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AERIAL CARGO HANDLING TECHNOLOGY FOR ADVANCED CARGO ROTORCRAFT

by

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Abstract

The role of Army cargo rotorcraft is expanding as the United States military scales down its forces and faces reduced funding. Increasing in importance is cargo rotorcraft's ability to carry and safely deliver high-priority cargo in support of scout, attack and assault helicopters. In addition, the U.S. Army is playing an ever growing peacetime role in disaster and humanitarian relief efforts as evidenced by Operation Provide Comfort, Operation Restore Hope, and Hurricane Andrew disaster relief in Florida, USA. The result is an increased need and expanded emphasis on expedient and efficient internal/external cargo operations. To meet this need, future cargo rotorcraft system design must address the operational aspects of transporting cargo in new and innovative ways.

The paper addresses the significant findings from the technical report, "Aerial Cargo Handling Technology Analysis," USAAVSCOM-TR 90-D-1, and the subsequent research planned at the Aviation Applied Technology Directorate (AATD), U.S. Army Aviation and Troop Command, Fort Eustis, Virginia, USA, in the area of advanced cargo rotorcraft design and supporting cargo handling equipment.

The paper covers integrating rotorcraft, aircrew and instrumentation into system design for safer and more efficient sling load operations, be they routine or low visibility. Also discussed are the changes necessary to rotorcraft cargo compartment design to facilitate acquisition and discharge of cargo loads and the in-flight transition of internal loads to external loads (and vice-versa).

1 Introduction

The U.S. Army is faced with an aging fleet of cargo helicopters. Initially fielded CH-47D Chinooks, currently the cargo workhorse for the Army, will be 20 years old by the year 2002 and ready for retirement [1]. Army planners are currently weighing two options to solve the aging fleet problem: either modernize the CH-47D (called the follow-on (FO) version of the CH-47) or continue to develop the heretofore conceptualized Advanced Cargo Aircraft (ACA) as a CH-47D replacement. The Aviation section (Annex L) of the 1993 U.S. Army Modernization Plan, a plan which stresses the need for modern, high-technology aircraft to face increasingly sophisticated threats, deemphasizes the FO version of the CH-47. Despite the hope that it would be given some early research funding in 1993, the plan does not project fielding of the

CH-47FO until 2009. Meanwhile, the concept of a joint-service ACA helicopter remains in the modernization plan as a viable alternative. Perhaps it is even possible that the CH-47FO and an ACA can be rolled into one program [2]. One thing is certain, with the increasing emphasis on regional conflicts and expanding humanitarian missions, the need for efficient and expedient air mobility is growing. If the U.S. Army is to adequately meet this challenge, aerial cargo transport after the year 2000 requires thought, planning and action now.

In order to identify the current deficiencies of U.S. Army helicopter aerial cargo handling methods and to define advanced aerial cargo handling systems for a CH-47FO or future ACA, an AATD contracted study entitled "Aerial Cargo Handling Technology Analysis" was undertaken by an industrial team from AAR Brooks and Perkins Company, Breeze Eastern Corporation and Boeing Helicopter Company. The ongoing work of the concept study and the final written report were monitored by AATD engineers. The technology analysis, which examines the current U.S. Army cargo helicopters and future cargo handling needs, identifies multiple cargo handling deficiencies, internal and external, and proposes design solutions.

2 Review of Current Shortcomings and Desired Capabilities

In order to define the requirements for an advanced aerial cargo system, a comprehensive review and assessment was performed which examined how operations are currently being conducted and how future operations will most likely be conducted. The investigation consisted of background research, the compiling of shortcomings and deficiencies, and the formulation of system design goals necessary to eliminate the shortcomings and satisfy future needs.

2.1 Literature Search

An extensive literature search was undertaken which reviewed significant documents, reports of internal and external cargo systems and the Low-Visibility Acquisition System (LOVLAS). Information from these sources was assimilated and assessed for its applicability to the study effort.

2.2 On-Site Surveys

Early in the study the investigators visited U.S. Army, Marine Corps and Navy rotorcraft users and commercial manufacturers/operators. A total of ten on-site visits were conducted. An informal survey was conducted of service personnel with specific attention paid to their comments regarding future requirements for cargo cabin size and layout and internal/external transport modes. The two predominant concerns expressed regarding internal cargo handling were that the cargo compartments of current Army cargo helicopters are too small and that configuring the aircraft for different missions is time-consuming. The two predominant concerns for external cargo handling were load hookup difficulties and load instability during flight.

2.3 Accident History Survey

According to the U.S. Army Safety Center, Fort Rucker, Alabama, the number one cause of accidents during rotary-wing external cargo handling operations is the aircraft and load contacting each other, Fig. 1. This type of accident is typified by the aircraft settling down on the load and/or ground personnel during load hookup. Accidents occurring for this reason are extremely dangerous to the hookup person on the load, cause damage to the aircraft underbelly and are a major cost contributor for the Army, Fig. 2. With these facts in mind, an advanced aerial cargo handling system for U.S. Army cargo rotorcraft which incorporates a load monitoring/viewing system, makes sense from both a safety and a financial standpoint.

The category of "Other System Malfunctions" is equally costly to the Army because the malfunction of the engine/flight control or other systems, which causes the pilot to jettison the load, results in the total loss and subsequent replacement cost of the jettisoned load.

2.4 Specific Mission Capability

Discussions between the study team and the Army user community revealed several mission capabilities desirable in an advanced aerial cargo handling system. Included among them is the ability to use the cargo rotorcraft to supply Forward Area Rearm and Refuel Points (FARP's) to sustain attack helicopter long-distance operations. This capability requires that the cargo rotorcraft interior have adequate space for fuel and palletized arms storage.

Another desirable mission capability is the transport of a load internally with the ability to acquire and/or discharge the load from a hover, Fig. 3. This capability allows internal transport of cargo for high-speed flight, protection of the payload, eliminates the need for ground personnel to clear large landing zones for heavy resupply and provides a means of placing loads in remote areas where landing zones do not exist.

Two mission capabilities that are also desirable for an advanced aerial cargo handling system require rapid configuration of the interior of the rotorcraft. The first involves configuring a cargo helicopter to be an airborne command post. For this application, operator stations/avionics would be palletized to rapidly roll onto the aircraft. Electrical power and cooling would be provided through interfaces with the aircraft. The second mission capability is the evacuation of patients using a pallet mounted litter stanchion or patient evacuation system, Fig. 4.

The CH-54 Skycrane, with a single winchable hook with 100 feet of cable rated at 25,000 pounds, has a unique capability. However, the CH-54 Skycrane is being retired from the Army inventory. Desirable for an advanced aerial cargo handling system is a two-winch hook configuration to allow long sling load acquisition, (100 foot-cable length), Fig. 5. With differential length cable, the load attitude can be oriented for maximum load stability.

2.5 Compilation of Shortcomings

After completing literature and patent searches, on-site surveys with users and accident analyses, the study team compiled an expanded list of cargo handling deficiencies. Some of the internal cargo handling deficiencies that are costly to the U.S. Army in terms of dollars, manpower and mission efficiency are: insufficient cross sections of cargo aircraft cabins, lack of versatility reflected by the excessive time required for mission role changes and the inability to carry loads internally and deliver externally. Costly external cargo handling deficiencies include: the lack of adequate clearance between the load and aircraft during hookup, the lack of visibility of hooks and loads and the limiting of payloads/speeds due to external loads.

3 Candidate Solutions

3.1 Program Objectives/Design Goals

With the shortcoming and deficiencies in mind, the study team defined five program objectives for an advanced aerial cargo handling system: productivity, survivability, availability, affordability and safety. Using these five objectives, the study team formulated a set of design goals. In abbreviated form they are:

- Define a system to minimize the loading and unloading time.
- Improve current external load operations.
- Minimize time and labor required to configure the rotorcraft to accommodate the various modes of load transportation.
- Provide the capability for simultaneous internal/external cargo operations.
- Define a capability for externally acquiring and discharging loads without ground support personnel.
- Improve crew and flight engineer efficiency.
- Recommend general improvements.

3.2 Candidate Selection Methodology

With the design goals established, the study team formulated a process to select the most promising design concepts. Fig. 6, illustrates the methodology of candidate selection. Work done by the Army during the past 15 years was reviewed for its applicability to the study. A total of six technical papers/reports were reviewed, most having to do with the CH-47 helicopter. Following this, patent searches were conducted to determine if any patents, obtained by AATD, could be applied to the design concepts. Four patents were reviewed, however; only one patent, describing an auxiliary lifting system, was relevant to the study.

The next step undertaken by the study team was to review current U.S. military and commercial aircraft, (rotorcraft and fixed wing), to determine the pros and cons of their existing aerial cargo handling systems. Twelve fixed-wing aircraft and twelve rotorcraft were examined. Areas of review included: the maximum load carrying capacity of the aircraft, the cargo cabin dimensions (width, length and height), the aircraft's internal cargo loading devices and the types of loads most often transported.

3.3 Candidate Concepts

Throughout the research phase of the study, candidate concepts were formulated. Following the deficiencies/requirements identification and the establishment of design goals, the development of candidate concepts was formally undertaken. The following internal cargo handling concepts were considered worthy of continued evaluation:

- No Rollers
- CH-46 Standard Rollers
- CH-47 Helicopter Internal Cargo Handling System (HICHS)
- Flip-Over/Retractable Unpowered Rollers
- Powered Conveyors
- Overhead Hoist
- Air-Cushion
- Slip-Sheets

The variations and combinations of external cargo handling concepts were numerous and diverse. In general, the concepts considered can be categorized into six groups: fixed hooks, active arms, winchable hooks, load snubbing, semi-permanent/permanent structure, suspended platforms and combined loads.

4 Concept Selection

Following the development of candidate concepts, the number of candidates was reduced in two increments in order to focus effort on the most promising.

A weight and ranking scheme was developed which applied numerical scores to the concepts. The scheme gave the highest weights to the parameters of loading and unloading the aircraft, lifting loads externally, configuring the aircraft and high-speed/contour flight external transport. The various loads for each of these parameters were then ranked in order of importance. Lower weights were assigned to parameters such as simultaneous internal and external operations, safety, crashworthiness, reliability and maintainability. These parameters were also ranked in order of importance. Three existing aircraft, the CH-47D (with HICHS), the CH-54, the MIL-26 and a conceptual ACA, (with flip-over conveyor rollers, triple hook and a large cabin cross section) were evaluated. The ACA scored the highest for over half of the parameters listed.

In a parallel effort, the operational effectiveness of the cargo concepts was evaluated using a three-phase methodology. The first component of the methodology is the Advanced Tactical Combat Model (ATCOM), a player-interactive computer model using a time/event-sequenced simulation of combat. ATCOM was used to determine the probability of survival for the ACA carrying both internal and external loads. The second component of the methodology is the Hierarchical Level II-Effectiveness Analysis of Tactical Engagements (HEATE), an analytical, small-unit, combat model used to determine the probability of battle outcome states. The third component of the methodology is the Cargo/Utility Productivity Simulation (CUPS), a model which measures productivity (in ton-miles), payload, delivery (in pounds/day), flight hour usage, fuel efficiency and mission completion rates. CUPS allows the user to quantify productivity and compare improvements in mission time, aircraft weight, cube and speed. Executing the ATCOM/HEATE/CUPS methodology many times provided a statistical measure of the mission index. This index was then used to assess the worth of each candidate concept.

5 Internal Cargo Handling Concepts

5.1 Unpowered/Flip-Over Conveyor Rollers Cargo Handling System

The initial concepts of air cushions and slip-sheets were dropped from consideration because of their incompatibility with priority loads and/or their inability to perform the operations/missions of the ACA. The remaining concepts were then compared using the weight and ranking scheme and the ATCOM/HEATE/CUPS methodology. These two scoring exercises concluded that an Unpowered/Flip-Over Roller Cargo Handling System, Fig. 7, is the most highly recommended internal cargo handling concept. Based on the CH-47D HICHS, the system would have additional features; most notably, the system should be flip-over. This would allow one man to reconfigure the cabin hold from palletized loads to troops or rolling stock (and back) while in flight. The system would require no installation tools nor would it require aircraft power.

5.2 Flight Engineer Station (FES)

In addition to the eight internal cargo concepts explored in the study, other conceptual features located in the interior of the rotorcraft were proposed. While these features are not specifically for internal cargo movement, they do address deficiencies identified earlier in the study. One of these features is the Flight Engineer Station (FES). The FES is a permanent seated position outside the normal cargo compartment envelope. Six locations for the FES were considered, and the viewing angles associated with each of the locations were determined. The preferred location, Fig. 8, is a position just aft of the pilot. A FES located here features a bubble window for outside visibility and a television monitor to observe the cargo hooks. This station may be equipped with any number of the following features:

- A flat-surface table to accomplish the required paperwork and other administrative functions.
- Adequate variable light for night operation with night-vision goggles.
- Cargo compartment lighting controls for all interior/exterior lights.
- Door controls where remote electrical, mechanical, and /or hydraulic operation permits.
- Radio controls/Intercom controls that permit the flight engineer to monitor the pilots, crew, and outside ground radios.

Other features of the FES include: a crashworthy seat with a swivel-tilt function to permit viewing in all possible directions, an integral weight and balance system control panel for monitoring weight/balance changes during all phases of loading/unloading, a TV screen, and camera controls for viewing and adjusting remote cameras mounted inside, and underneath the aircraft.

5.3 Litter Configuration

The litter configuration shown in Fig. 9, where the litters are mounted on 463L-type pallets, allows patients to be rapidly loaded and unloaded, and transported to other modes of transportation.

6 Modes Interface

Some of the cargo handling concepts fell into both the internal and external cargo categories. This resulted in a separate classification called modes interface. These concepts were not rated.

6.1 Integral Cargo Handling Aft Ramp Hoist

The Integral Cargo Handling Aft Ramp Hoist allows palletized loading and unloading from the rear of the aircraft, internal transport of a load with external delivery/pickup (during hover), and decreases the need for ground handling equipment. Fig.10 shows the arrangement of the conceptual cargo hoist rail system, located in the overhead above the aft loading ramp. The overhead clearance and short ramp length allows a drop-side truck to approach the rotorcraft perpendicular to the aircraft centerline and load or unload without manhandling the pallet. A dual-rail/pulley configuration, similar to an automatic garage door opener, drives a trolley pulley from the rear at the fuselage ramp intersection to out beyond the ramp. The overhead aft ramp trolley leads are connected to the cable of the internal cargo winch (located forward in the cargo cabin on the CH-47D), thus eliminating the need for a dedicated winch motor in the rear of the cabin.

Fig.11 shows the location of the cargo-winch motor, located in the forward cabin roof (along with associated snatch-block and pulley locations), permitting the single-motor/dual drum configuration to serve as the conventional cargo winch or as an overhead hoist drive source.

6.2 Variable-Height Landing Gear

Variable-height landing gear allows the raising and lowering of the rotorcraft to facilitate loading and unloading of cargo. This type of adjustable landing gear may only be necessary if the aircraft's fuel tanks are located outside the aircraft, (in pods), Fig. 12. If the fuel tanks are located under the cabin floor, (a situation where the cabin floor is raised to approximately truck bed level), variable-height landing gear would not be needed.

7 External Cargo Handling Concepts

7.1 Dual Winchable Hooks

The scoring methodology determined that the preferred external handling concept is two hoistable cargo hooks and one fixed cargo hook on the rotorcraft for external cargo hookup operations.

Dual winchable hooks allow standoff hookup operations and the mitigation of environmental effects, such as blowing sand, snow and dust due to the rotorcraft hovering (20 feet typical) above the ground during hookup. The dual winchable cargo hooks would be located fore and aft on the rotorcraft, while a center cargo hook would be fixed. This arrangement is similar to the current hook arrangement on the CH-47D, with the exception of the fore and aft hooks being winchable.

The use of hoistable hooks involves lowering the cargo hooks prior to cargo hookup and then raising them after hookup. For a low-power hoist, this operation could be time-consuming. The study team determined that a 1-minute (or less) hoisting operation is desirable. Assuming a 100-foot length cable and a 1-minute hoisting operation, the speed of the hoist should be approximately 100 feet per minute. If the ACA has approximately a 30,000 pound payload capacity, and the load is shared equally between the fore and aft hooks (where each hook is rated for 60% of the load), then the two winchable hooks would be rated for approximately 18,000 pound a piece.

The two hoists may be operated independently or in concert. The control system has a feature which allows the control processor to be programmed for typical loads, so that when activated, the control unit automatically achieves the correct pitch attitude and tension member length. The study team completed a preliminary design for an advanced-technology hoist, which specifies the motor, gear train, tape, brake, press roller and tape cutter to be used.

7.2 External Load Acquisition System

The study team reviewed the external load acquisition concepts proposed in the USAAVSCOM-TR-86-D-12 report. Concepts considered for short-range load acquisition include: a manual system, two charge-coupled-device cameras mounted on the helicopter underside, ultrasound, laser and millimeter-wave radar.

Two concepts for load acquisition were chosen. The first concept is a Zero-Man Option (no ground personnel required) whereby the load is prerigged for pickup, then the ground personnel departs. At a later time the aircraft approaches the load and intercepts an elevated hookup yoke. The aircraft transceiver emits a pattern of ultrasound signals, Fig. 13. This is picked up by the transponder on the load, recognized and a reply is generated. The reply is directly porportional to the distance separating the receiver and the load. This time is tracked. Through a simple algorithm, the distance separating each receiver and the load-engaging loop is computed. Another simple algorithm can then determine the relative x, y, z coordinates of the load hookup loop with the aircraft. The relative positions are fed to the aircraft Automatic Control System in real time for precise guidance, hover and hookup.

The second concept for load acquisition is a One-Man Option, where one person is available on the ground to attend to the load. It is envisioned that visual or audio contact could be made with this one man who would direct the helicopter directly above the load. Once over the load, the winchable hooks would be lowered, attached to the load and the loading zone cleared of ground personnel. The load would then be winched and transported.

8 Concluding Remarks

The cargo handling design goals of the program presented in Section 3.1 were met by the study team in the following way:

-Flip-Over Conveyor Roller System - minimizes the time needed for loading and unloading cargo, and reduces the labor required to configure the rotorcraft to accommodate various modes of load transportation.

-Aft-Ramp Hoist - provides the capability for simultaneous internal/external cargo operations, decreases loading/unloading time and reduces the need for ground cargo handling equipment (forklift, etc).

-Dual Winchable Hooks - facilitates safe and expedient external load operations, since the pilot does not need to hold such a precise hover. Provides a benign environment for the hookup personnel, with less rotor downwash, noise and anxiety from fear of being pinned between the aircraft and the load.

-Flight Engineer Station - improves crew and flight engineer efficiency and assists in external load operations by providing visibility of the load through the bubble window and by means of a controllable television camera.

-External Load Acquisition - assists in external cargo operations by reducing and/or eliminating the need for dedicated ground personnel.

As of this writing, AATD is planning an advanced technology cargo handling demonstration of selected concepts from this study beginning in 1994. The concepts to be demonstrated include: aft ramp hoist, flip-over conveyor rollers, flight engineer station, dual winchable hooks, external load viewing system and hands-off load aquisition.

The Army has not yet determined whether the next generation of cargo rotorcraft will be a CH-47FO or an ACA, nevertheless; each of the cargo handling features to be demonstrated are applicable to both. By successfully demonstrating these concepts now and advertising the proven benefits to the Army community, it is hoped that some, if not all, of these advanced cargo features will be incorporated into the cargo rotorcraft of the Army's future.

9. References

1. S. D. Dodge, Chinooks in Peace and War, Now and in the Future, Vertiflite, November-December 1992.

2. Army Mod Plan: Pro-Comanche, Pro-Technology, Rotor and Wing, March 1993.

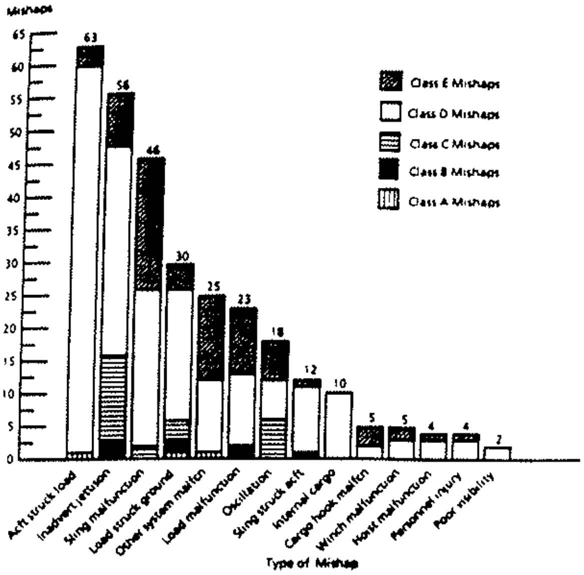


Fig. 1 U.S. Army rotary-wing internal/external cargo handling mishaps by mishap category

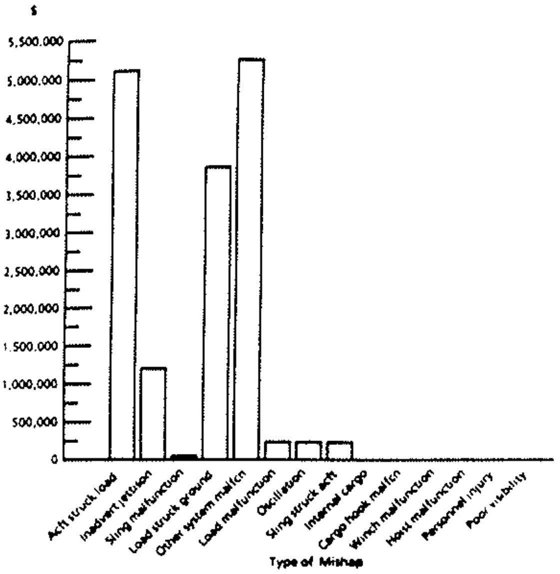


Fig. 2 U.S. Army rotary-wing internal cargo handling mishaps by cost

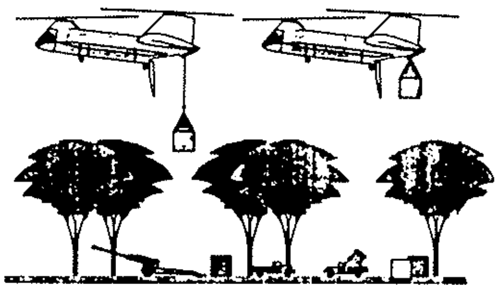


Fig. 3 Hover on-load

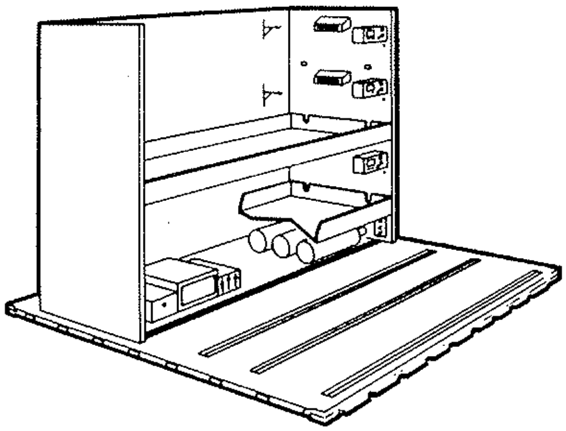


Fig. 4 Patient evacuation transport system

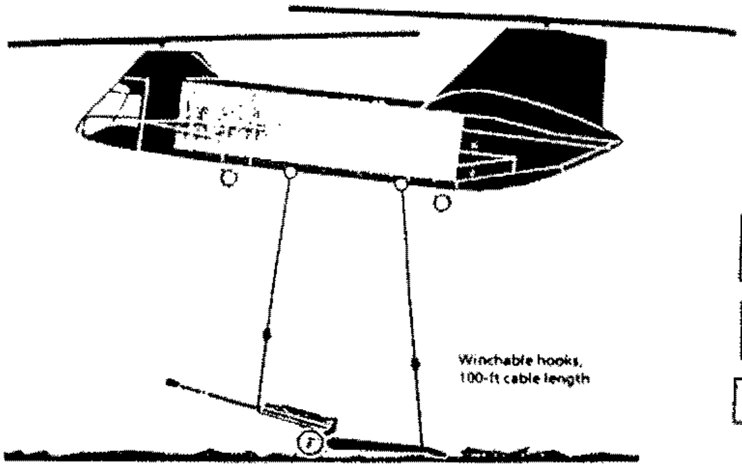


Fig. 5 Dual winchable hooks

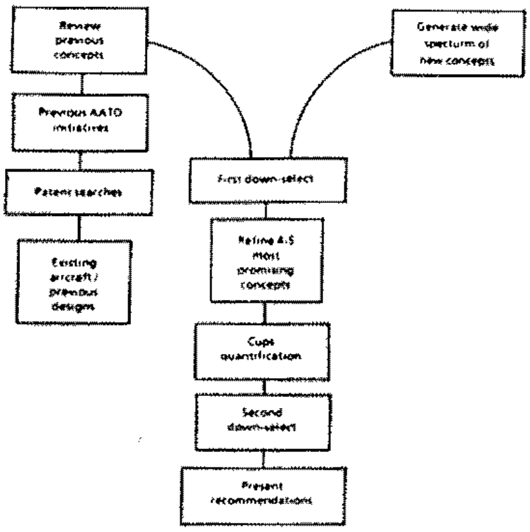


Fig. 6 Candidate selection methodology

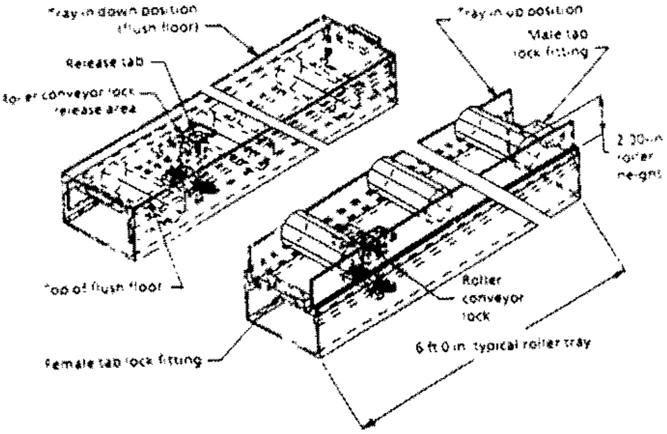


Fig. 7 Flip-over roller conveyor

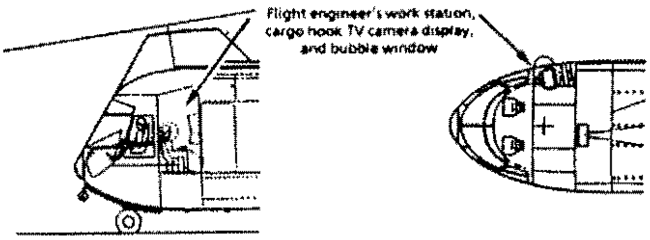


Fig. 8 Preferred flight engineer location

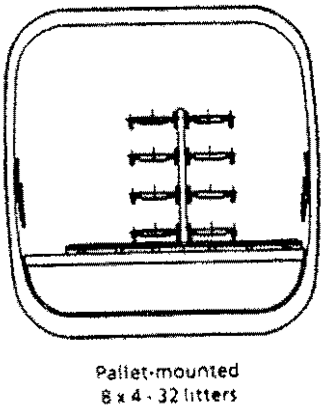


Fig. 9 Litter configuration

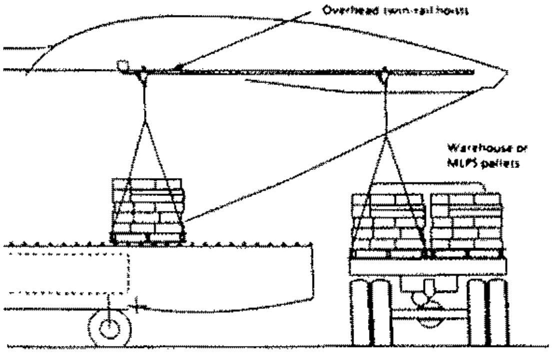


Fig. 10 Aft ramp hoist

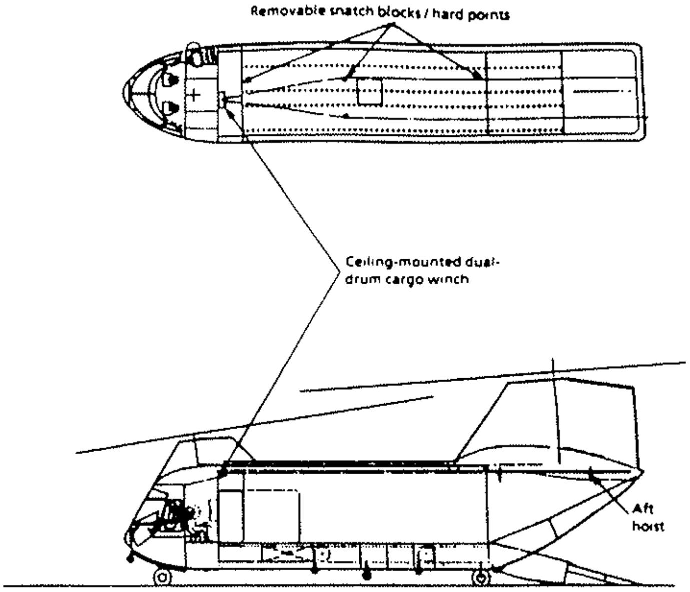


Fig. 11 Cargo winch/rescue hoist

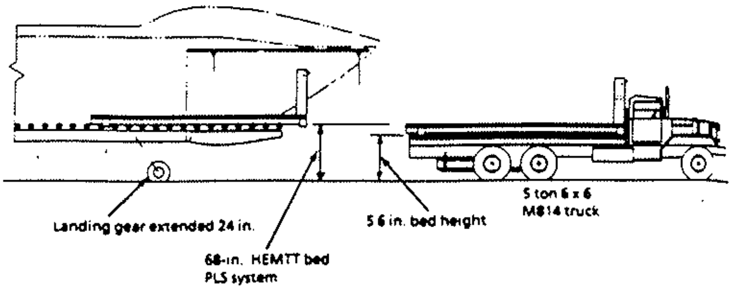
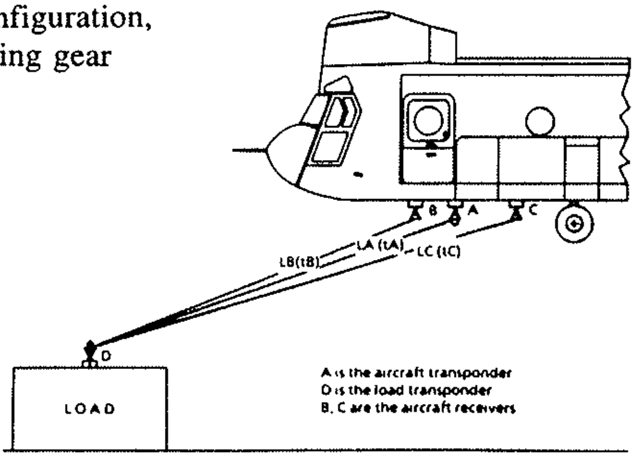


Fig. 12 Podded fuel configuration, extendable landing gear



- Use of 1 transceiver and 2 receivers on aircraft
- Use of 1 transponder on load
- Aircraft transponder emits ultrasound signal pattern
- Signal received by load transponder, recognized, and reply generated
- Reply picked up by aircraft receivers and time is measured
- Load transponder coordinates generated by geometry
- Relative position fed into AFCS for automatic hookup

Fig. 13 Ultrasound concept for load detection