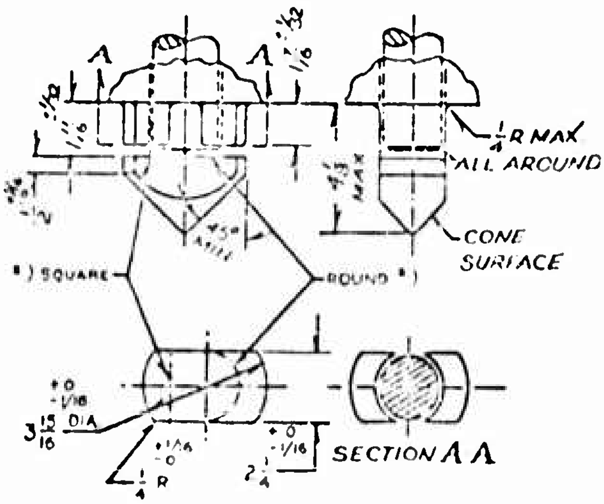
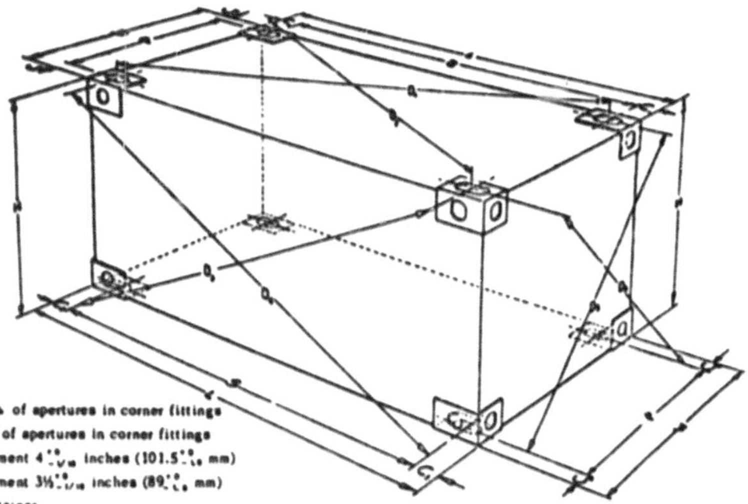


Figure 24. Twist Lock (Safety Type) Dimensions.

Engagement and latching of the device to the container involves simultaneous placement of the four twist locks in the box corner fittings and 90° rotation of the locks to the secure position. Figure 25, from Reference 1, shows the assembled corner fitting diagonal tolerances which will dictate the dimensions and tolerances for the container handling device.



S - Length between centers of apertures in corner fittings
P - Width between centers of apertures in corner fittings
C_1 - Corner fitting measurement $4^{+0}_{-1/16}$ inches ($101.5^{+0}_{-1.5}$ mm)
C_2 - Corner fitting measurement $3\frac{1}{2}^{+0}_{-1/16}$ inches ($89^{+0}_{-1.5}$ mm)
L - External length of container
W - External width of container
D - Distance between centers of apertures of diagonally opposite corner fittings resulting in 6 measurements, D_1, D_2, D_3, D_4, D_5 and D_6
K_1 - Difference between D_1 and D_2 or between D_3 and D_4, i.e., $K_1 = D_1 - D_2$ or $K_1 = D_2 - D_1$ or $K_1 = D_3 - D_4$ or $K_1 = D_4 - D_3$
K_2 - Difference between D_5 and D_6; i.e., $K_2 = D_5 - D_6$ or $D_6 - D_5$
H - Overall height

*At the present time this size is not included in the air mode. Future revisions may consider this container for such service.

Nominal Length Feet	Length Overall (L)		S		P		K1 Max.		K2 Max.	
	mm	Ft-In	mm	Ft - in	mm	Ft - in	mm	in	mm	in
40	12190 +2 -6	40 0 0 -3/8	11985	39 3 7/8	2259	7 4 31/32	19	3/4	10	3/8
*35	10668 +0 -10	35 0 0 -3/8	10464	34 3 7/8	2259	7 4 31/32	17	11/16	10	3/8
30	9125 +0 -10	29 11-1/4 +0 -3/8	8918	29 3 1/8	2259	7 4 31/32	16	5/8	10	3/8
*24	7320 +0 -10	24 0-3/16 +0 -3/8	7113	23 4 1/16	2259	7 4 31/32	14	9/16	10	3/8
20	6055 +3 -3	19 10-1/2 +0 -1/4	5853	19 2 7/16	2259	7 4 31/32	13	1/2	10	3/8
10	2990 +1 -4	9 9-3/4 +0 -3/16	2787	9 1 23/32	2259	7 4 31/32	10	3/8	10	3/8

Width Overall (W): 8 Ft. 0 $^{+0}_{-3/16}$ in., 2435 $^{+3}_{-2}$ mm

Height Overall (H): 8 Ft. 0 $^{+0}_{-3/16}$ in., 2435 $^{+3}_{-2}$ mm or 8 Ft. 6-1/2 $^{+0}_{-3/4}$ in., 2600 $^{+3}_{-16}$ mm

NOTE: Dimensions S and P are reference dimensions only. The tolerances to be applied to S and P are governed by the tolerances shown for the overall length (L) and overall width (W)

Figure 25. Assembled Corner Fitting - Diagonal Tolerances.

2.8 Positioning Criteria

The handling device must be guided from the reasonable extremes of hover precision for the prescribed helicopter types to that position required to engage the twist locks in the container corner fittings. This applies to containers which are standing free and to those located in containership cell guides.

Hover precision of a helicopter depends on many factors: some related to inherent machine stability; others to pilot skill, experience, and physical location; and still others associated with the ambient atmospheric conditions such as wind speed and direction. Pilot estimates place the hover precision of the CH-47 and CH-54 helicopter at ± 2 to 3 feet and ± 1 to 2 feet, respectively. The design specification for the HLH calls for a hands-off hover capability to maintain a given hover position within ± 4 inches horizontally and within 2 degrees of heading.

Considering the twist lock as a point and the top openings in the container as the targets, a precision required for engagement can be established. Longitudinal and lateral precision must be within approximately ± 2.5 inches and ± 1.3 inches, respectively. Heading accuracy must be within ± 0.05 degree. Obviously, the accuracy required for engagement is substantially tighter than helicopter hover precision and in certain instances is an order of magnitude more stringent.

The helicopter-transported device will be equipped with retractable guides which will engage a free-standing container and provide sufficient self-centering action to complete final alignment of the twist locks. The maximum practical misalignment compensation which can be built into the guides will be established during the Phase II detail design stage. Some doubt exists that it will be physically possible to compensate for ± 2- to 3-foot offsets.

For extraction of containers from ship cells, the guides must be retracted since their normal position is outside the 8x20-foot container planform. For this mode of operation, the device will be provided with tag lines so that ship personnel can manually complete the final alignment. Ship cells are provided with integral flared entry guides. The slope offset of these guides varies from ship to ship, from a maximum of 24 inches on the SS Hawaiian Enterprise to 4-1/2 inches on the Container Forwarder shown in Figure 26. These flared entry guides will aid device positioning, but in some cases the entry size is substantially smaller than helicopter hover precision.

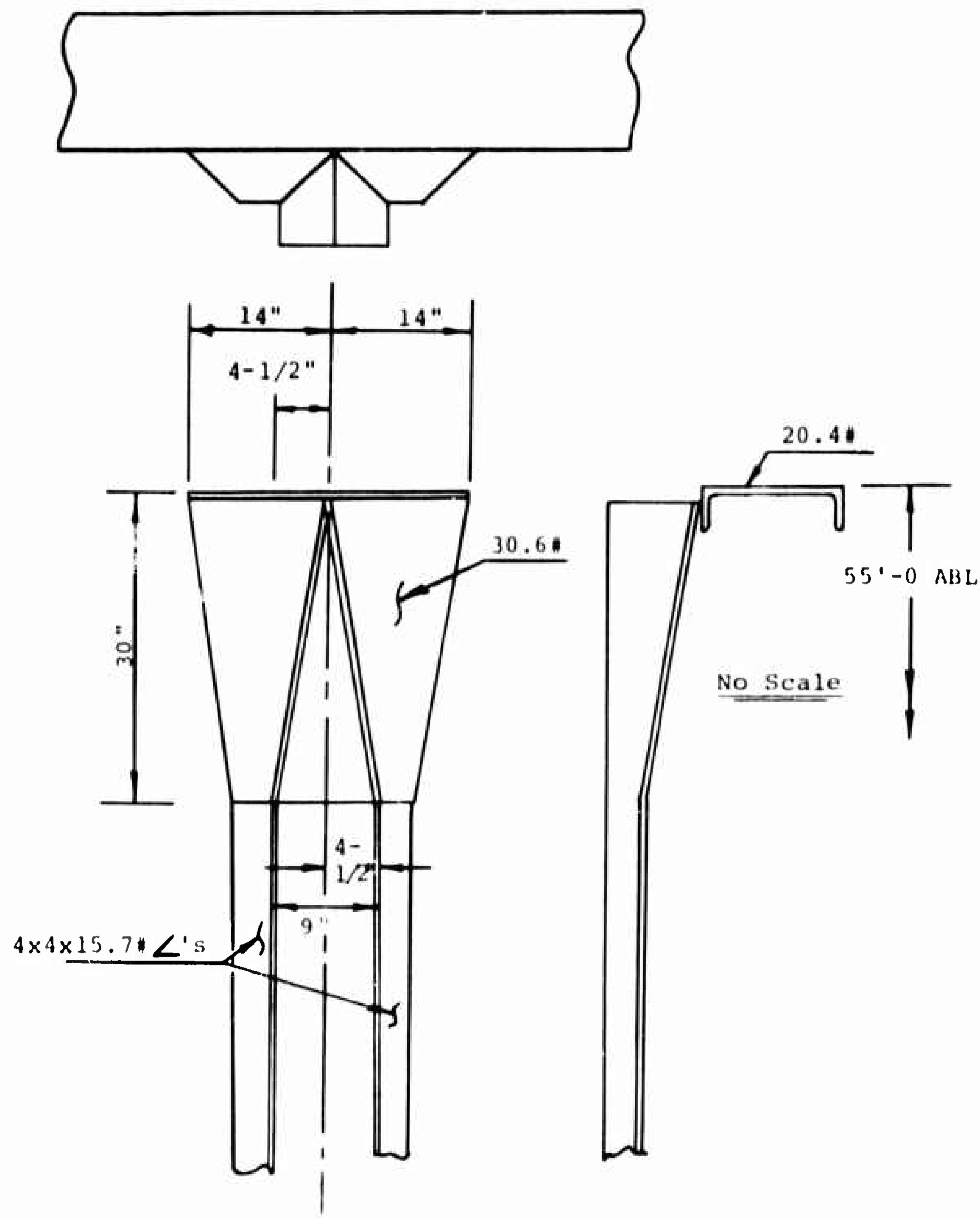


Figure 26. Existing Cell Guide Taper (Reference 3).

2.9 Commercial Handling Devices

The commercial containerization industry employs pieces of equipment alternately called lifting frames, spreader frames, or top lift adapters to transfer containers from ship to shore, from port side to stacked storage areas, and from storage areas to container frames for truck delivery.

Commercial adapters are used in conjunction with gantry cranes having two- and four-point suspensions, boom cranes with either single- or two-point suspensions, straddle cranes, and mobile container transporter/stackers called straddle carriers. Adapter weight is not a critical factor in any of the commercial applications. Four typical commercial adapter designs are shown in Figures 27 and 28. Fixed-length adapters, such as those shown in Figure 27, have basic weights of 2900 pounds and more. Adding powered twist lock actuation, fixed or retractable corner guides, or self-leveling systems, all increase adapter weight.

Commercial adapters are suspended from cranes or carriers which are normally resting on the ground or sometimes mounted on ships. Corner guides on these adapters are sized for the positioning errors which are encountered with ground-mounted cranes, which are essentially stable platforms.

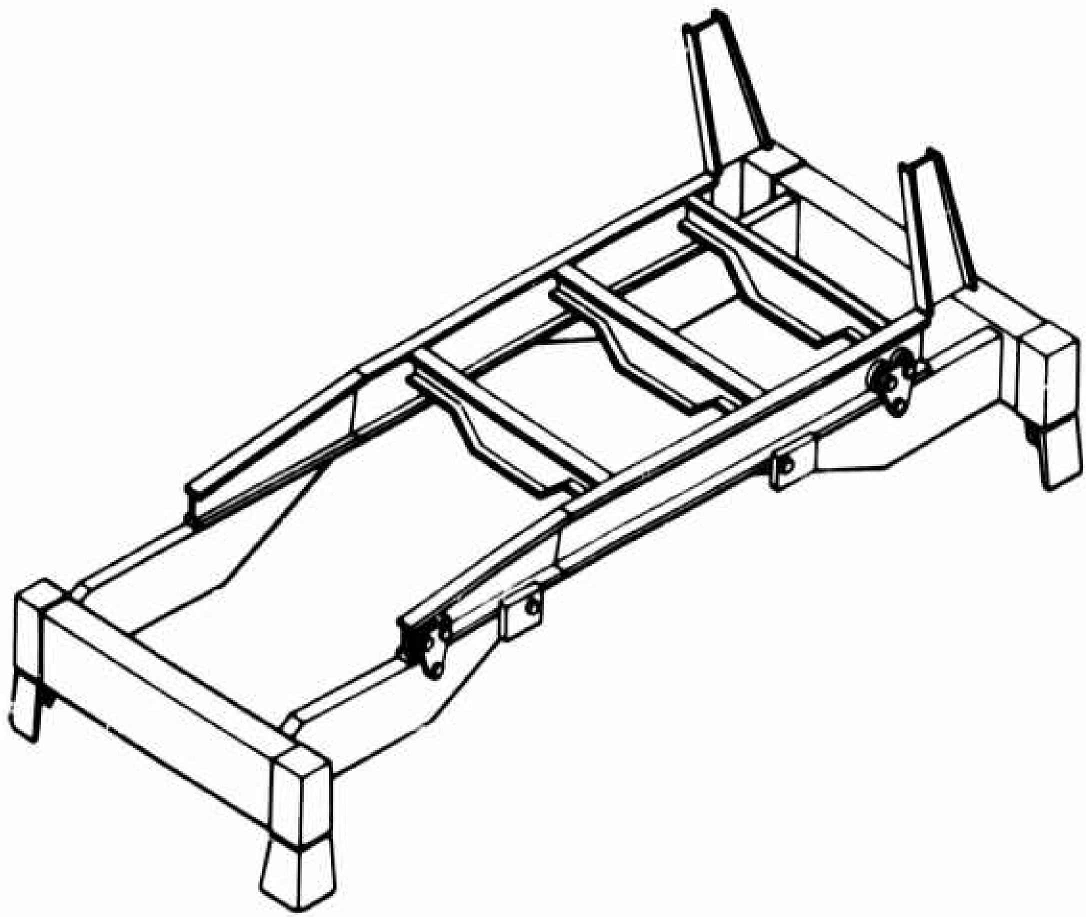


Figure 27. Typical Adjustable-Length Commercial Handling Devices.

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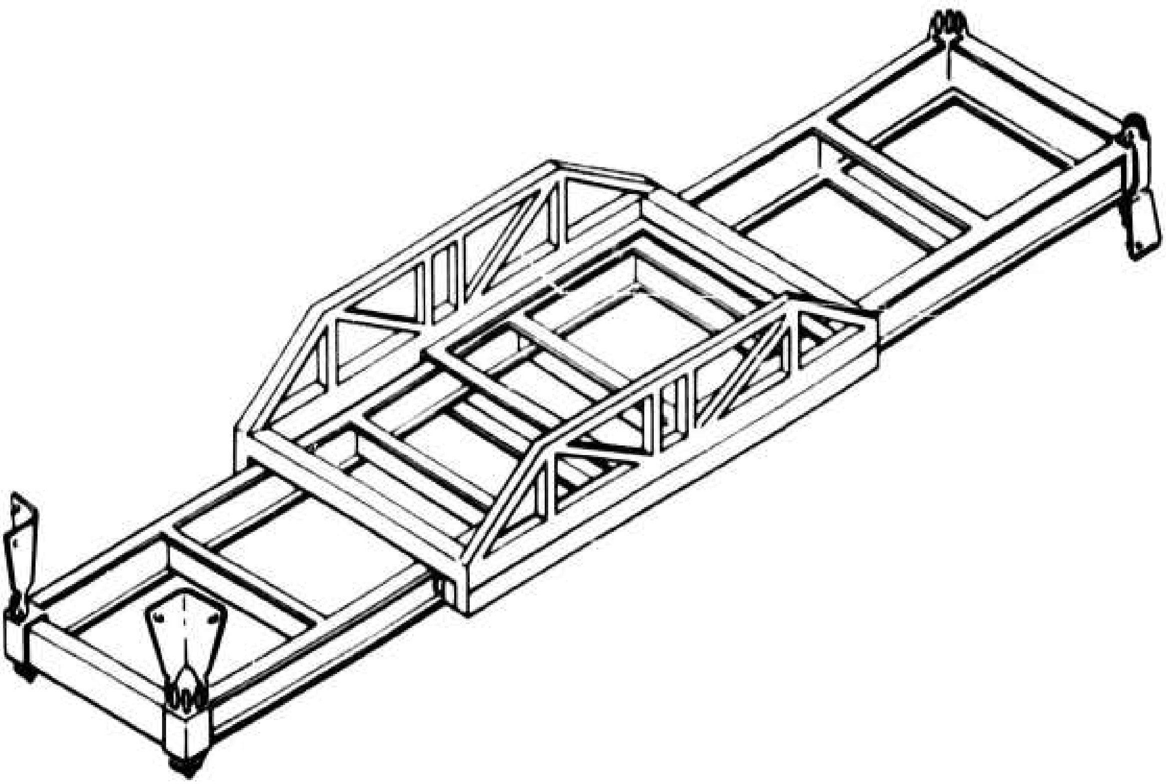


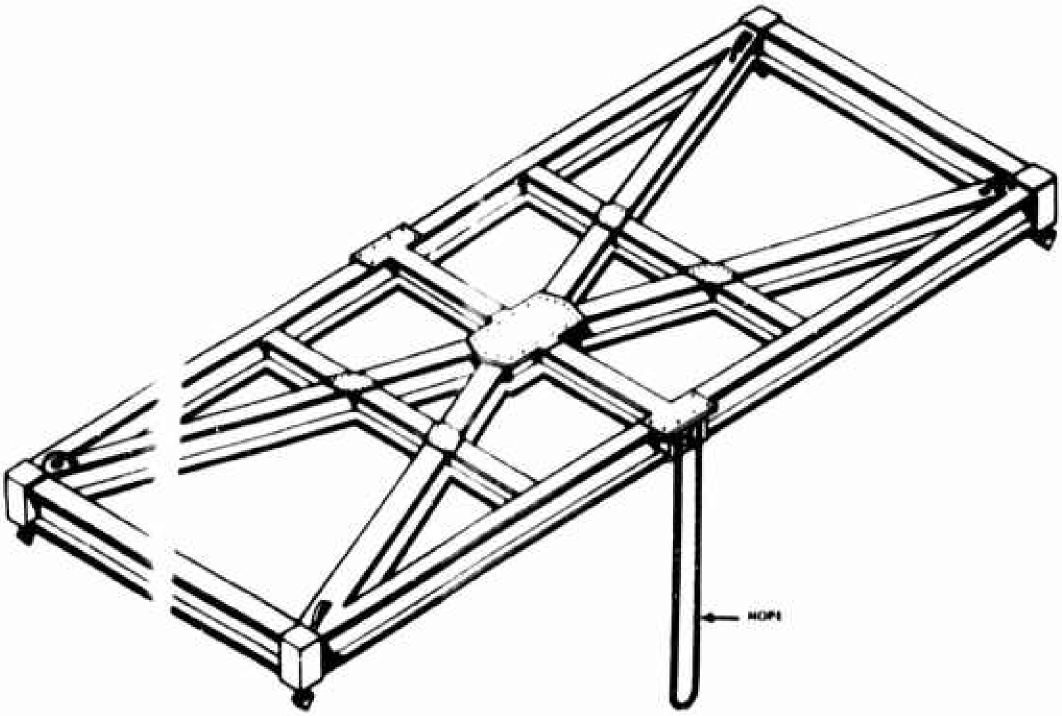
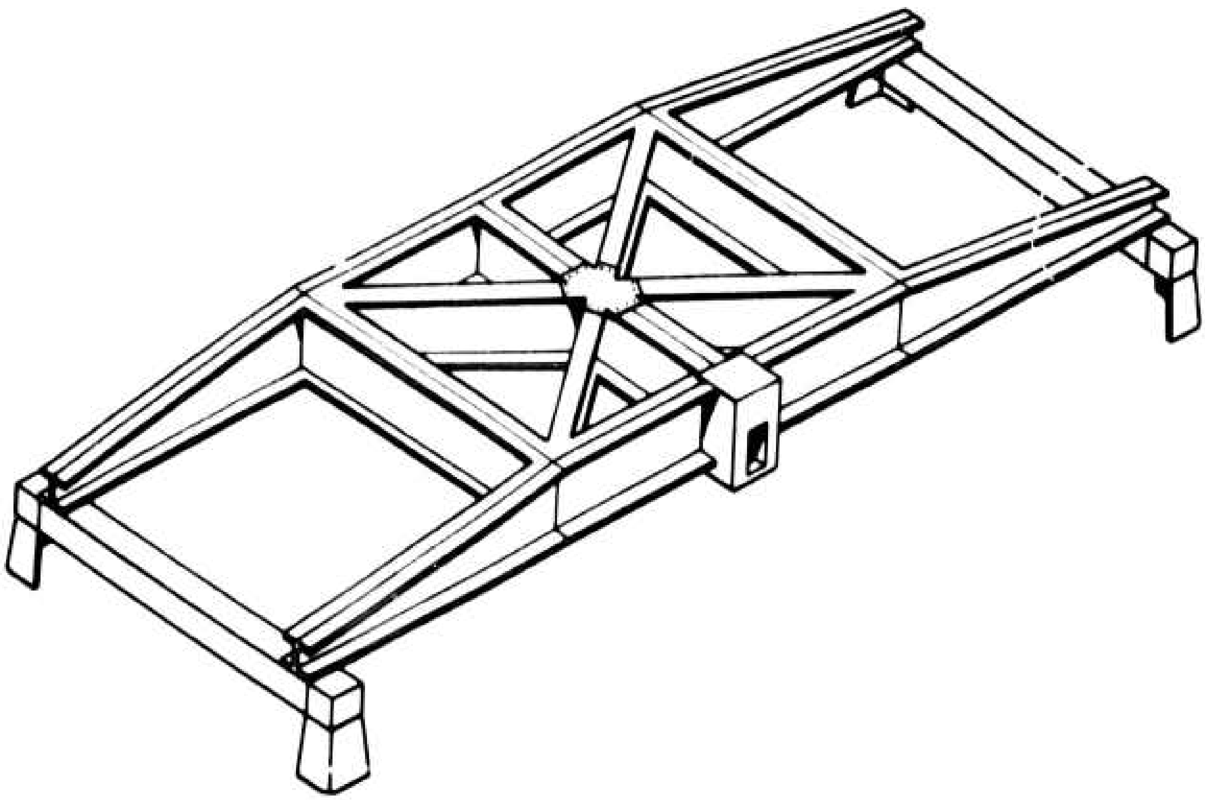


Figure 28. Typical Fixed-Length Commercial Handling Devices.



2.10 Army Helicopters External Cargo Handling Systems

The container handling device will be compatible with the CH-47, CH-54 and HLH helicopters shown in Figures 29, 30, and 31. Fundamental characteristics of the external cargo handling systems in each of these helicopter types are presented below.

CH-47C Helicopter

A fixed (nonwinchable) external cargo hook capable of suspending 10 tons is furnished at the center cabin rescue hatch. It can be actuated for load releases up to maximum capacity by three separate systems: hydraulic, electrical and mechanical.

The hook itself is mounted on a carriage which travels laterally on a curved beam in such a way that the line of action of the load always intersects the centerline of the helicopter slightly below its center of gravity, thus providing maximum lateral stability and minimizing the induced rolling moment created by a swaying load.

The hook is nonswiveling and, because of its open-throat design, is easily engaged by a donut either held by a man standing on top of the load or snatched by a helicopter crewman reaching through the rescue hatch.

CH-54B Helicopter

A single-point hoist system consisting of a standard, single-drum, hydraulically operated hoist is located in an inverted well directly under the main rotor shaft. The maximum capacity of the hoist for hydraulically raising or lowering loads is 12.5 tons at a cable speed of approximately 50 feet per minute. A maximum usable winch cable length of 100 feet is provided. An open-throat, full 360° swiveling, electrically actuated cargo hook is attached to the cable.

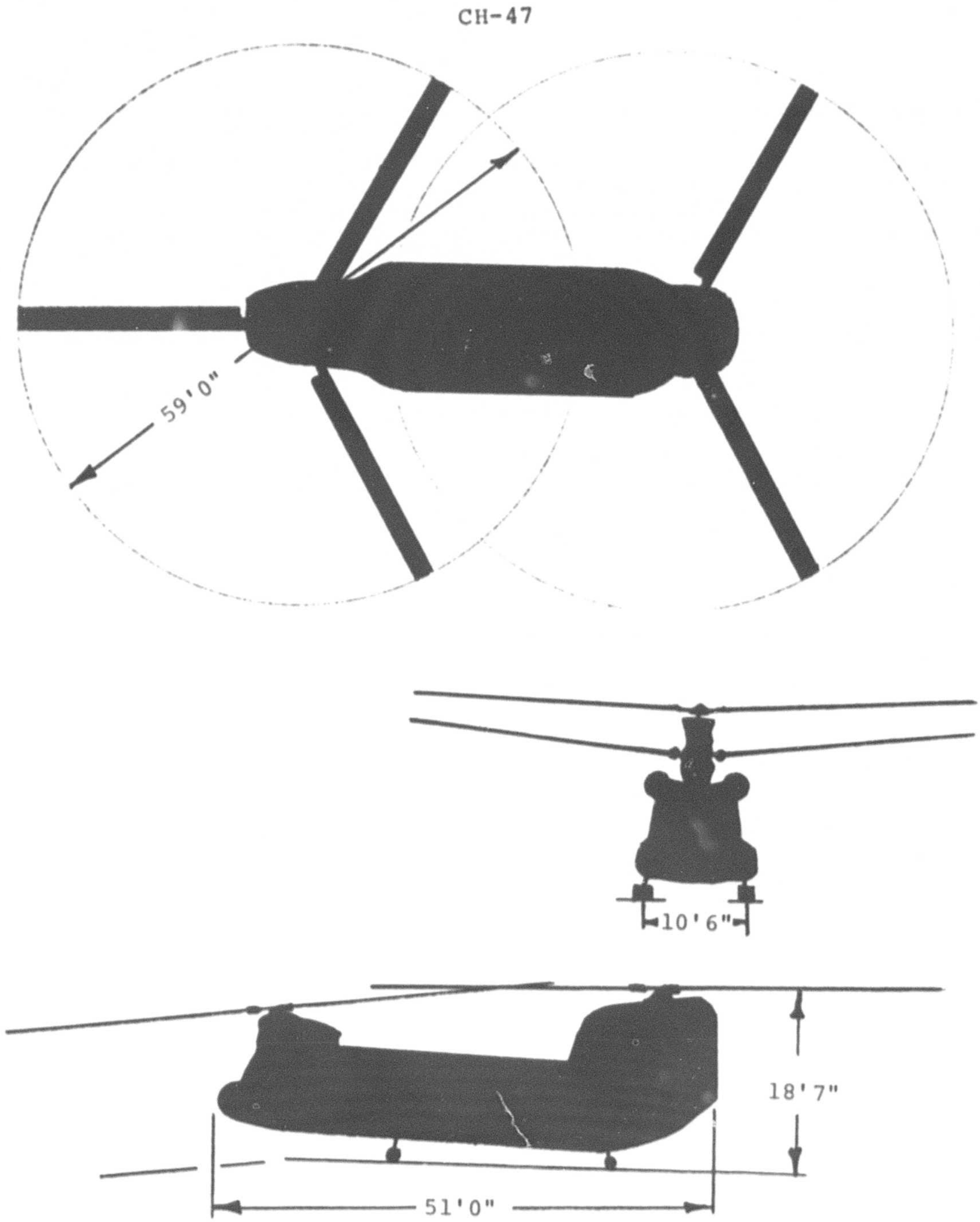


Figure 29. Container Handling Device Compatibility with CH-47.

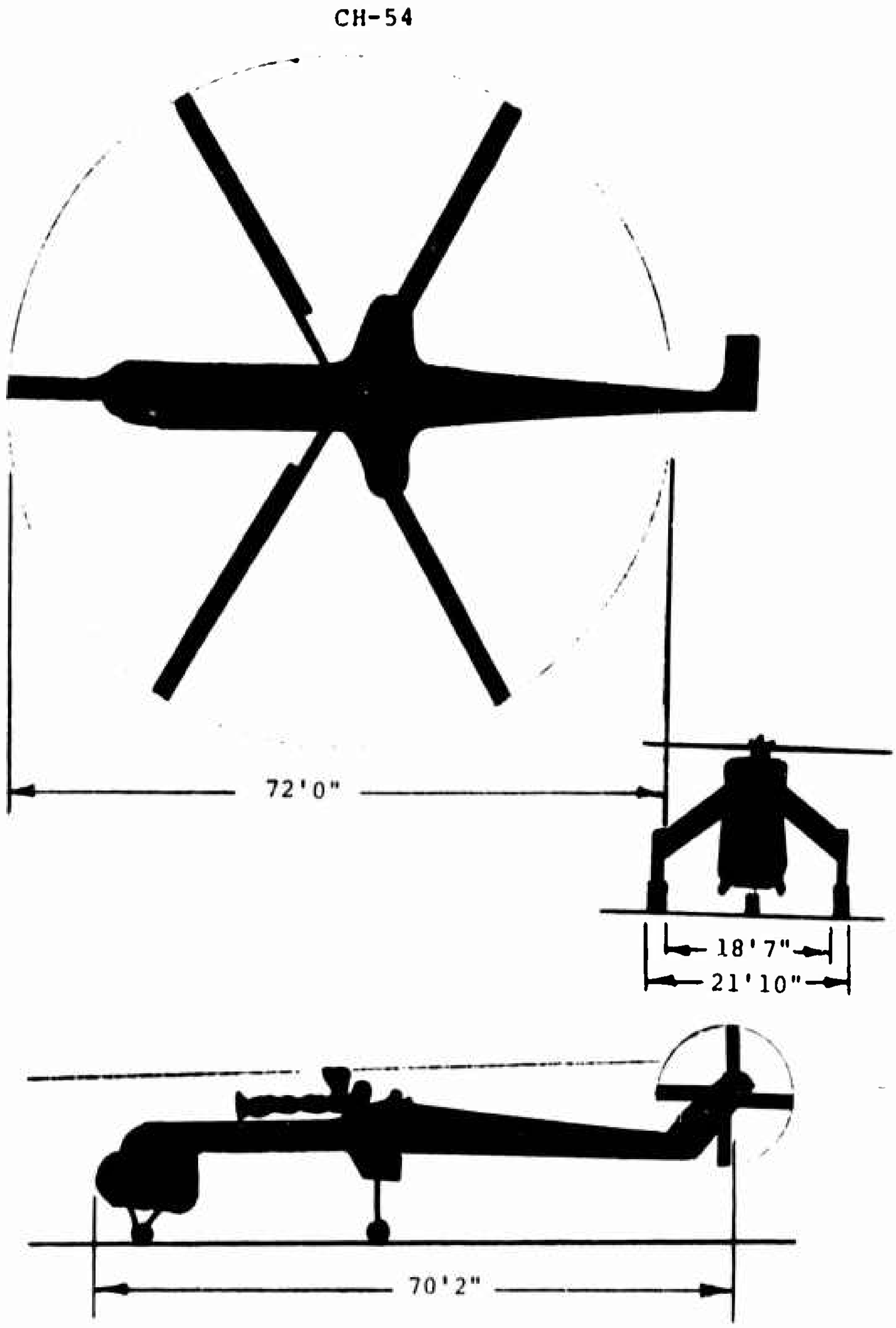


Figure 30. Container Handling Device Compatibility with CH-54.

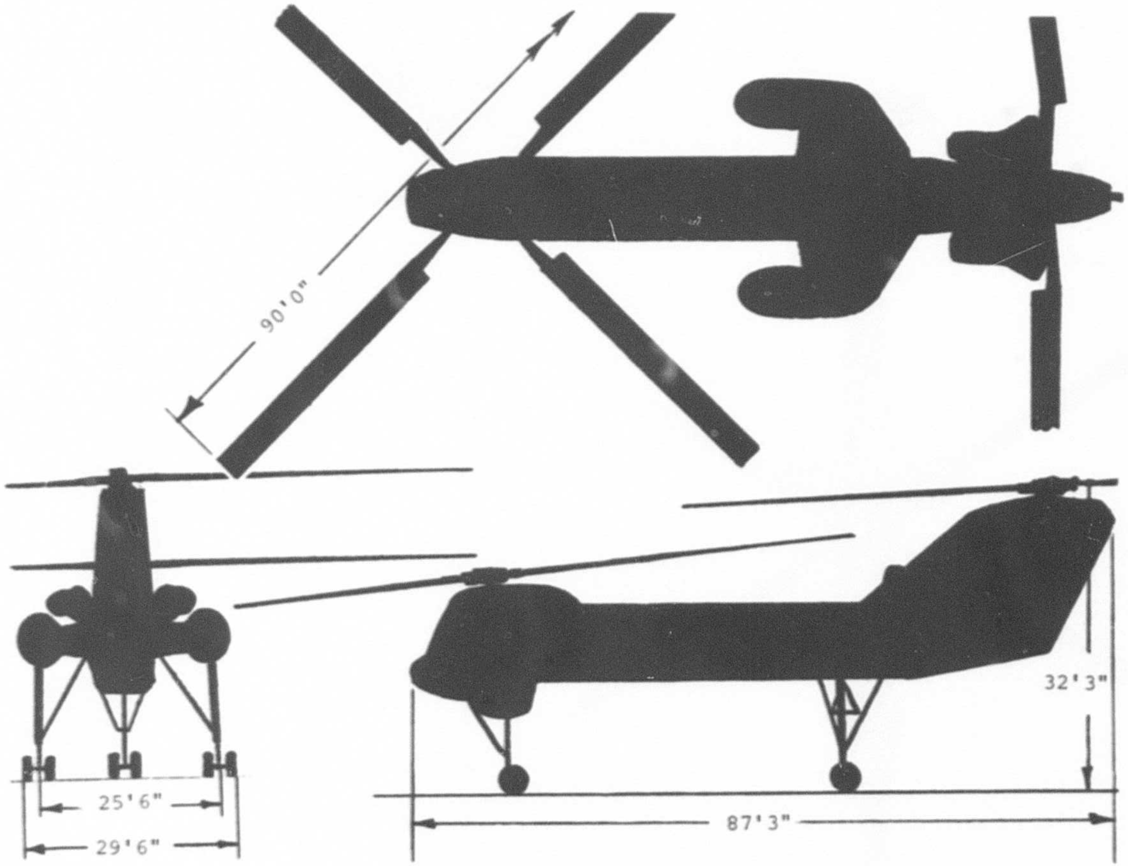


Figure 31. Container Handling Device Compatibility with HLH.

HLH Helicopter

The cargo handling system on the HLH consists of the tandem dual hook system shown in Figure 32. Pneumatically powered dual drum hoists are located in tunnels in the underside of the fuselage. The system is designed to hoist and transport loads up to 28 tons using either the dual hook mode or a single-point mode. Load distribution between the forward and aft points in the dual hook mode can be asymmetrical up to a 60/40 split. The hoists are adjustable in longitudinal position within the tunnels to accommodate a wide variety of cargo and to permit extractions from confined areas and from container-ships. A maximum usable winch cable length of 100 feet is provided. Maximum hoist speed at full system capacity is 60 feet per minute. The unloaded hooks can be lowered at speeds up to 120 feet per minute.

Full 360° swiveling cargo couplings are provided at the lower end of each dual cable. The couplings are mechanically prevented from opening with any load weight above 1000 pounds to avoid inadvertent cargo loss.

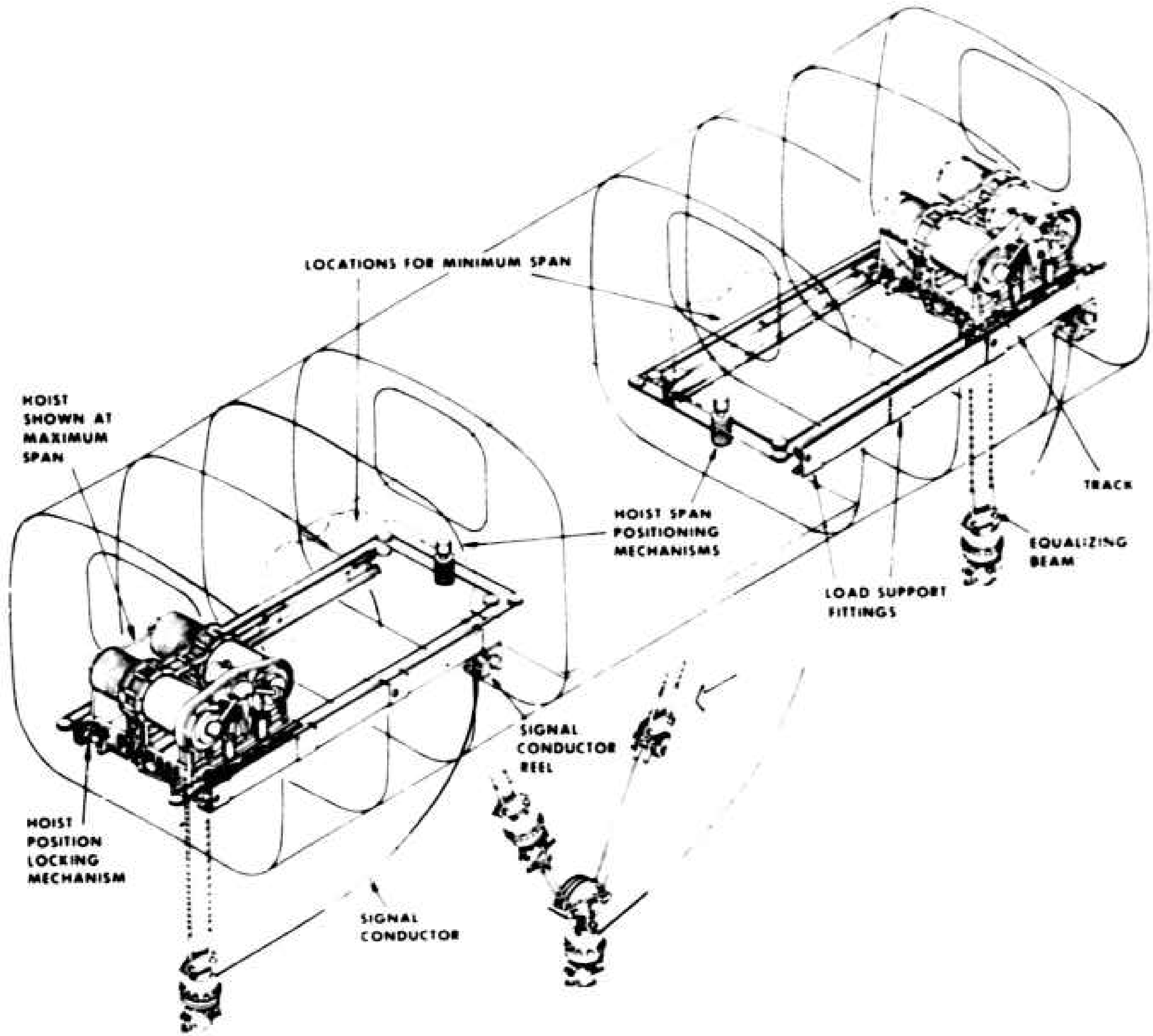


Figure 32. Hoist Installation.

3.0 Preliminary Designs

Preliminary design layouts were prepared for four potential configurations for the helicopter handling device. Each configuration embodies a different structural concept as outlined below:

Rectangular Frame - Primary structural load paths in this configuration, shown in Figure 33, are the four outer elements. Interior members are used to stiffen the outer members against column buckling and to support the twist lock and corner guide actuation systems and linkages. Figure 34 shows the same basic structural arrangement adapted to use side guides to minimize the concentration of subsystems at the corner locations.

"X" Frame - Primary structural load paths in this configuration, shown in Figure 35, are two diagonal members. Small members join the corners at each end to react compressive loads and to provide attachment points for side guides, if used.

Adjustable Length - This configuration, shown in Figure 36, is adjustable from 20 feet to 40 feet. Symmetrical I-beam end frames are supported by a single telescoping beam which is mounted in a central lifting frame. Twist lock and side guide actuation systems are provided at each end frame.

Cooperative - This design, shown in Figures 37 and 38, solves the problem of positioning accuracy for the helicopter and the corner or side guide systems. Part of the system is prerigged to the container before the helicopter arrives and provides positioning latitude commensurate with the hover precision of the helicopter.

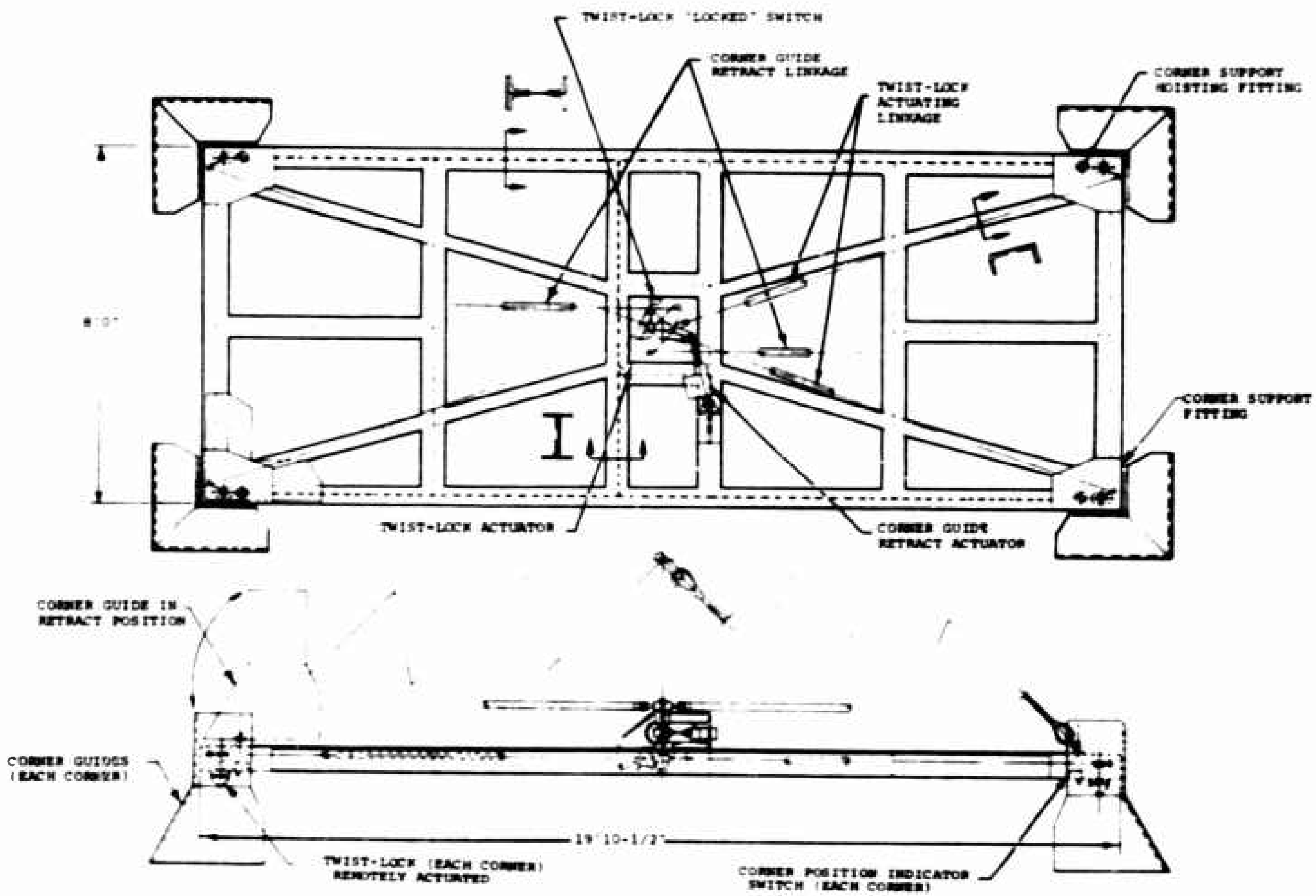


Figure 33. Container Handling Device - Rectangular Frame - Primary Structural Load Paths.

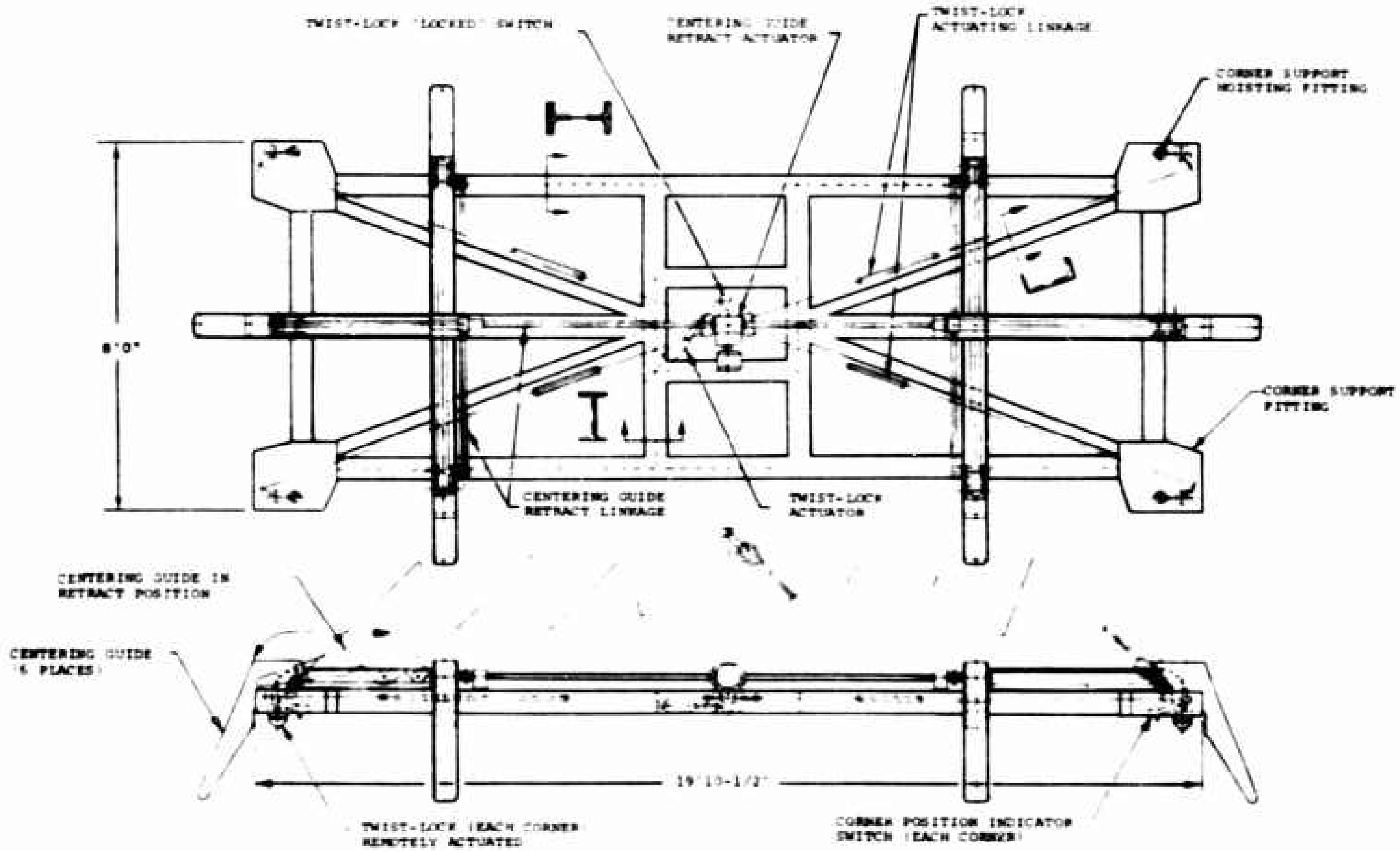


Figure 34. Container Handling Device - Rectangular Frame - Primary Structural Load Paths - Adapted to Use Side Guides.

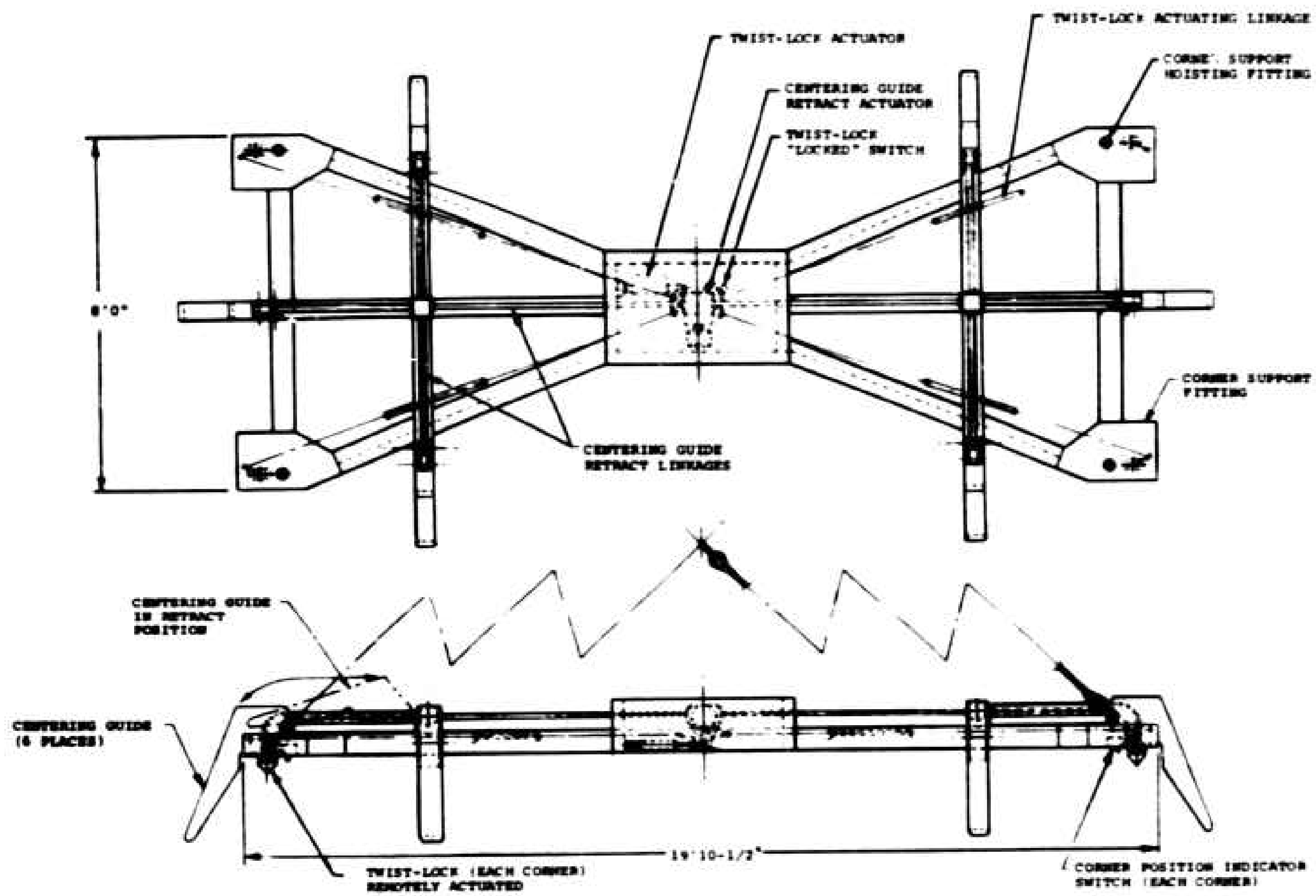


Figure 35. Container Handling Device - "X" Frame - Primary Structural Load Paths - 2 Diagonal Members.

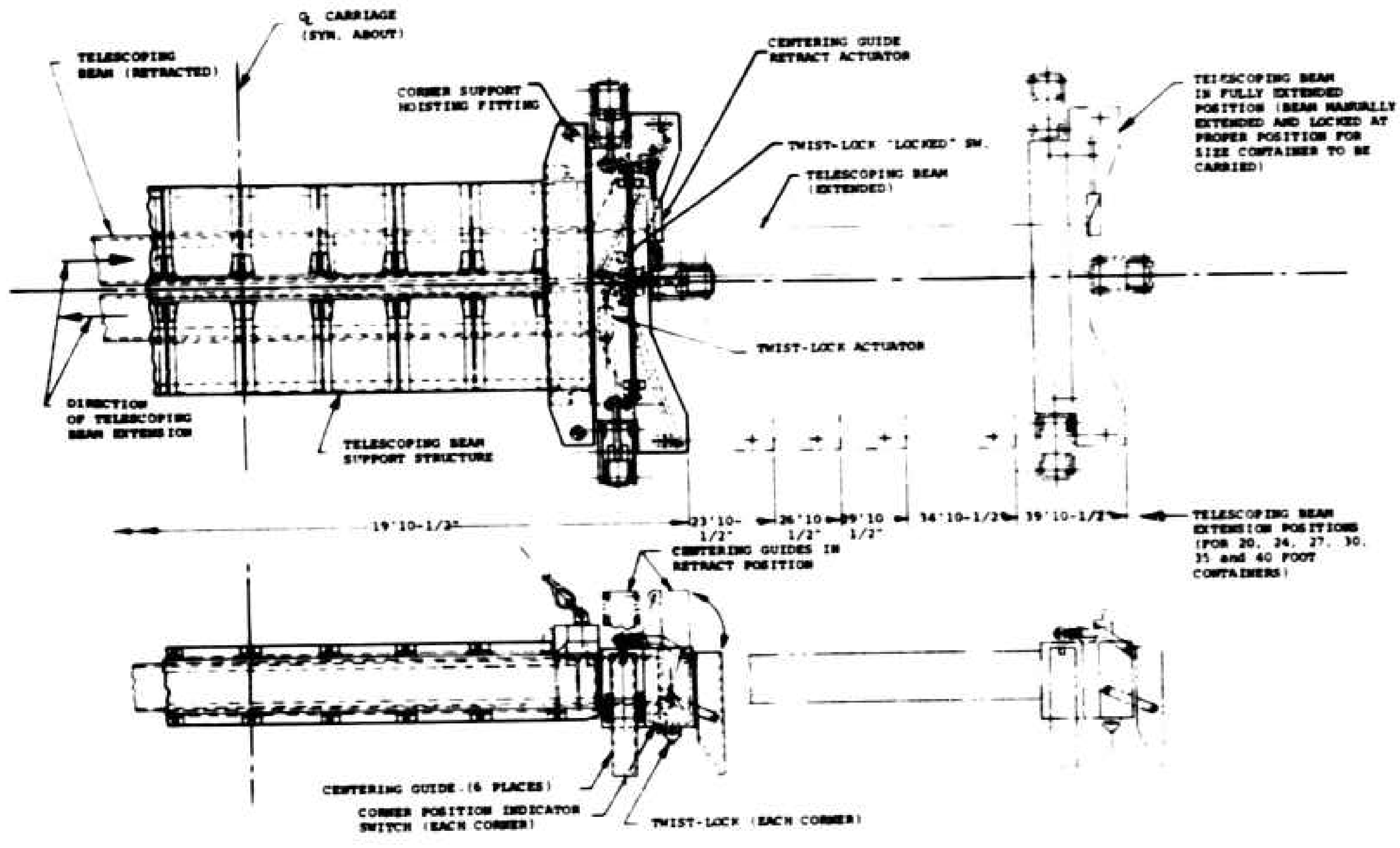


Figure 36. Container Handling Device - Adjustable Length - From 20 ft. to 40 ft.

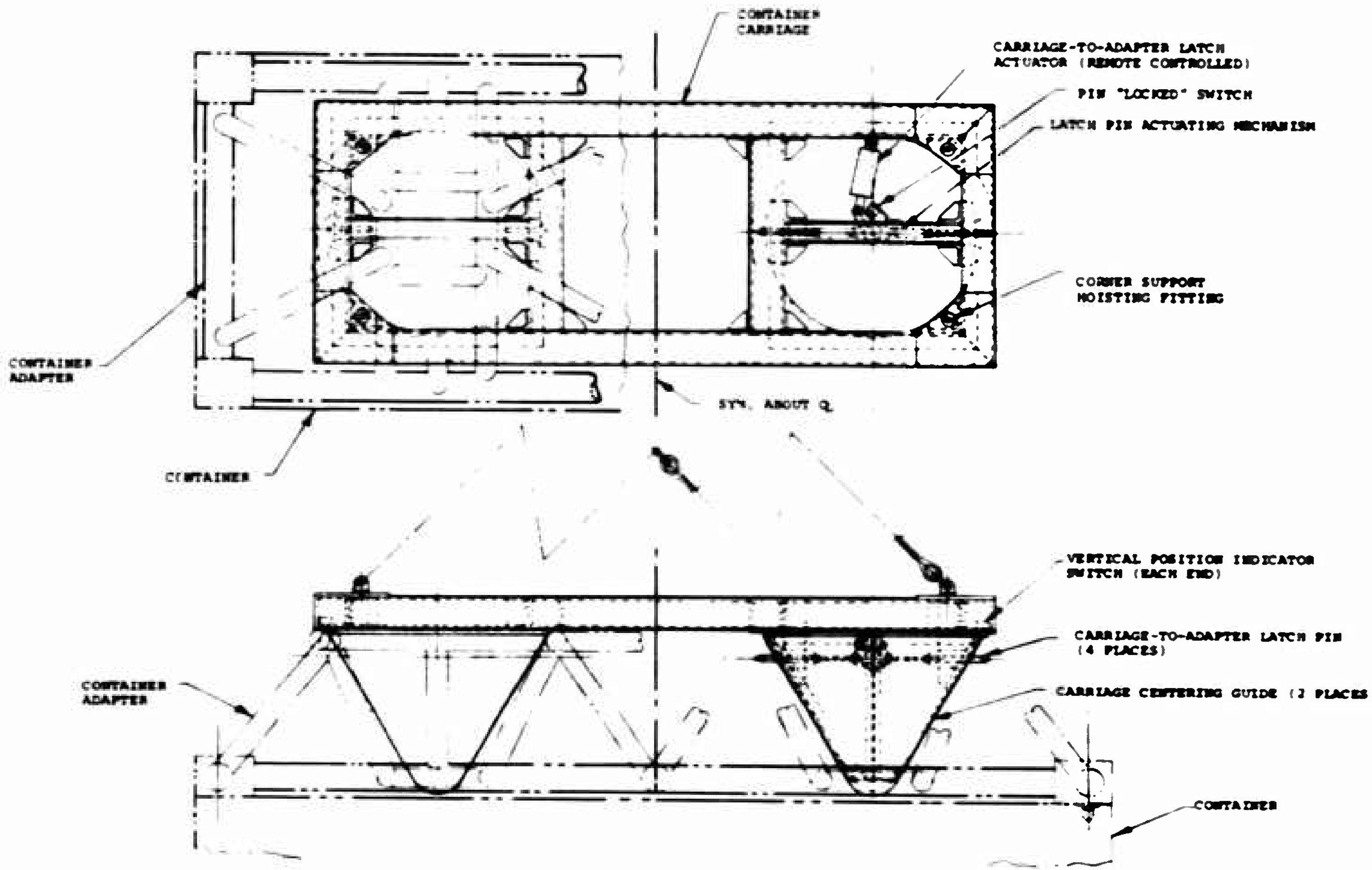


Figure 37. Container Handling Device - Cooperative Container Carrier.

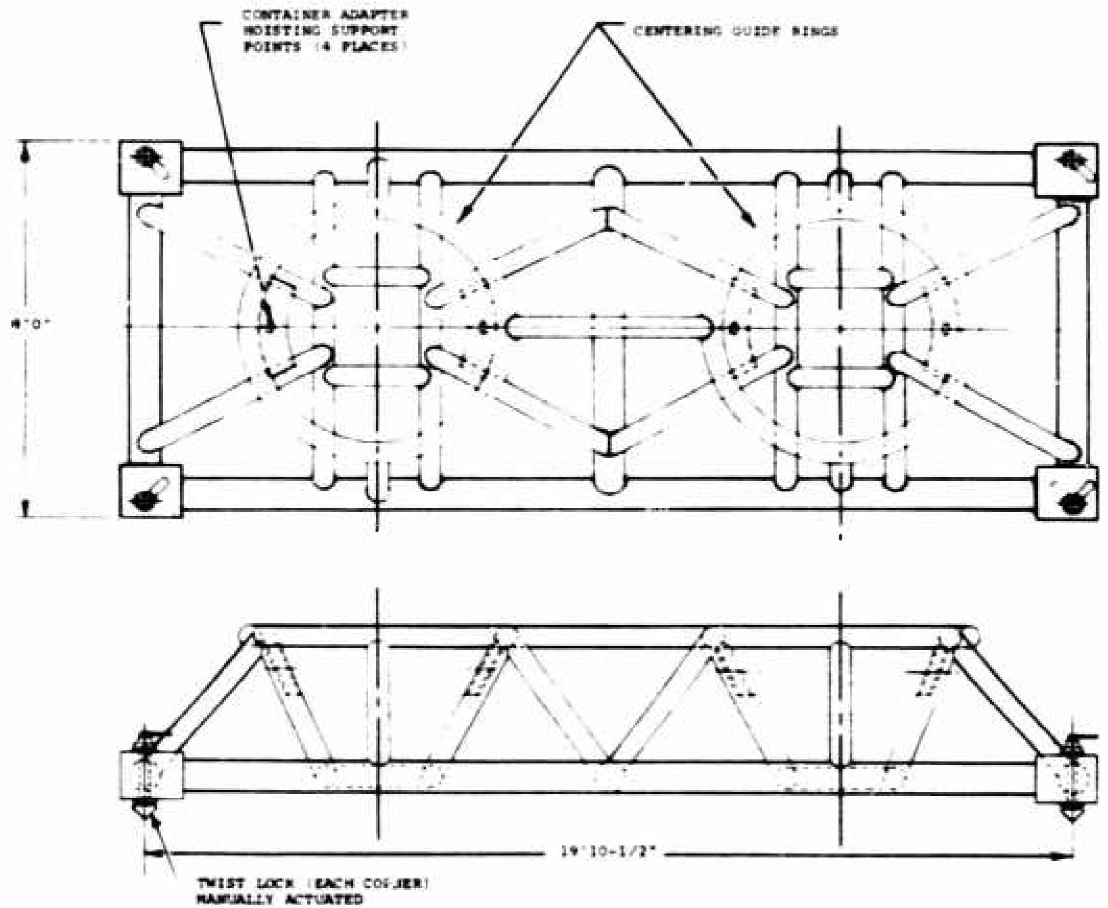


Figure 38. Container Handling Device - Cooperative Container Adapter.

4.0 Trade-Off Study

The four potential configurations for the helicopter handling device were compared using a weighted parameter technique. First, the properties of performance which are desired in a helicopter-transported container handling device were listed:

a) Minimum Weight
b) Lowest Mission Time
c) Simplicity
d) Low Cost
e) Minimum Height (Ability To Land HLH With Device & Container)
f) Low Power Requirement
g) Positioning Ease
h) Adaptability (to Various Container Lengths)
i) Reliability
j) Maintainability
k) Minimum Logistics

A weighted value was established for each property by examining each possible comparison of two properties on the basis of relative importance. The more important property in each decision process was assigned a value of 1; the other property, a value of 0. The sum of all decisions was then totalled for each property to establish an emphasis coefficient "E". The mechanics of this process are shown in Figure 39.

A similar process of weighting was next performed for the four potential solutions: rectangular frame, "X" frame, adjustable, and cooperative device, as shown in Figure 40. Here each possible comparison of two solutions was evaluated on the basis of which one could best satisfy a desired property. A value of 1 was assigned to the better of two solutions, when a clear-cut advantage existed. In two cases, both solutions were comparable and a value of 0 was assigned to both.

Next, a matrix was constructed (Figure 41), with the four possible solutions across the top and the properties of performance down the side. Next to each property was placed its corresponding emphasis coefficient "E" from Figure 39. Under each solution the weighted values for that solution were tabulated and multiplied by "E". The products were then added vertically to arrive at a final figure of merit for each solution. For the helicopter-transported container handling device, the figures of merit show that the "X" frame is the best solution based primarily on low weight, reliability, and potential for low overall height.

PROPERTY	DECISIONS																																	
Minimum Weight	1	1	1	1	1	0	1	0	1	1																								
Lowest Mission Time	0										1	1	1	1	1	1	0	1	1															
Simplicity		0									0									1	1	1	0	1	0	1	0							
Lowest Cost			0									0								0								0	1	0	1	0	0	0
Minimum Height				0									0								0							1						
Low Power Required					0									0								0							0					
Positioning Ease						1									0								1							1				
Adaptability							0									0								0							0			
Reliability								1									1								1							1		
Maintainability									0									0								0							1	
Minimum Logistics										0									0								1							1

PROPERTY	DECISIONS																					EMPHASIS COEFFICIENT OF PROPERTY "E"
Minimum Weight																						8
Lowest Mission Time																						8
Simplicity																						5
Lowest Cost																						2
Minimum Height	1	0	1	0	1	0																4
Low Power Required	0						0	0	0	0	0											0
Positioning Ease		1					1					1	0	1	1							8
Adaptability			0					1				0				0	0	0				1
Reliability				1					1				1			1			1	1		10
Maintainability					0					1				0			1		0		0	3
Minimum Logistics						1					1				0			1		0	1	6

Figure 39. Trade-Off Study - Emphasis Coefficients of Properties.

	WEIGHT						WV	MISSION TIME						WV	SIMPLICITY						WV
Rectangular Frame	0	1	1				2	0	1	0				1	0	1	0				1
"X" Frame	1			1	1		3	1			1	0		2	1			1	0		2
Adjustable		0		0		0	0		0		0		0	0		0		0		0	0
Cooperative			0		0	1	1			1		1	1	3			1		1	1	3

	COST						WV	HEIGHT						WV	POWER REQUIREMENTS						WV
Rectangular Frame	0	0	0				0	0	1	1				2	0	1	0				1
"X" Frame	1			0	1		2	1			1	1		3	1			1	0		2
Adjustable		1		1		1	3		0		0		1	1		0		0		0	0
Cooperative			1		0	0	1			0		0	0	0			1		1	1	3

	EASE OF POSITIONING						WV	ADAPTABILITY						WV	RELIABILITY						WV
Rectangular Frame	0	1	0				1	0	0	0				0	0	1	1				2
"X" Frame	1			1	0		2	0			0	0		0	1			1	1		3
Adjustable		0		0		0	0		1		1		1	3		0		0		0	0
Cooperative			1		1	1	3			1		1	0	2			0		0	1	1

	MAINTAINABILITY						WV	MINIMUM LOGISTICS						WV
Rectangular Frame	0	1	0				1	0	1	1				2
"X" Frame	1			1	0		2	0			1	1		2
Adjustable		0		0		0	0		0		0		1	1
Cooperative			1		1	1	3			0		0	0	0

WV = WEIGHTING VALUES

Figure 40. Trade-Off Study - Weighting Values for Solutions.

PROPERTY	"E" EMPHASIS COEFFICIENT OF PROPERTY	SOLUTIONS							
		RECTANGULAR		"X" FRAME		ADJUSTABLE		COOPERATIVE	
Weight	8	2 x E =	16	3 x E =	24	0 x E =	0	1 x E =	8
Mission Time	8	1	8	2	16	0	0	3	24
Simplicity	5	1	5	2	10	0	0	3	15
Cost	2	0	0	2	4	3	6	1	2
Height Low Profile	4	2	8	3	12	1	4	0	0
Power Requirement	0	1	1	2	0	0	0	3	0
Ease of Handling	8	1	8	2	16	0	0	3	24
Adaptability	1	0	0	0	0	3	3	2	2
Reliability	10	2	20	3	30	0	0	1	10
Maintainability	3	1	3	2	6	0	0	3	9
Minimum Logistics	6	2	12	2	12	1	6	0	0
Figure of Merit			81		130		19		94

Figure 41. Trade-Off Study - Figures of Merit.

5.0 Recommended Design Approach

Based on the analyses and trade-off study described above, the "X" frame structural configuration shown in Figure 35 is recommended for expansion into a detail design under Phase II of this program.

APPENDIX II
STRESS ANALYSIS

CONTAINER HANDLING DEVICE

Structural Configuration - General

The container handling device has been designed to meet the minimum weight requirement of a 1,200-pound system (1,000-pound structure) and to be capable of lifting and transporting a 20-foot container in either the dual-mode or single-mode support systems.

As a result of the trade-off study and recommendations in Phase I, the basic "X" frame configuration was selected for prototype detail design. The "X" frame is optimum for support of a container when using the four-cable sling off a single support cable. The configuration was modified to include transverse frame structure for pickup of the dual-point attachments and an upper drag beam to act as a spreader bar between these attachments.

The basic structure consists of the truss type "X" frame with its stabilizing end truss (lower portion of the dual-mode truss), guides, and guide backup trusses. The device in this configuration is used to lift and transport a 20-foot container (12.5-ton capacity), with the single-point sling picking up the four single-mode pickup points. In this mode, all container load feeds from the twist lock into the corner twist lock housing and into the main "X" frame. The load is reacted by the four cables at the single-mode pickup points, and the "X" frame acts as a truss which takes the bending moment and spreader compressive loads in the longitudinal direction.

The basic structure is adapted for use in the dual mode by addition of the dual-mode superstructure. The superstructure consists of the upper portion of the dual-mode truss, the dual-mode shackle, a drag beam, and a drag link structure. This superstructure bolts to the basic structure as shown and is used in place of the single-mode sling. The device, in this configuration, is capable of lifting and transporting a 20-foot container (28-ton capacity), with dual-mode helicopter hooks picking up the shackles. In this mode, however, the main "X" frame carries the vertical shear and bending resulting from the vertical corner load, but not the compressive loads due to spreader bar effects. This is reacted by the upper drag beam directly at the shackle support pin. Net forward or aft (drag and acceleration) container loads feed directly into the main "X" frame, are carried up through the lower drag link structure, and are reacted by the dual-mode cables.

Structural Design Approach

The configuration of the prototype structure was developed by design trade-off against the following requirements: load requirements, overall stiffness requirements for operation, handling requirements, and reasonable manufacturing constraints required for a cost-effective structure. Although the prototype structural design was dictated primarily by operational load requirements, overall stiffness and handling requirements necessitated detail overdesign in certain minimum-load regions of the structure. For example, irrespective of strength required, the minimum element thickness acceptable for buried structure and external structure respectively was .090 and 0.100 inch. This is necessary to produce a structure sufficiently rugged to withstand the abuse of normal handling for this type of equipment. As a result, in order to produce a low-weight design, a configuration was developed that provided for maximum utilization of the structure elements, and this structure was then designed to minimum margins of safety as per normal aircraft structural design practice.

Detail Configuration

The structure, in detail, consists of 6061-T6 welded subassemblies. The maximum subassembly dimension is limited to 7' -0" (maximum size acceptable for available heat-treat facilities). The welded subassemblies are trusses or frames made up of tube and channel chord and web members. All unwelded elements (fittings and riveted members) are 7075-T6, except when stiffness or handling requirements controlled the structural design, and the higher strength alloy was unnecessary. Pins and bushings are basic AN hardware (125,000 psi heat-treat), except in isolated regions of high load concentration. The one unique material is the Carpenter Custom 455 Steel Shackle.

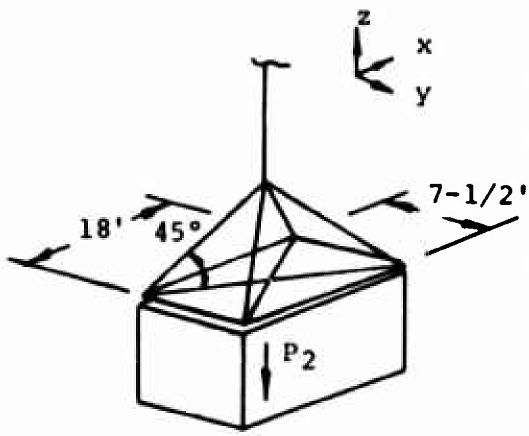
Structural Analysis

The device has been analyzed as a statically determinate structure, employing standard methods of analysis. No unique analysis methods have been used. Margins of safety for most primary structure for the design are low, consistent with aircraft design practice. Material properties (allowable stresses, etc.) are from MIL handbook -5B, September 1, 1971, revision. Methods of analysis for detail structural elements (columns, shear webs, crippling allowable stresses, etc.) are from the Boeing Vertol Structures Design Manual, 86L1.

Margins of safety in excess of 25 percent are not considered critical and are not shown in this report.

STRUCTURAL DESIGN CRITERIA

Single-Point Suspension - CH-47 and CH-54 A/C only.



Cargo Weight = 25,000 lb

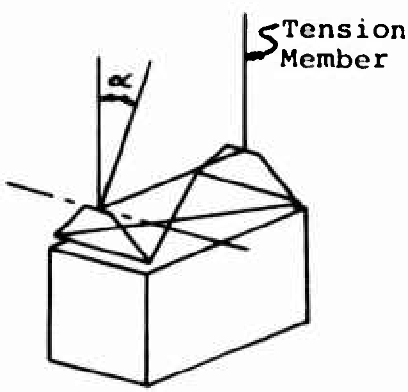
Vertical Load Factor = 2.3 Limit*

*Includes an estimated 15% increase due to dynamic coupling of cargo and A/C.

Pz = 25,000 x 2.3
= 57,500 lb limit
= 86,200 lb ultimate

Aft Trail (Swing Back) Angle Capability = 30°

Dual-Point Suspension - HLH A/C only.



Payload	= 56,000	lb
Wt of Cable & Coupling	= 700	lb
	56,700	lb

Load Factor = 2.5 Limit
(Increase due to dynamic coupling considered to be negligible)

Aerodynamic Load on Cargo = 2780 lb limit

Load Distribution = 60/40 or 40/60

Design Cable Angle (a) = 30°

Max Load on One Tension Member = 1.15 x .60 x (2.5 x 56000 + 2700)
= 100,000 lb limit
= 150,000 lb ultimate

For the symmetrical case, 50% of this load will be considered to be the vertical component at each corner of the handling device.

The device must be capable of withstanding dual-point vertical load factors with the tension member oriented at a 30° maximum inclination with vertical in any polar direction.

Dual-Point Suspension (Continued)

Drag Force -

Drag Force = 6,260 lb Limit (Ref: V.I.M. 8-5716-1-104)
= 9,390 lb Ultimate

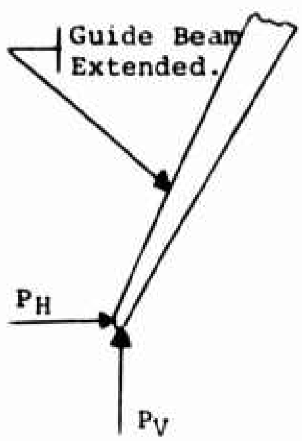
The drag force causes the container to trail aft and should not be combined with maximum cable load condition (page 106). It is design critical only for the lower portion of the dual-mode superstructure.

Side Shear -

The Maximum Side Shear = 5,000 lb Limit
7,500 lb Ultimate

This force is limited by HLH capability to sustain lateral reaction during operation. It is design critical only for the shackle assembly, and will be used for production shackle design. The prototype shackle has a limited capability of 4,000 lb limit/device (page 110).

Guide Systems

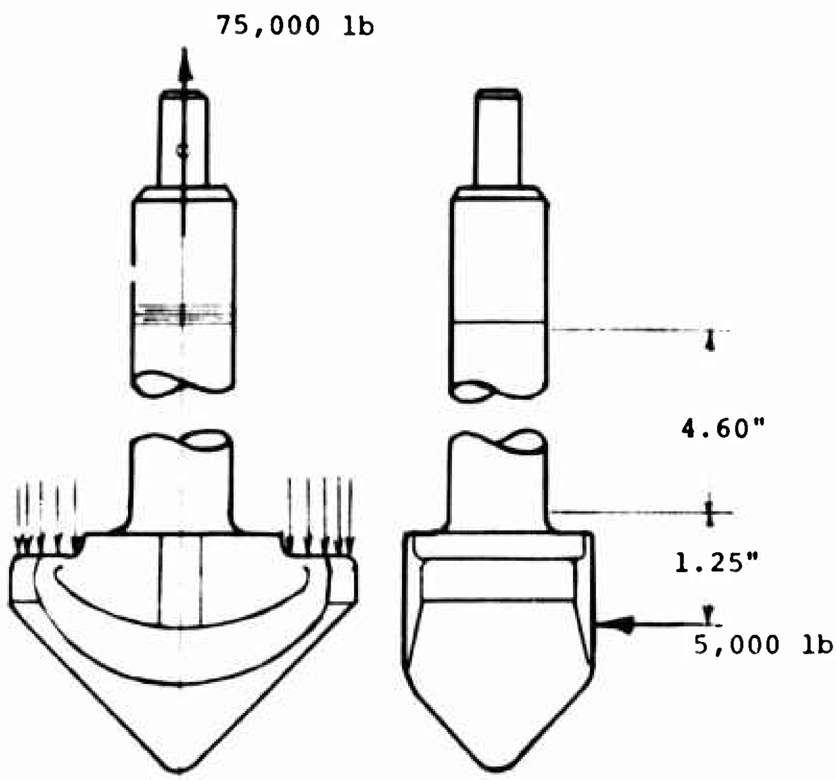


Design criterion is a 2,000-lb limit load (approximately 2G on device struct.weight)
Applied as either a positive Pv (UP), or $\pm$ P_H (inbd. or outbd.).

CONTAINER HANDLING DEVICE

Twist Lock Pin

The twist lock pin is a spreader bayonet type which mates with the container corner fitting and transmits the container load to the device corner fittings. The pin is 1-1/8-inch-diameter, 125,000-ksi (min) heat-treated steel, and each pin is designed to carry ultimate loads of 75,000 lb vertical and 5,000 lb horizontal in combination.



CONTAINER HANDLING DEVICE

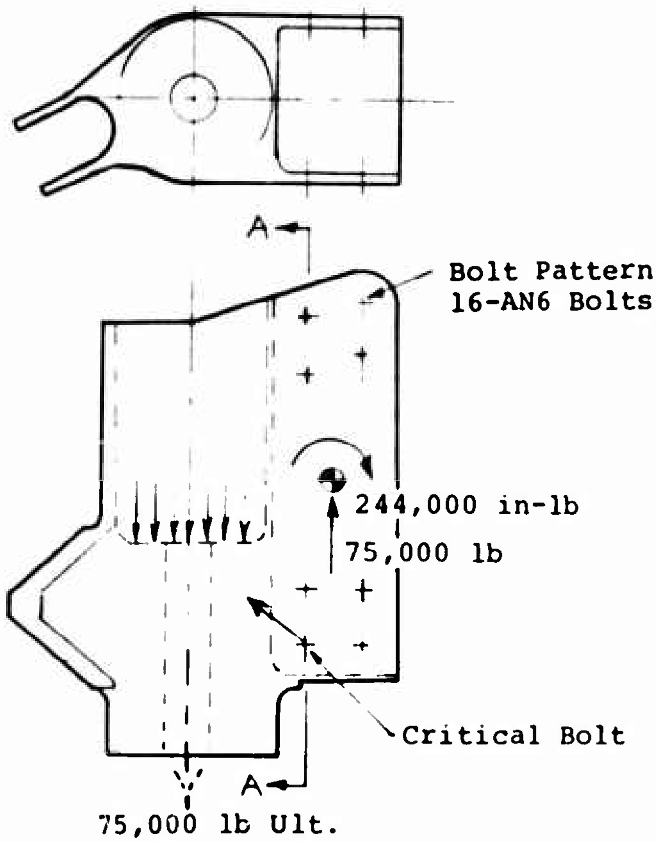
Twist Lock Housing - Ref. SK24888

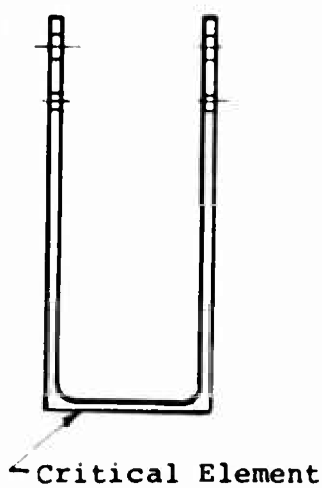
The twist lock housing is a 7075-T651 machined fitting which transmits the corner twist pin load to the main frame structure. The critical design load is 75,000 lb vertically, introduced as a bearing pressure between the twist pin washer and the upper surface of the housing body. The load is transmitted to the side-walls of the main frame structure by 16 - AN6 bolts.

Critical Margins of Safety:

TYPE OF STRESS	FAILURE MODE	M.S.
Bending Compressive Stress in Lower Element (Sect.A-A)	Local Crippling of Element	0.35
Maximum Shear Stress on Critically Loaded Bolt	Shear Failure in Bolt Shank	+0.08

Structure, Loads & Reactions





Section A-A

CONTAINER HANDLING DEVICE

Experimental Shackle:

The shackle is the hook pickup for the dual-mode support system. It consists of a Carpenter Custom 455 bending beam attached to 180 H.T. 4330 side tension plates. This assembly connects to the 1-1/8-inch-diameter bolt located at the intersection of the centerline of the dual-mode support frame and the drag link axial member.

Examination of shackle requirements indicates that a machined forging would produce the most efficient structural configuration, but because of limited quantities and rapid delivery requirements, the forging configuration is not feasible. The experimental shackle, however, incorporates the significant similarity to the recommended production design: the use of Carpenter Custom 455 steel for the bending beam of the shackle. This material is a precipitation hardenable stainless steel which can be heat treated to 260 ksi ultimate, and has good corrosion resistance, fatigue, and fracture toughness properties. Boeing has expended considerable effort in testing this material for HLH hook application and as a result has developed a specification for control of properties of the purchased material. This material, as a result, is ideally suited for interface with the HLH hook.

The critical design load is a 150,000 pounds ultimate shackle load.

Lateral Load Capability

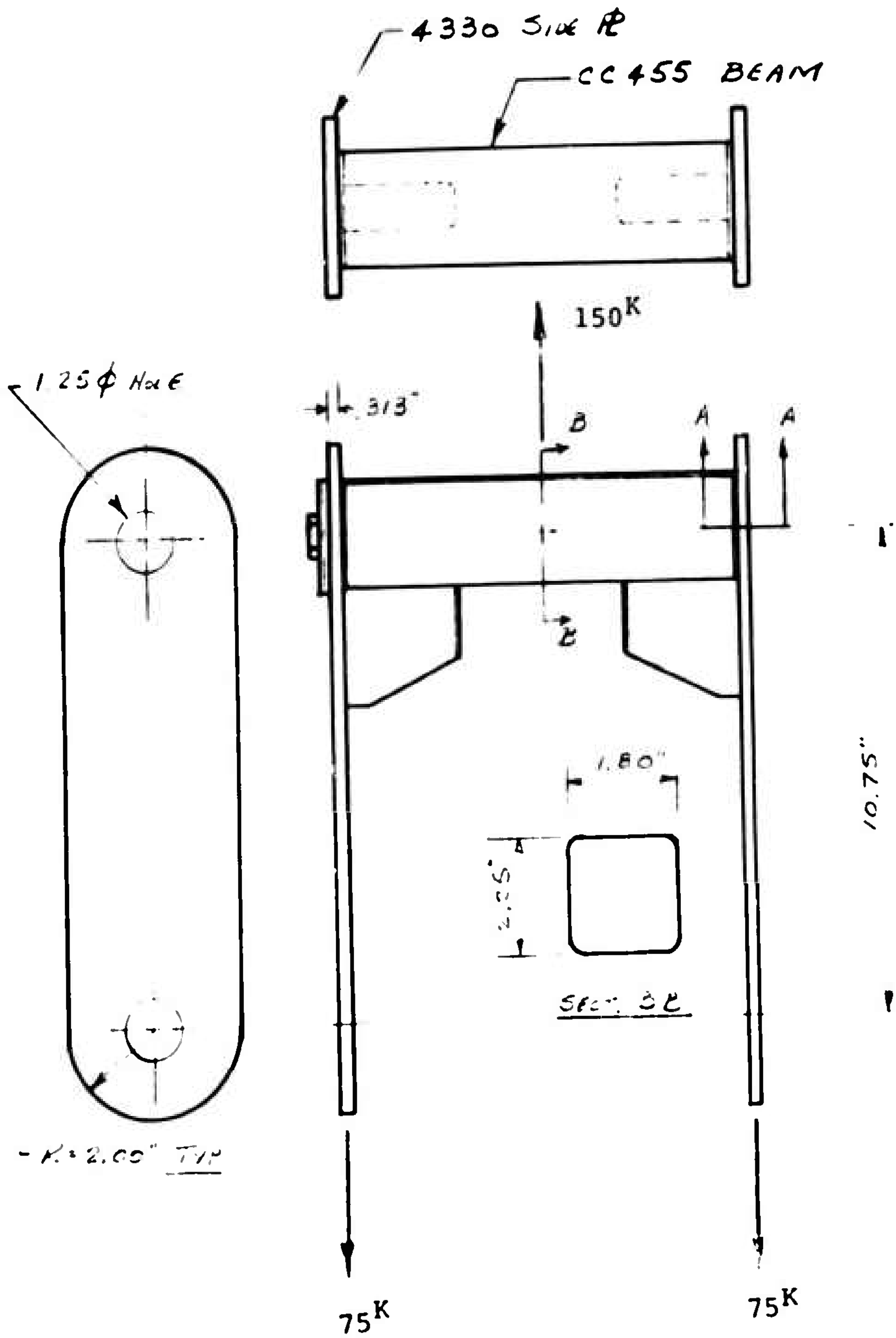
The experimental shackle has a limitation on lateral load capability. Maximum lateral capability is a 4000-lb actual (limit) load/device. This can be exceeded during rapid pickup of the 28-ton cargo when cable angle shackle axis exceeds 4°. The prototype shackle, therefore, is not recommended for rapid pickup of the 28-ton cargo.

Critical Margins of Safety:

TYPE OF STRESS	FAILURE MODE	M.S.
Bearing in sideplate hole @ Section A-A	Bearing in sideplate	+0.41
Bending in Shackle Beam @ Section B-B	Yield @ Limit Load	+0.34

CONTAINER HANDLING DEVICE

Structure and Loads:



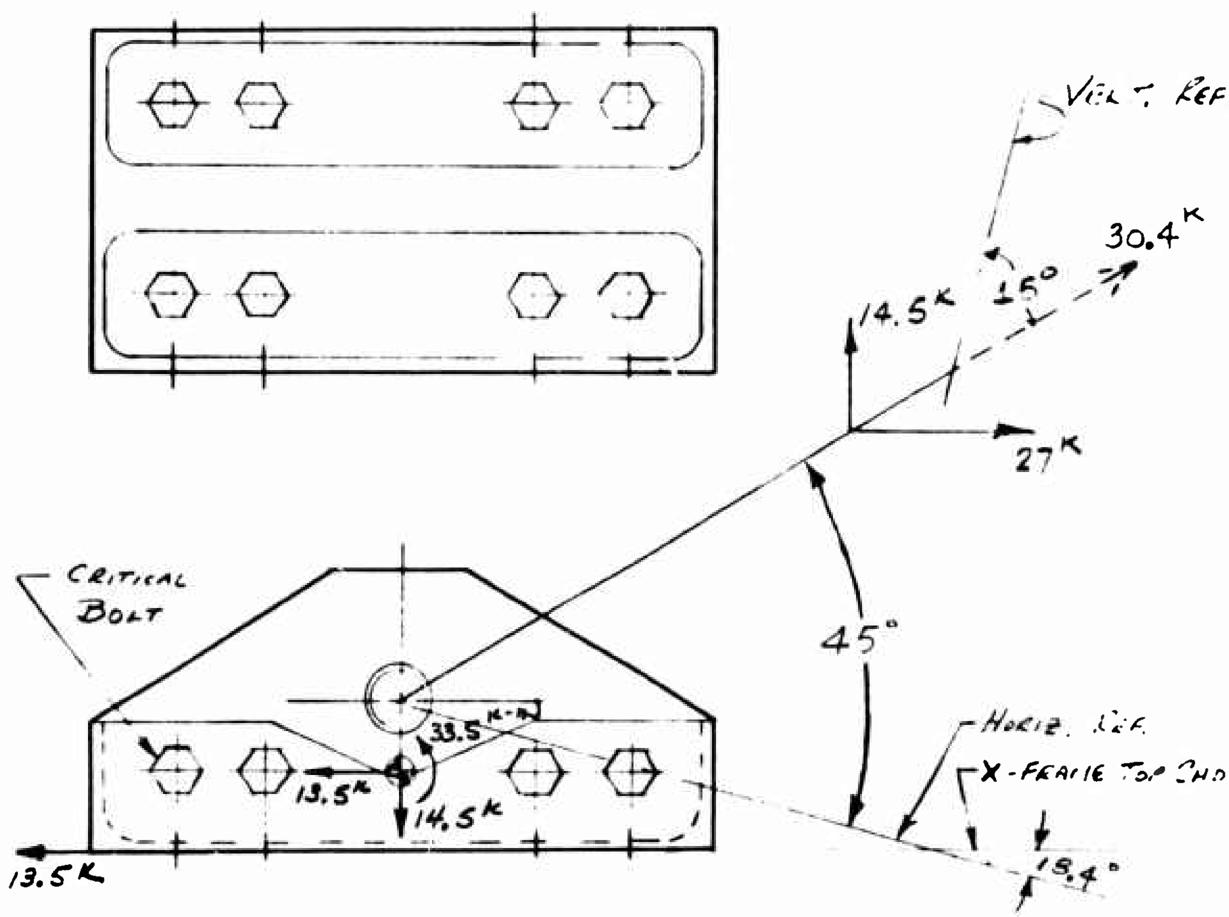
CONTAINER HANDLING DEVICE

Single-Point Pickup Fittings

The four single-point pickup fittings are 7075-T651 machined. They connect to the upper chord of the main cross frame structure and transmit the total container plus device load to the single-point sling. Critical design condition is a vertical corner load of 21,500 lb ultimate, with cable attitude of 45°. The fitting connects to the main frame thru 16 - AN5 bolts (8 thru the top chord rate and 8 thru the extended sidewalls). Ref. SK24911.

Critical Margin of Safety:

TYPE OF STRESS	FAILURE MODE	M.S.
Maximum Shear Load on Critically Loaded Bolt	Bearing Stress in Fitting Wall	+0.12



CONTAINER HANDLING DEVICE

Main Cross Frame Structure:

The main cross frame is the primary structure of the container handling device. The planform configuration is that of a cross, such that the frame centerlines are in alignment with the four pickup cables of the single-point sling. This minimizes lateral load effects on the main frame structure during single-point operation.

The cross frame consists of four outboard sections (SK24908) spliced to a hub center section (SK24911) to form the planform cross configuration. This primary structure when spliced forms two crossed Warren trusses running diagonally corner to corner across the container.

Each of the five sections is a 6061-T6 aluminum welded assembly. The outboard section, in the sloped chord region, undergoes transition from truss frame to a box beam to accommodate attachment of the corner twist lock housing, the single-point pickup fitting, and the dual-mode beam.

During single-point support, the load application is a vertical corner load through the twist lock housing (Ref. Page 109), reacted by the vertical component of the single-point sling cable. During dual-point support, the vertical corner load is reacted at the dual-mode frame attachment. In both cases the main cross frame carries the longitudinal bending resulting from the offset between container corner load point and its reaction.

The critical design condition for this structure is a 75^k ultimate vertical corner load during dual-mode operation.

Critical margins of safety:

TYPE OF LOAD	FAILURE MODE	M.S.
Upper chord-tension load	Ultimate tensile stress on net section	+0.02
Upper chord-splice tension load	Bolt - bearing in splice	+0.07
Upper chord - splice angles tension load	Ultimate tensile stress on net section	+0.08

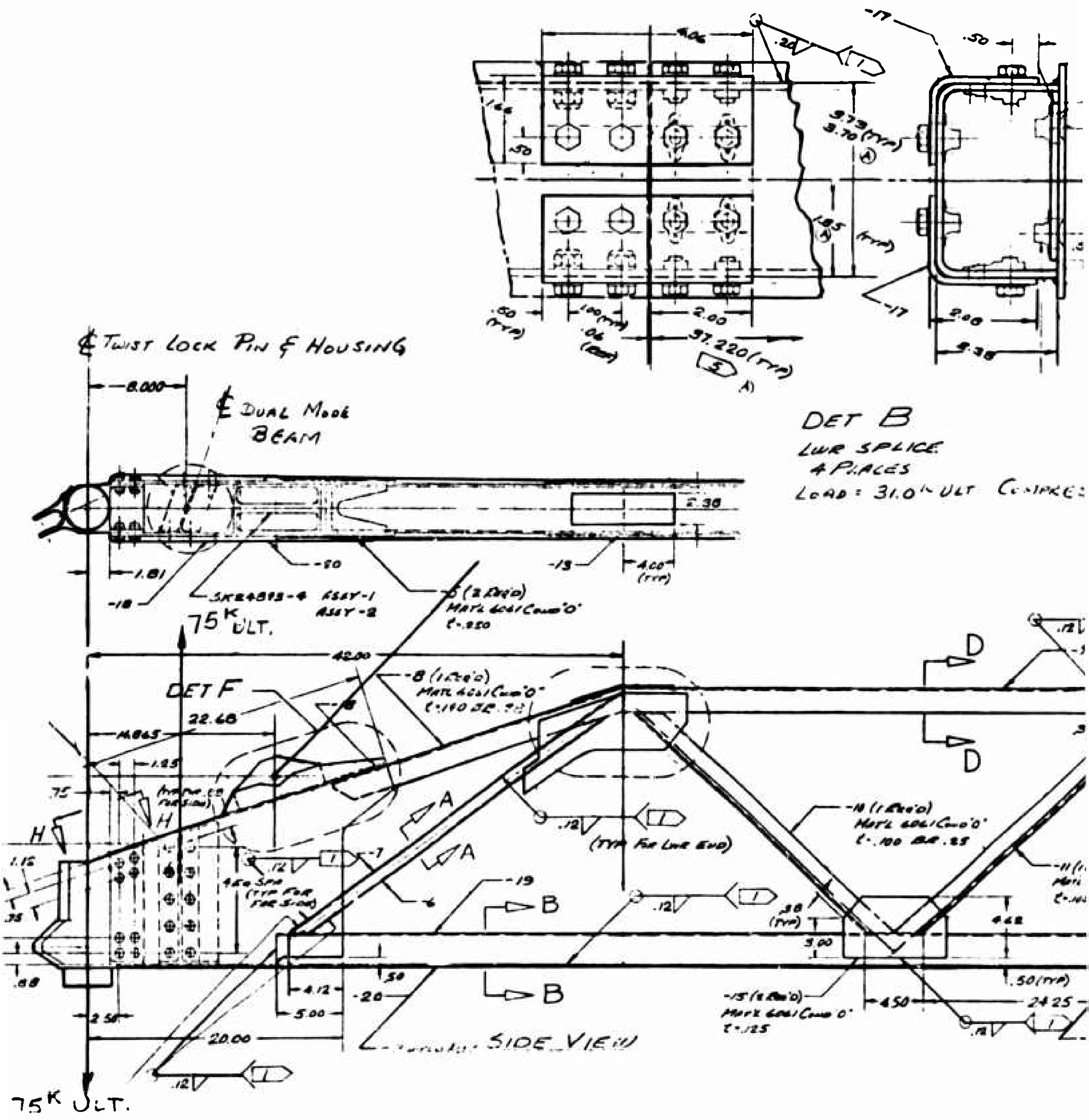


Figure 42. Container Handling Device - Main Cross Frame Structure.

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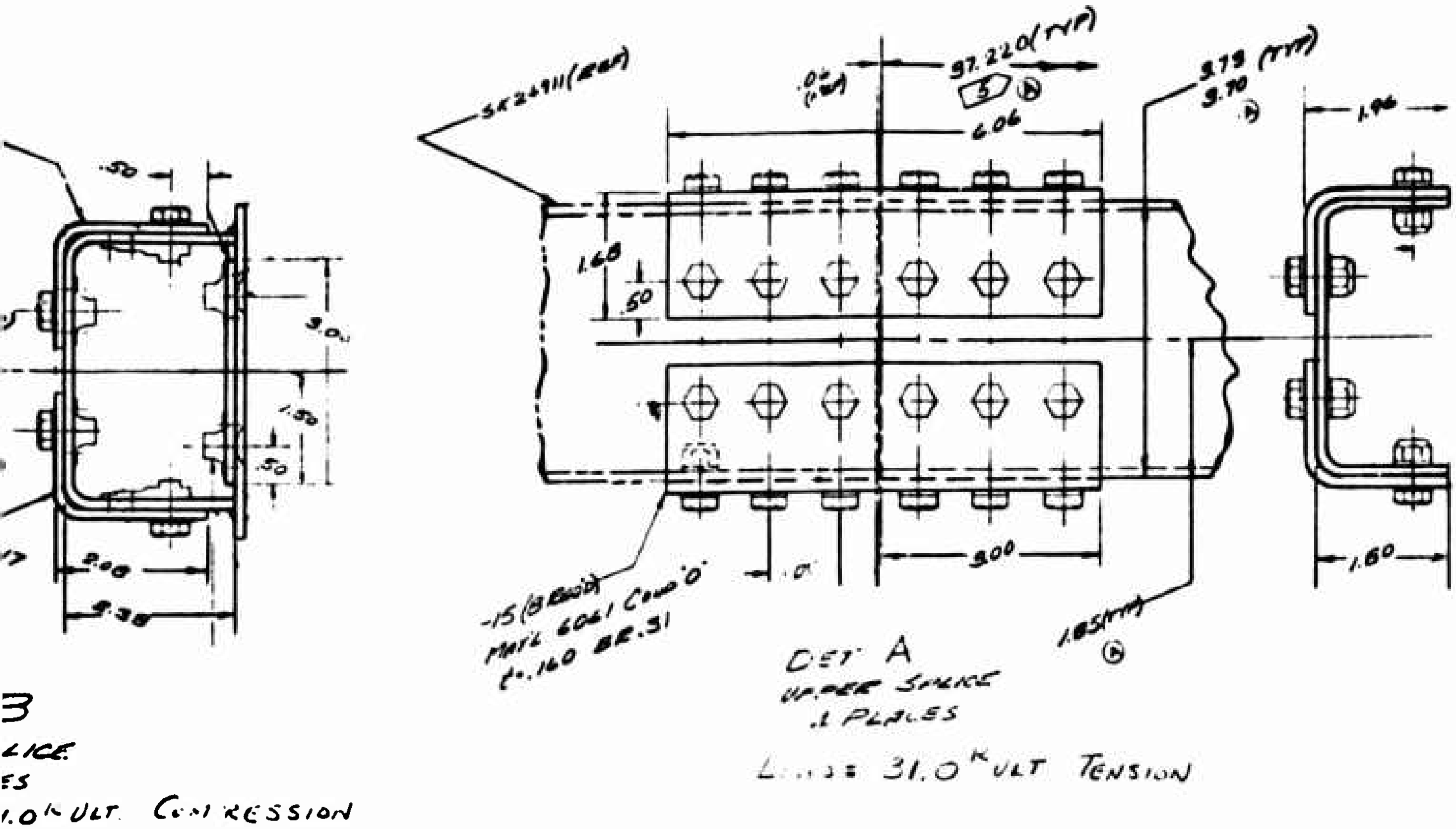
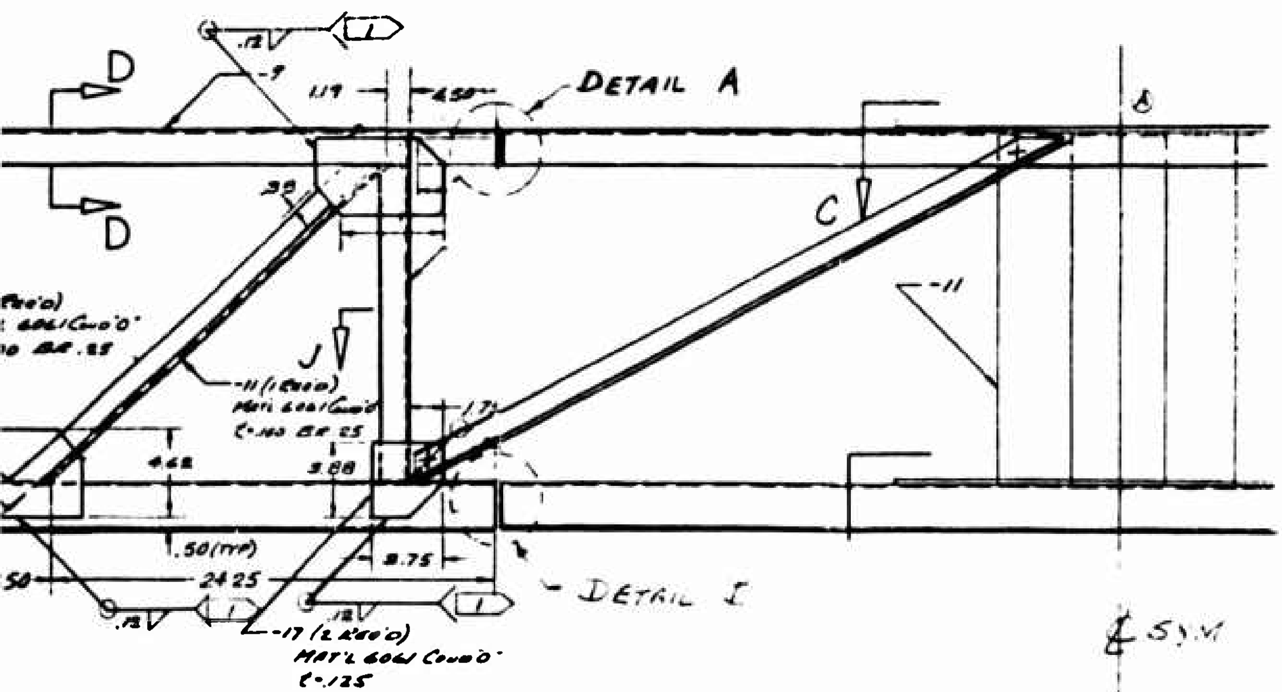


DET A
UPPER SPLICE
2 PLACES
31.0K ULT TENSION
1.0K ULT COMPRESSION
6.06
3.00
1.60
1.96
-15 (8 REQ'D)
MAT'L 6061 COND 'O'
t=.160 BR.31



DETAIL A
DETAIL I
D
D
C
J
-11
-11 (1 REQ'D)
MAT'L 6061 COND 'O'
t=.160 BR.25
-17 (2 REQ'D)
MAT'L 6061 COND 'O'
t=.125
24.25
2.75
3.88
4.62
.50 (TYP)
1.19
4.50
℄ SYM

CONTAINER HANDLING DEVICE

Dual-Mode Frame: Ref.: SK24934

The dual-mode frame has two basic functions. During operation in the dual-mode support system, it is the transverse structure which transmits the vertical component of shackle load outboard to the main cross frame structure. During single-mode support operation, when sling pickup is directly to main cross frame, the upper portion of the dual-mode frame is removable as part of the dual-mode superstructure. This leaves a parallel chord truss frame which provides the necessary lateral stabilization for the main cross frame structure. In either configuration, the end frame provides the secondary function of supporting the end guide structural system.

The critical design condition for this structure is an applied 75^k ultimate vertical corner load during dual-mode operation. This load is introduced at the outboard attachment to the main cross frame and is reacted by the shackle (see Figure 43), attached to the frame at the apex fittings. Transfer of load from shackle to fitting is through a steel bushing (SK24962). The results of analysis of the bushing are shown here, since the bushing also is critical for this condition.

The dual-mode frame structure is a 6061-T6 weldment. All aluminum parts not requiring welding (fitting, links, etc.) are 7075-T6 or T651 depending on part thickness. All steel parts (bushings, bolts, etc.) are 125-ksi heat-treat steel.

Critical margins of safety are as follows:

PART - LOADING	FAILURE MODE	M.S.
Apex bushing - Extreme fiber bending at maximum moment	Yield at limit load	+0.24
Apex fitting - Upper diagonal chord tension	Shear bearing in diagonal lugs	+0.07
-5 Upper diag. chord attachment to removable link-upper chord tension	Shear bearing in upper chord lugs	+0.06
Inboard diagonal web member-tension load	Ultimate tensile stress on net section	+0.04
Outbd.diagonal web member-compression load	Column failure based compress yield cutoff	+0.10
AN6 bolts - attachment - Dual frame to main cross frame	Bearing at ultimate load	+0.10

Structure Configuration

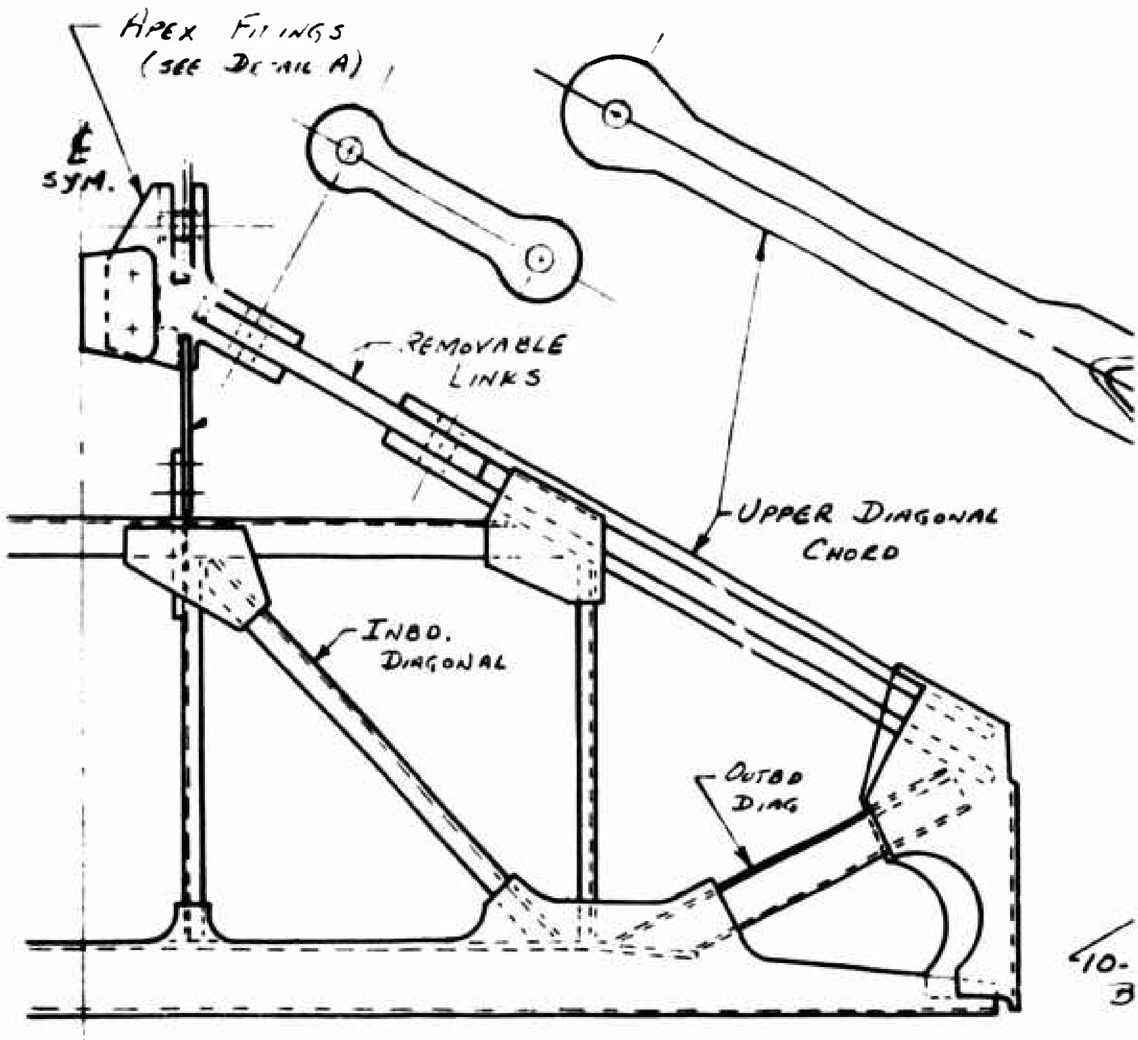


Figure 43. Container Handling Device - Dual Mode

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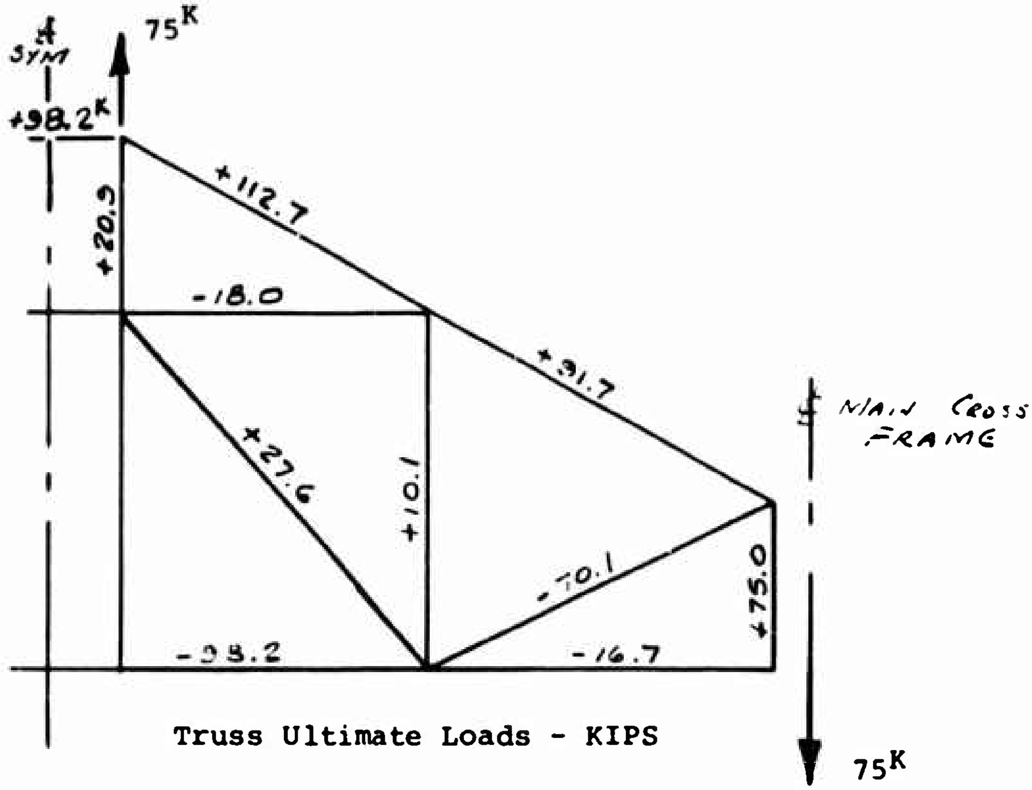
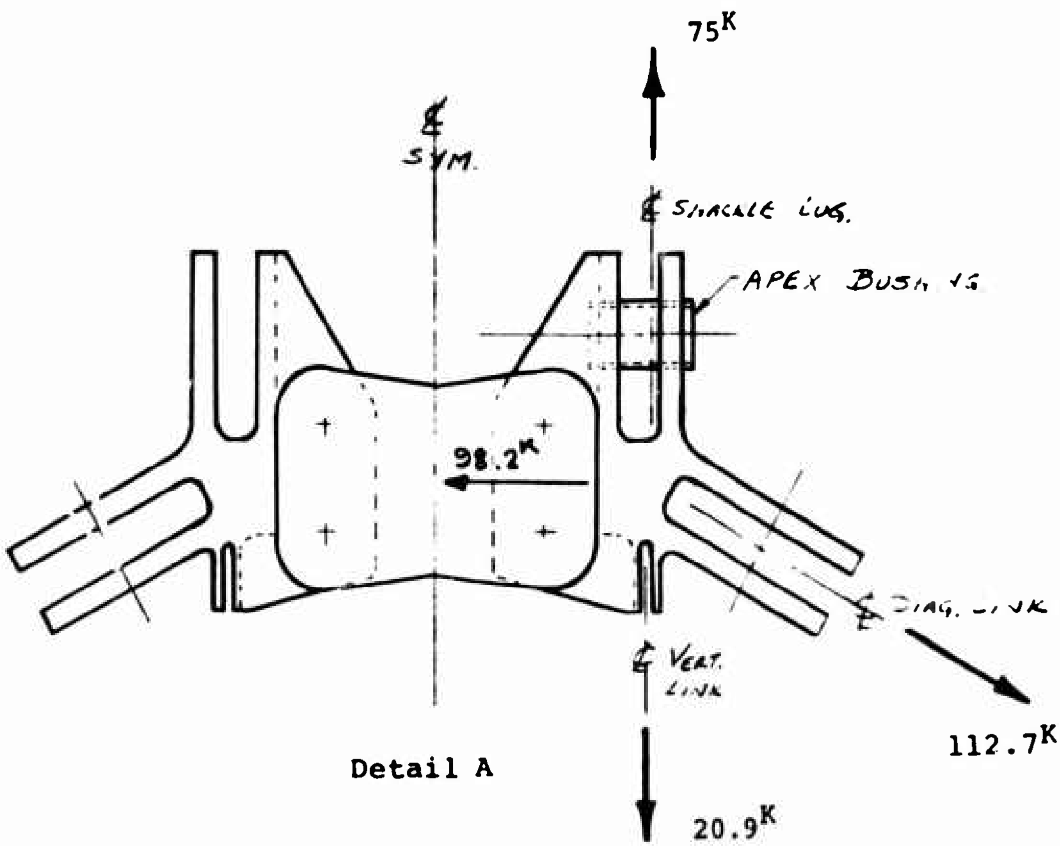


Truss Ultimate Loads - KIPS



Detail A

rame.

CONTAINER HANDLING DEVICE

Drag Link Structure - Ref.: SK24955

The drag link structure is the longitudinal section of the dual-mode superstructure. It consists of an upper drag link strut and a lower drag link structure.

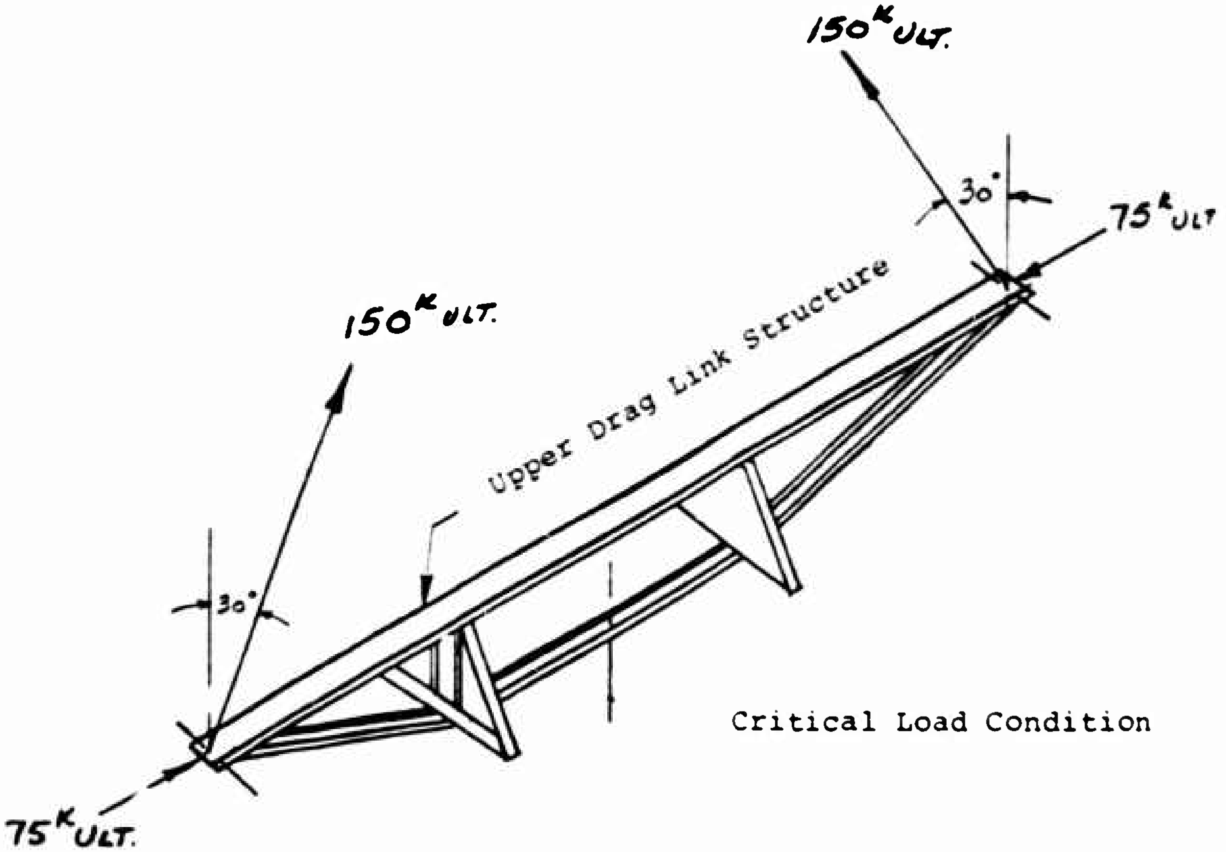
The upper drag link strut is the longitudinal box section which extends full length from forward to aft shackle pickup point (apex bushing). Its function is to provide an axial load path between pickup points, so that the horizontal components of forward and aft dual-mode cables can reactively balance each other, directly in the upper portion of the dual-mode superstructure. The box section is an aluminum riveted assembly, consisting of two 6061-T6 channel extrusions with 7075-T6 top and bottom cap plates. A pair of 7075-T6 side plates, bolted to the sidewalls of the box, act as lug attachments to the apex bushing.

Critical design condition for the drag link strut occurs with dual-mode cables operating at 30° vertical inclination toward device center while carrying maximum cable load. Critical load is a $\pm$ 75 kip ultimate axial load. The link design is controlled by stiffness requirements, with the limitation that limit load axial deformation will not produce out-of-plane warping of the dual-mode beam (Figure 44). As a result, the member has a relatively high margin of safety as a three-spar column.

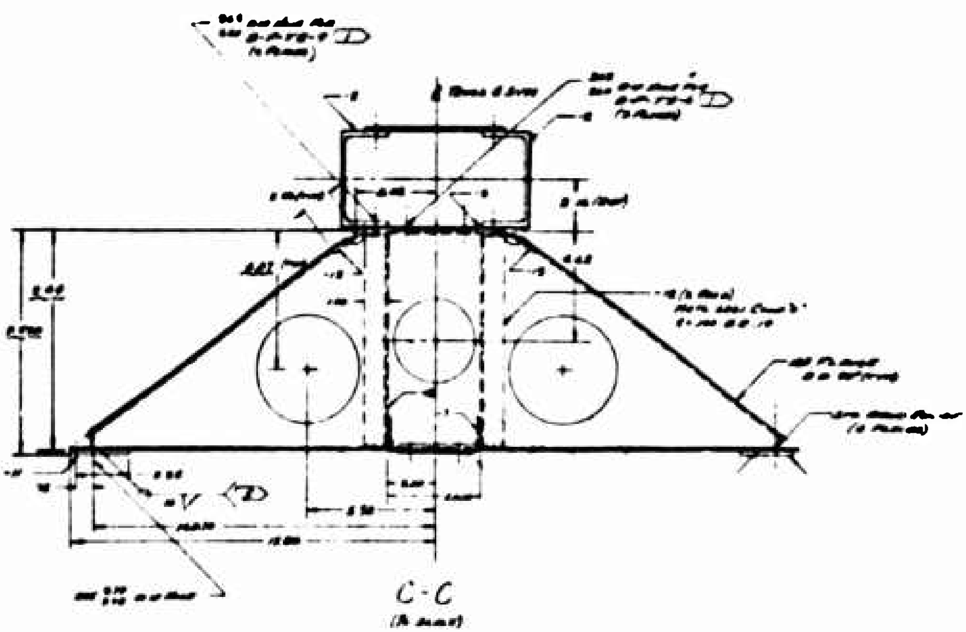
The lower drag link structure is 6061-T6 aluminum and consists of end diagonal links, a horizontal drag member attached to the top chord of the main cross frame, and two stabilizing cross frames at approximately third points on the structure. The lower drag link structure has two basic functions. The drag link members carry the net forward or aft container load up to the cables, and the stabilizing cross frames provide lateral support for the upper drag link strut, so that its effective column length is approximately one-third span.

The critical design condition for the lower drag link structure is 9.36^k ultimate drag force applied at the attachment bolt from main cross frame to lower horizontal drag member.

The critical margin of safety occurs in tension through the net section of the diagonal drag link strut and is equal to +0.22.



Critical Load Condition



Typical Stabilizing Cross Frame

Figure 44. Container Handling Device - Drag Link Structure.

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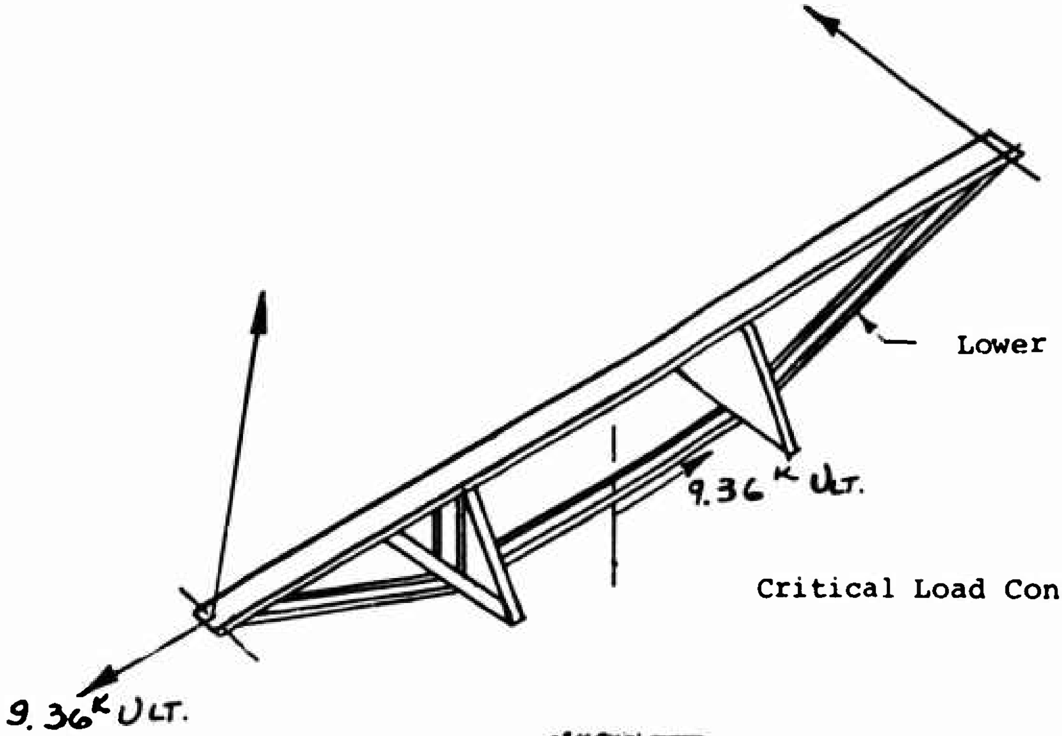
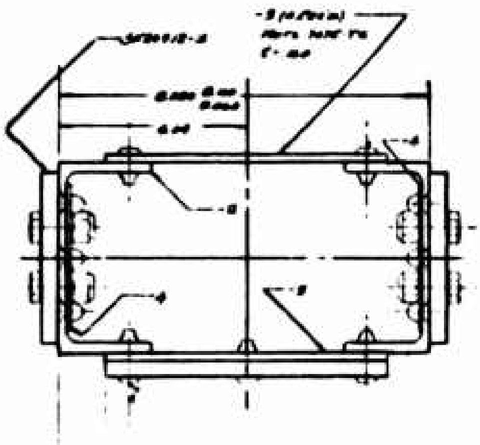
K ULT

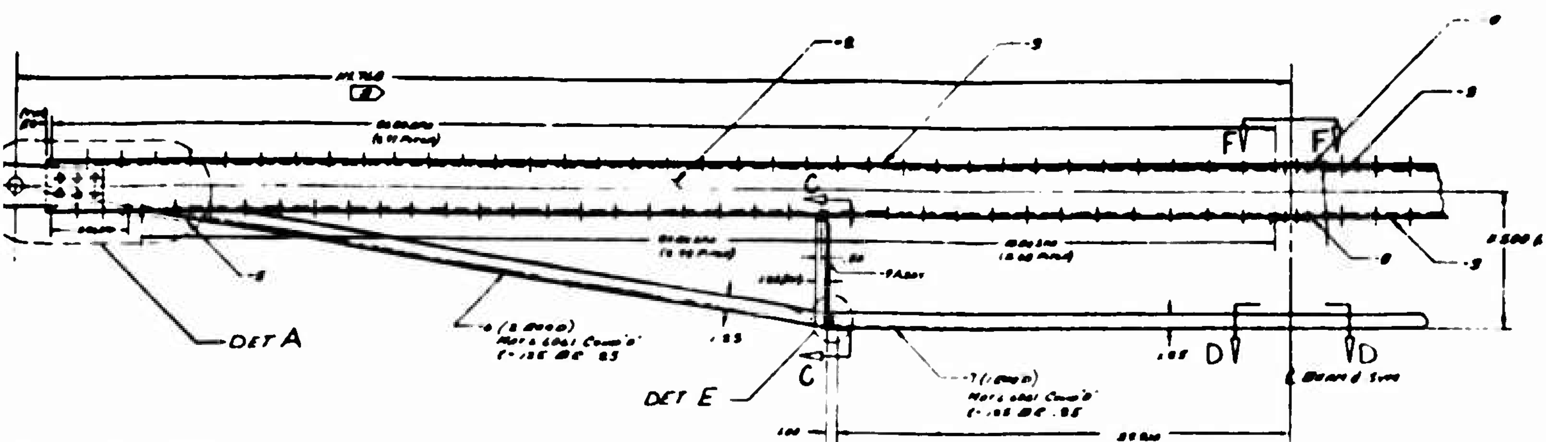


Lower Drag Link Structure

Critical Load Condition



Upper Drag Link Strut
Cross Section



nk Structure.

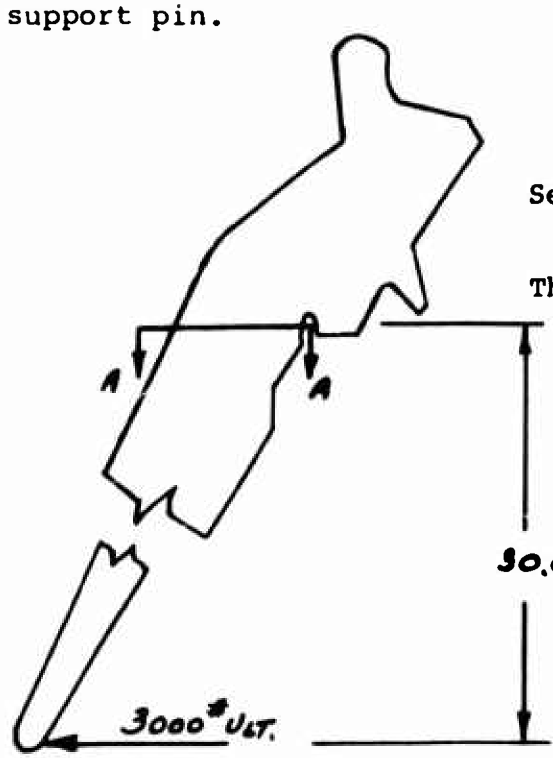
Drag Link Structure

CONTAINER HANDLING DEVICE

Guide System: Ref.: SK24924

The guide system consists of six retractable guide beams supported by cantilever frames to truss type backup structure. In the guide operating position, the guide beams are oriented down at a 30° vertical angle such that the container edge comes in contact with the inboard sloped edge of the beam as the device is lowered over the container. The device, therefore, positions itself over the container with sufficient accuracy to engage the corner twist lock pins. During this operation the guide system can experience bump loads in the plane of the guide beam. As shown below, the guide system has been designed to withstand a 2g limit load based on device weight.

The beam is a 7075-T6 machining supported by cantilever backup frame structure. With the exception of the beam itself, all structure in these systems is designed to ample margins of safety. The critical design condition for the guide beam is a horizontal bump load (inbd or outboard) at the beam tip, and the critical margin of safety is +.07 in bending at the lower beam support pin.



Sect. A-A Critical
Bdg. Section

Thickness = 0.375"

APPENDIX III
LABORATORY TEST RESULTS

PURPOSE OF TESTS

The tests described herein were conducted to demonstrate the structural integrity, inherent self-alignment capability, and normal latching and unlatching functions of a conceptual helicopter-transported container handling device.

TEST SPECIMEN

The helicopter-transported container handling device is a metal framework (see Figure 45) designed as a semiautomatic system to interface between any of three U.S. Army helicopter types (CH-47, CH-54, and HLH) and a MILVAN 8x8x20-foot shipping container. Two devices were designed and built.

TEST HARDWARE

The following equipment was used to conduct the tests described herein:

1. Two U.S. Army MILVAN containers, 8x8x20-foot, FSN 8115-168-2275
2. One 35-Ton PH Mobile Boom Crane
3. One 10-Ton Overhead Trolley Crane
4. One U.S. Army 60,000-lb Wire Rope Sling Assembly, Sikorsky P/N 38850-00002

TEST INSTRUMENTATION

No instrumentation was used. Visual observations were made and recorded on test data sheets.

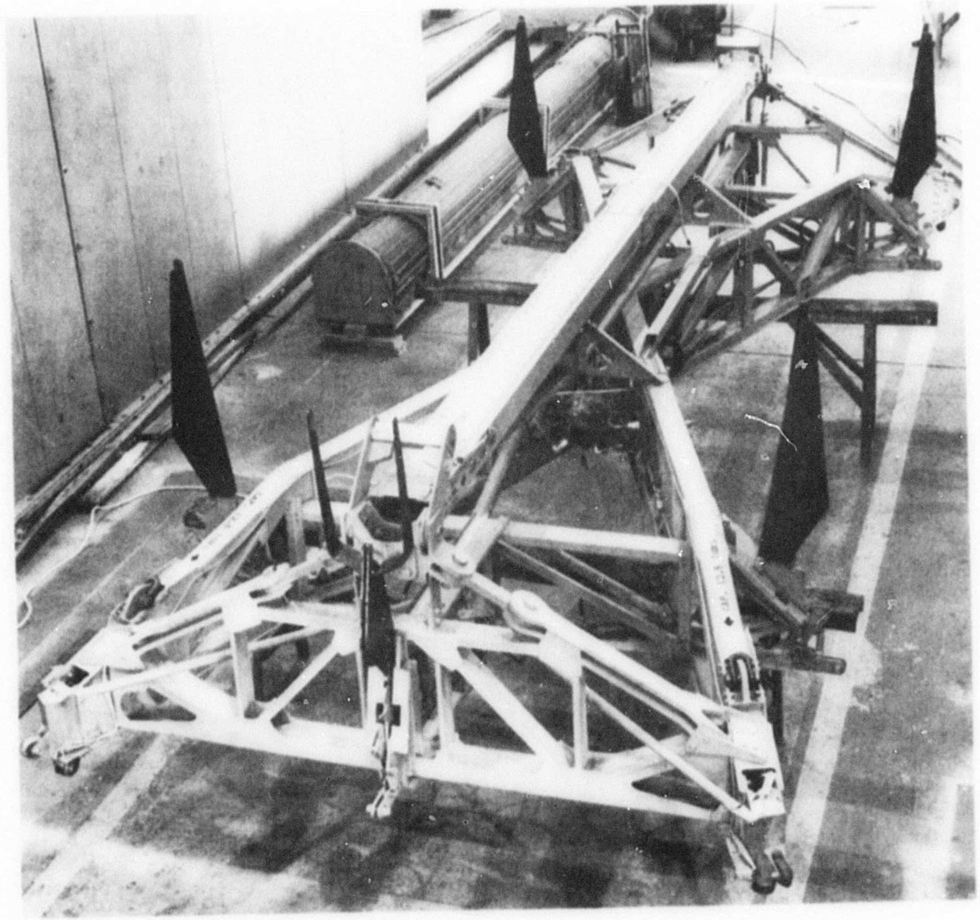


Figure 45. Helicopter-Transported Container Handling Device.

SCOPE OF TESTING

The following types of testing were performed under this program. Numbers in parentheses indicate the devices (serial number 1 or 2, or both) subjected to each test.

1. Vertical Load Test (1) - Lifting of the MILVAN ballasted to 67,200 pounds.

2. Self-Alignment Demonstrations (1 and 2) - With a MILVAN Container.

   a. Longitudinal Offset
   b. Lateral Offset
   c. Azimuth Offset
   d. Random Offset
   e. Lateral Approach to Load

3. Latching Demonstration (1 and 2) - With a MILVAN Container.

4. Unlatching Demonstration (1 and 2) - From a MILVAN Container.

DETAILED TEST DESCRIPTIONS

All testing of unit serial number 1 is discussed first, followed by the testing of unit serial number 2.

1. Container Handling Device (Serial Number 1)

a. Vertical Load Test (1)

Purpose - The vertical load test is intended to demonstrate the structural integrity of the container handling device design for limited Government flight test evaluations.

A MILVAN container, ballasted to a combined ballast and container weight of 67,200 pounds, was lifted by one of the two devices and suspended statically. This load weight represents the container device dual-mode design load of 56,000 pounds (28 tons) times a simulated maneuver load factor of 1.2g's (56,000 x 1.2 = 67,200 lb).

Procedure - U.S. Army MILVAN container S/N 3524 was uniformly loaded with lead pig ballast to a combined container and ballast weight of 67,200 pounds. The ballast consisted of 31 banded, approximately 2-foot-square bundles of lead bars, each bundle weighing 2,000 pounds, and 500 pounds of bagged sand. The empty container tare weight was 4,700 pounds.

A 35-ton PH commercial boom crane was positioned next to the long side of the ballasted container. A U.S. Army 60,000-pound wire-rope, four-leg, sling set was connected to the dual-mode pickup shackles of the container device. Two of the four sling legs were attached to each dual-mode shackle. A guide rope was also attached to the device. The crane lifted the empty device to a position above the container, where the crane operator, a container device operator, and a man on the guide rope completed alignment and engagement of the device twist locks with the container corner fittings. The twist locks were then set in the locked position using the helicopter control box and umbilical cord provided as part of the device assembly. A 230/460-volt 60-cycle motor was substituted for the 400-cycle 115/208-volt aircraft motor which is standard on the device, for compatibility with shop electrical power. The 60-cycle motor was also used for all subsequent laboratory tests.

The procedure outlined below was next repeated 10 times:

(1) The container device and ballasted container were gently lifted until daylight could be observed between the bottom of the container and the ground. Lifting was stopped and the system was held suspended for 5 minutes.

(2) The two side/end guide systems were cycled, using the production control box and umbilical cord, from the down and locked position to the up position and returned.

(3) The device and container were gently lowered until all the weight was removed from the wire rope sling.

(4) The device twist locks were actuated to the unlocked position, which was confirmed visually, and then returned to the locked position, which was also confirmed visually.

(5) Engineering representatives of the U.S. Army, Boeing Vertol, and the device fabricator then visually inspected the container device for signs of actual or impending structural damage.

Results/Conclusions - Visual inspections of the container handling device at nine intermediate points during the vertical load test and following completion of the tests indicated complete structural integrity of the device. The vertical load test was satisfactorily completed in accordance with the required test procedure.

Other Observations - Audible creaking sounds, originating in the wooden floor area of MILVAN S/N 3524, were heard during setdown on the ground following the third lift and the seven subsequent cycles. Inspection of the floor after completion of the tests and deballasting uncovered no significant container damage.

The test procedure was expanded to include cycling of the side/end alignment guides with the ballasted container suspended in the air. This was done to confirm that none of the structural deflections in the device prevented or inhibited normal guide operation. No difference was detected between guide operation with an empty device and with the ballasted container suspended below.

b. Self-Alignment Demonstration - Longitudinal Offset (1)

Purpose - This test was performed to demonstrate an inherent self-alignment capability from a pure longitudinal offset of 1 foot relative to a MILVAN container.

Procedure - Initially, the container device was suspended approximately 2 feet above the container using the 60,000-pound wire-rope sling, which was attached to the hook of an overhead trolley crane. The device was in a level attitude and aligned with the container, using the guide rope, in all respects except that it had a longitudinal offset of 1 foot. The 1-foot offset was established by visually aligning the device twist locks with a 1-foot offset mark placed on the long side of the container. The guide rope was next freed. The device was then lowered by the trolley crane until it either engaged the container corner fittings or otherwise unloaded the suspension system. No assistance was provided by ground handling personnel.

Results/Conclusions - The first attempt using the above procedure resulted in a nonengagement with the container. The device was lowered slowly with some jerking caused by the trolley crane. One end alignment guide contacted the container and then the device began to rotate about this contact point instead of sliding down the guide ramp. The twist locks at the end opposite the contact point dropped off the edge of the container, and the device stopped in a cocked attitude, out of alignment with the container.

A second attempt using the above procedure, but with a slightly greater vertical velocity, estimated to be between 20 and 30 feet per minute, resulted in proper self-alignment and twist lock engagement.

Other Observations - The double ramp configuration used on the end guides appears to be marginally acceptable at a 1-foot longitudinal offset.

c. Self-Alignment Demonstration - Lateral Offset (1)

Purpose - This test was performed to demonstrate an inherent self-alignment capability from a pure lateral offset of 1 foot relative to a MILVAN container.

Procedure - Initially, the container device was suspended approximately 2 feet above the container using the wire rope sling and overhead trolley crane. The device was in a level attitude and aligned with the container, using a guide rope in all respects except that it had a lateral offset of 1 foot. The 1-foot offset was established by visually aligning the device twist locks with a 1-foot mark on the 8-foot side of the container. The guide rope was freed. The device was then lowered by the trolley crane until it either engaged the container corner fittings or otherwise unloaded the suspension system. No assistance was provided by ground handling personnel.

Results/Conclusions - The first attempt using the above procedure, but with well over the 1 foot of offset, resulted in a nonengagement with the container. The second attempt resulted in satisfactory self-alignment and twist lock engagement. The wire rope sling legs, where they attached to the trolley crane, were observed to be in a crossed condition, possibly contributing some torsional moment to the device during the test. A third attempt, made with the sling legs straight, also resulted in satisfactory self-alignment and engagement.

Other Observations - None.

d. Self-Alignment Demonstration - Azimuth Offset (1)

Purpose - This test was performed to demonstrate an inherent self-alignment capability from a pure azimuth misalignment of 10 degrees relative to a MILVAN container.

Procedure - Initially, the container device was suspended approximately 2 feet above the container using the wire rope sling and overhead trolley crane. The device was in a level attitude and aligned with the container in all respects except that it had an azimuth offset of 10 degrees. The offset was established as follows. The device was visually positioned directly above the container by aligning the four twist locks with the four container corner fittings. The guide rope was then used to rotate the device until the tips of two diagonally opposite side guides contacted the container. This position had previously been calculated to be equivalent to 10 degrees of azimuth misalignment. The overhead trolley crane hook was of the full swivelling type, and therefore the suspension system did not contribute any identifiable torsional restoring moment. The guide rope was next freed. The device was then lowered until it either engaged the container or otherwise unloaded the suspension system. No assistance was provided by ground handling personnel.

Results/Conclusions - The first attempt using the above procedure resulted in self-alignment and proper twist lock engagement. A second attempt was made using, in addition to the 10 degrees of azimuth offset, a longitudinal offset of 1 foot. This test resulted in self-alignment and proper twist lock engagement.

Other Observations - None.

e. Self-Alignment Demonstration - Lateral Approach to Load (1)

Purpose - This test was performed to demonstrate and evaluate the concept of a quartering approach to the container prior to final self-alignment and engagement.

Concept - The container device is equipped with six self-alignment guides which are controllable in two sets of three guides each. Each set consists of the two side guides on one 20-foot side and the guide on one end. With only one set of guides in the down and locked position, the device can be brought toward the container from one quartering direction at a vertical distance which will allow the guide arms to contact the container. When the device is in this roughly self-aligned condition, the second set of guides may be lowered to complete alignment.

Procedure - Each of the three required tests was performed in general accordance with the following procedure:

(1) The device is suspended by a wire rope sling and overhead trolley crane approximately 2 feet above the container at a vertical separation which allows the side/end guides to contact the container.

(2) The device is then offset horizontally from the container in a quartering direction by 3 to 4 feet.

(3) The appropriate set of guides is placed in the down and locked position with the other set retracted.

(4) The device is now moved horizontally in the proper quartering direction until the down and locked guides contact the container.

(5) The retracted guides are moved to the down and locked position.

(6) The device is next lowered until it self-aligns and engages the container corner fittings or otherwise unloads the suspension system.

Results/Conclusions - The first attempt using the above procedure resulted in self-alignment and proper twist lock engagement. The second attempt resulted in the device tilting in the lateral direction, which prevented proper engagement. The third and fourth attempts resulted in self-alignment and proper twist lock engagement. The three required tests were satisfactorily completed.

Other Observations - None.

f. Self-Alignment Demonstration - Random Misalignment (1)

Purpose - This test was performed to demonstrate an inherent self-alignment capability from random combinations of lateral, longitudinal and azimuth offsets within a 1-foot and 10-degree offset zone relative to a MILVAN container.

Procedure - Each of the three required tests was performed using the following general procedure:

(1) The device is positioned approximately 2 feet above the container with a vertical separation which allows the side and end guides to contact the container when in a down and locked position.

(2) The device is then randomly displaced relative to the container within a zone of 1 foot laterally and longitudinally and 10 degrees of azimuth, using a guide rope.

(3) The guide rope is freed, and the device is lowered until it either properly engages the container corner fittings or otherwise unloads the suspension system.

Results/Conclusions - The first and second attempts using the above procedure resulted in proper self-alignment and engagement. The third attempt was made with the device rotated 180° relative to the container and also resulted in proper self-alignment and engagement. The three required tests were satisfactorily completed.

Other Observations - None.

g. Latching Demonstration (1)

Purpose - This test was performed to demonstrate the normal capability of the device to latch to a MILVAN container without the aid of ground handling personnel. Actuation of the latches was through the helicopter control box and umbilical cord provided as part of the device assembly.

Procedure - Each of the three tests was performed using the following procedure:

(1) The device is placed on the MILVAN container such that the twist locks are properly engaged in the container corner fittings.

(2) All device weight is rested on the container.

(3) The twist lock actuation system is switched to the locked position.

(4) Positive latching at each of the four corner fittings is verified visually.

(5) The device and empty MILVAN container are lifted clear of the ground by an overhead trolley crane to verify positive latching.

(6) The container is set back on the ground and the suspension system is unloaded.

Results/Conclusions - All required tests were satisfactorily completed in accordance with the specified procedure.

Other Observations - None.

h. Unlatching Demonstration (1)

Purpose - To demonstrate the capability of the device for remote unlatching from a MILVAN container.

Procedure - Each of the three tests was performed using the following procedure:

(1) The device is placed on a MILVAN container such that the twist locks are engaged in the container corner fittings and properly located in the latched position.

(2) The device and the empty MILVAN (tare weight, 4,700 pounds) are raised clear of the ground and set back down using a wire rope sling and overhead trolley crane.

(3) The suspension system cables are unloaded.

(4) The device twist locks are then actuated to the unlocked position using the helicopter control box and umbilical cord. No assistance is provided by ground handling personnel.

(5) The device is then lifted clear of the top of the container to demonstrate that proper unlatching and disengagement have been accomplished.

Results/Conclusions - The three required tests were satisfactorily completed in accordance with the specified procedure.

Other Observations - None.

2. Container Handling Device (Serial Number 2)

a. Self-Alignment Demonstration - Longitudinal Offset (2)

Purpose and Procedure - Same as paragraph 1b. MILVAN container serial number 3528 was used for all tests of device serial number 2.

Results/Conclusions - The required test was satisfactorily completed in accordance with the specified procedure.

Other Observations - None.

b. Self-Alignment Demonstration - Lateral Offset (2)

Purpose and Procedure - Same as paragraph 1 c.

Results/Conclusions - The first attempt ended with the device cocked laterally on top of the container in a non-engaged condition. The device was lifted clear of the container and the test was repeated. On the second attempt, the device self-aligned and properly engaged the container corner fittings.

Other Observations - None.

c. Self-Alignment Demonstration - Azimuth Offset (2)

Purpose and Procedure - Same as paragraph 1 d.

Results/Conclusions - The required test was satisfactorily completed in accordance with the specified procedure.

Other Observations - None.

d. Self-Alignment Demonstration - Lateral Approach to Load (2)

Purpose and Procedure - Same as paragraph 1 e.

Results/Conclusions - The three required tests were satisfactorily completed in accordance with the specified procedure.

Other Observations - None.

e. Self-Alignment Demonstration - Random Misalignment (2)

Purpose and Procedure - Same as paragraph 1 f.

Results/Conclusions - The three required tests were satisfactorily completed in accordance with the specified procedure.

f. Latching Demonstration (2)

Purpose and Procedure - Same as paragraph 1 g.

Results/Conclusions - The three required tests were satisfactorily completed in accordance with the specified procedure.

Other Observations - None.

g. Unlatching Demonstration (2)

Purpose and Procedure - Same as paragraph 1 h.

Results/Conclusions - The three required tests were satisfactorily completed in accordance with the specified procedure.

Other Observations - None.