Heavy Lift Helicopter Program: An Advanced Technology Solution to Transportation Problems

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This paper describes the DOD's Heavy Lift Helicopter Advanced Technology Component (HLH/ATC) in the light of the historical background of the ship-to-shore cargo handling problem. The helicopter's role in the DOD'S current logistic concept is discussed, along with the consequent need for an advanced technology program in order to develop the necessary vertical lift system and subsystem capabilities. After describing the Heavy Lift Helicopter baseline design, the paper outlines the specific component developments in the areas of rotor, drive, flight controls, and cargo handling systems. Projected commercial application of the HLH System is briefly discussed.

Introduction

FOR the past 2500 yr or more, material has been carried aboard ship in what we know as the break-bulk method. This has required piece-by-piece handling and storing of loads on and below deck. Over the years, fork-lifts, pallets and booms have helped mechanize the handling of cargo, but it has essentially remained a piece-by-piece operation. Because piers and docking space are at a premium at many ports, ships have historically lain at anchor for many days awaiting their turn. This problem is intensified in times of military crisis. During the massive buildup in RVN, the confusion became almost unimaginable, and the situation did not improve until the required port facilities were built and equipped. Even then, this forced unloading resulted in the stockpiling of tremendous concentrations of material which are difficult to catalog, warehouse or transship.

In the mid-1950's shippers started to pack break-bulk cargo in containers. The container introduced a new technology and forced changes in the maritime industry that have become irreversible. The sealed containers offer, in addition to greatly reduced handling time, the advantages of damage-free, weather-proof and pilferage-free cargo. A further value of the container is that it offers the flexibility of having the shipper filling the container with exactly what the receiver wants.

DOD logistical problems of the 1960's demanded revision of previously accepted operational concepts. The result was recognition of a seaborne containerization/vertical lift system approach. The operational sophistication necessary to off-load containerized shipping identified systems requirements not achievable by today's vertical lift aircraft. Although not considered candidate offload systems at that time, today's large cargo helicopters were initially developed at approximately the same time that the shift to containerization in commercial shipping occurred. With the delivery to the U.S. military of the CH-47C and CH-54B, the capability of routinely moving payloads of up to 10 tons became a reality. The Heavy Lift Helicopter System (HLHS) will provide the capability of offloading the standardized 8 ft × 8 ft × 20 ft MILVAN container at its maximum gross weight of 44,800 lb on a 95°F day, and the 8 ft × 8 ft × 27 ft, 8 ft × 8 ft × 35 ft, and 8 ft × 8 ft × 40 ft containers at less severe ambient conditions.

The dramatic shift to containerization, coupled with the projected availability of a vertical lift system matched to the container lift requirement, has provided the opportunity for significant improvement in logistics support to both military and commercial customers.

Military Requirements

The commercial transportation industry's shift to containerization at the expense of break-bulk shipping has had a parallel effect on the U.S. military services, which draw on the Merchant Marine in time of augmented overseas logistic requirements. Since the commercial shipping furnished to the military will henceforward be containerized, the services must be prepared to utilize the container as a principal element in their logistic systems. A system designed to exploit the use of containers must include all elements of the system, including not only the containers, but the container ships, the port facilities, and the handling equipment and must include the full range of alternative uses of each. It also becomes apparent that if containers are to offer their greatest potential to the deployed forces, the delivery system must be capable of moving the containers as quickly as possible from the ships to the user.

The department of Defense Joint Logistics Review Board (JLRB) has established a program to develop and test logistics-over-the-shore container operations for the purpose of defining and delineating the ship/container/handling equipment interface requirements.[1] The recommendations of the JLRB resulted in a joint Army/Navy operational evaluation

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of offshore discharge of container ships at Fort Story, Va., in Dec. 1970.[2] The purpose of this evaluation was to determine the effectiveness of current equipment in the handling and transportation of containers over the beach. The aviation portion of this test program, designated Project LOG LIFT I, had as its objectives 1) determination of the ability of the helicopter to offload MILVAN containers in various sea states and during periods of reduced visibility and 2) to assess the ability of the helicopter to extract containers from a cellular container ship. Three CH-47 and two CH-54 aircraft were utilized in this test program.

The helicopters demonstrated a virtual all-weather, day and night capability to transport the MILVAN container (with its payload derated to match the lift capability of the helicopters) and the ability to work over the deck of the vessel underway up to sea state 4 conditions. The exercise further proved that the helicopter can extract containers from ship cells; however, it was apparent that the hover time required was substantially greater than expected for the aircraft utilized for the tests. It can be concluded from this test program, as well as from other DOD containerization studies, that, if a solution to the problems associated with the exacting requirements of aircraft systems performance, position over the load and load stability can be achieved, the helicopter offload concept offers a cost-effective means of container ship discharge.[2, 3]

However, these are not the only requirements that the HLHS must meet. Cost of acquisition and operating costs are no less important considerations to the development of the HLHS. Since acquisition cost has historically been a function of empty weight, all systems must be responsive to the requirement of substantially improved performance at weights less than current helicopter technology would provide. At the hover out of ground effect, sea level, 95°F design point, a lift efficiency (payload/gross wt.) of 0.4 is expected. (To appreciate the significance of this challenge, note that the MIL-12's lift efficiency under the same conditions is only 0.2.) To provide operating costs competitive to those elements of the logistic system that the HLHS must complement or replace, this system must demonstrate operational availability at levels superior to today's helicopters. This increment in availability demands reliability and maintainability indices that are step improvements over those of today's CH-47 and CH-54 aircraft.

It is this required improvement in systems performance, cost, and availability that necessitates an advanced technology component development program prior to development of the end-item air vehicle. The systems requirements that have been delineated for the HLHS (Fig. 1), are responsive to these demands.

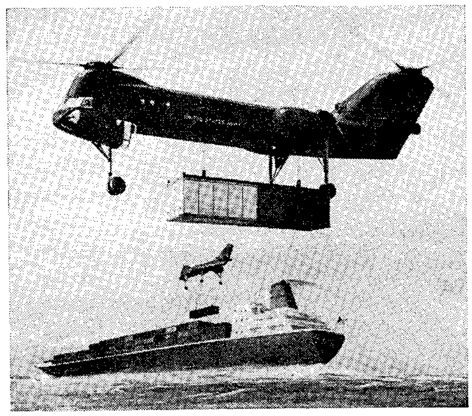

Fig. 1 Boeing heavy-lift helicopter system.

The HLH Program

The HLHS baseline design (Fig. 2) is fully responsive to the exacting systems requirements stipulated by the U.S. Army The air vehicle is designed to have an empty weight of 59,580 lb and a design gross weight of 118,000 lb. It will be powered by three advanced turboshaft engines. The 92-ft-diam rotor system is designed for a disk loading of 8.9 psf at the design gross weight. The design includes 4 blades at each rotor head. Main transmissions at each head are designed to absorb 10,600 hp, which is 60% of the 17,700 hp over-all transmission rating. The integral tanks located outboard of the landing gear stubs are designed to carry 11,080 lb of fuel for the design mission, which includes 2 trips of 25 naut miles radius. The integral tanks are designed to carry a total of 19,120 lb. The aircraft is designed to have speed capability of over 140 knots with a 22½-ton external load, and more than 170 knots without payload.

The design permits the landing gear to be collectively or individually kneeled to 8-ft 6 in. ground clearance or extended to 14-ft ground clearance. This will provide the helicopter with the capability of being leveled on uneven terrain so that two-point hook-ups can be made while straddling the load. The crew of 5 will include pilot, copilot, flight engineer, load controlling crewman, and crew chief. The cargo compartment design allows sufficient space for 12 troops and 2 gunners. Moderate size cargo can also be carried in this area. Length of the aircraft will be 162 ft 3 in. with the rotors turning and 87 ft 3 in. with the blades folded. Maximum width will be

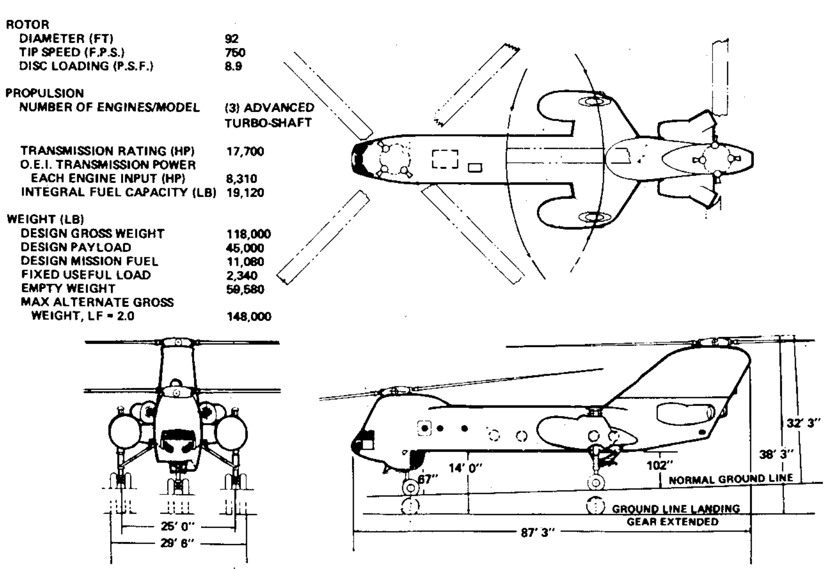

Fig. 2 HLH major characteristics: baseline design.

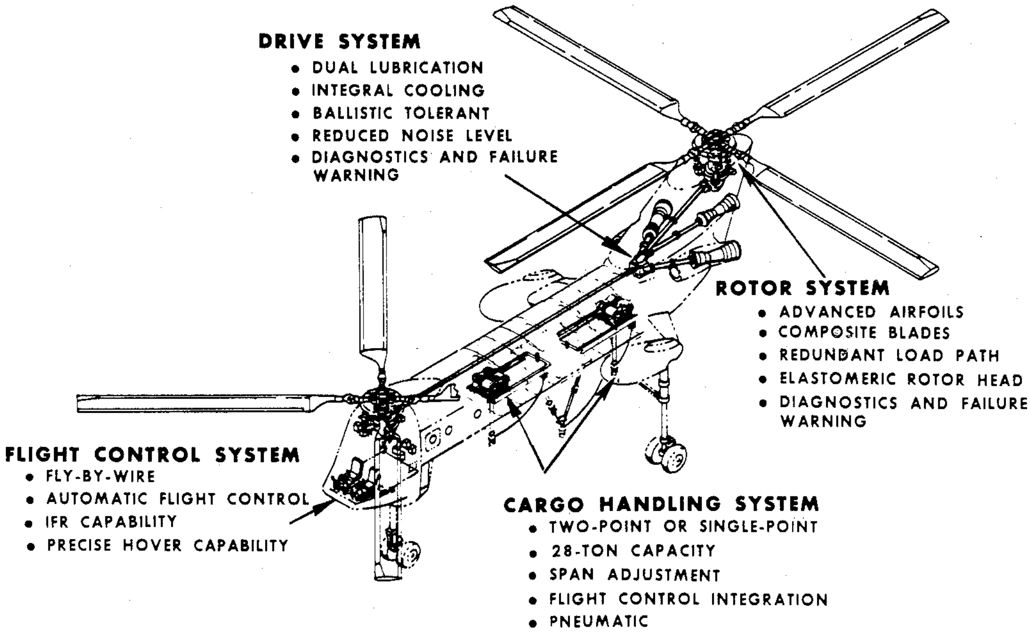

Fig. 3 ATC projects.

92 ft with the rotors turning and 29 ft 6 in. with the blades folded.

The purpose of the Heavy Lift Helicopter Advanced Technology Component Program currently under contract with the U.S. Army is to minimize technical, cost, and schedule risks associated with the future HLH system RDT&E and production programs. This will be achieved by design, fabrication, and test of specific Advanced Technology Components in the critical air vehicle subsystems.

The HLH ATC Program objectives are to advance the technology of these critical subsystems components so as to improve the future HLH system in areas of weight reduction, performance, mission operational capabilities, and product assurance and to demonstrate these improvements in critical areas by component and dynamic systems integration testing. Specifically, the ATC projects under contract are the rotor and drive, flight control, and cargo handling systems (Fig. 3).

Rotor System

The rotor blade design (Fig. 4) for the HLH features a fail-safe titanium/fiberglass composite spar incorporating a pneumatic failure detection system and a fiberglass and Nomex aft fairing assembly. It has an advanced airfoil profile that improves performance and flying qualities and reduces noise. Its sealed composite construction will improve maintainability, reliability, and repairability.

The use of composite materials with low-notch sensitivity eliminates the major problems associated with metal spar blades such as rapid crack progression, poor damage tolerance, little allowable field repair and poor corrosion protection. The fabrication concept for the rotor blade will yield a significant reduction in composite blade fabrication costs. This includes manufacturing the titanium and fiberglass spar as an integral "D" spar unit and bonding it to an aft fairing assembly in a second operation.

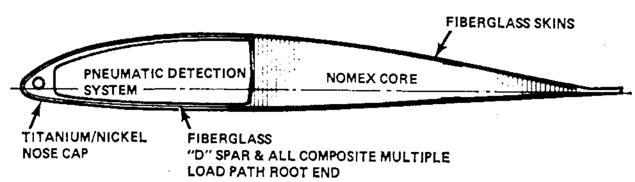

Fig. 4 Rotor blade concept.

The blade achieves fail-safety through the pneumatic failure detection system utilizing a gas leakage method similar to that developed for the CH-46 Integral Spar Inspection System (ISIS). The system will be designed to provide 200 hr of safe flight after failure detection and indication. This time extension in crack progression is achieved through the use of multiple load paths and inherent slowly propagating materials. Over the outboard blade sections, the titanium nose cap which provides erosion protection and torsional rigidity is a secondary load path for the fiberglass spar. It is anticipated that no scheduled overhauls will be required. The

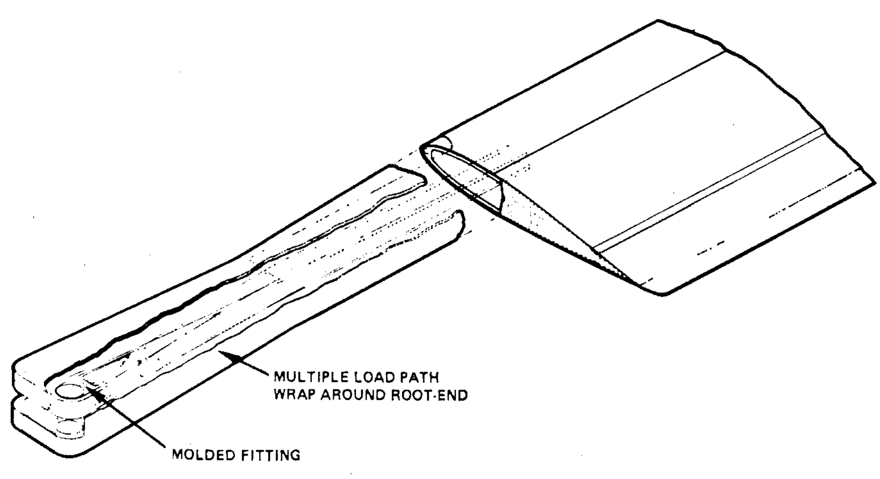

Fig. 5 Blade root attachment.

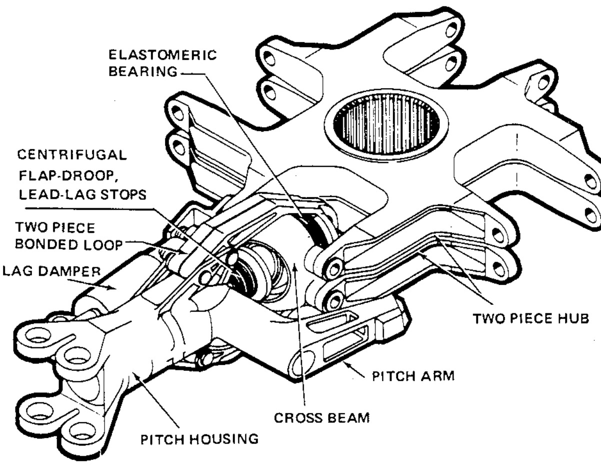

Fig. 6 Rotor hub and hinge assembly.

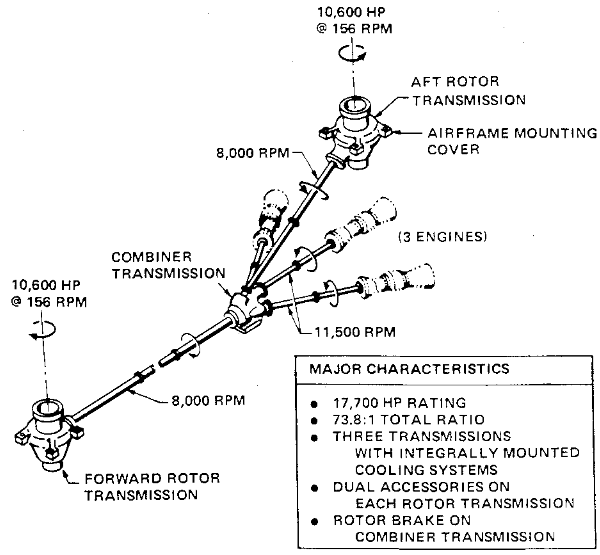

Fig. 7 Drive system arrangement.

failure detection system will monitor condition. The wear elements such as the nickel leading-edge strip are field replaceable. The blade construction provides an increased degree of field repairability.

The blade root attachment will be redundant and fail-safe. The all fiberglass root end (Fig. 5) inherently provides redundant load paths into the hub through four (4) individual lug attachments which are designed to be visually inspectable for condition. Two bolts secure the blade to the hub attachment. In the event of a single failure of a bolt or attachment lug the remaining components will sustain all blade loads. The joint will also act as the blade folding pivot.

The rotor hub design features a spherical fail-safe elastomeric bearing (Fig. 6) which will withstand all the radial blade forces and provide for coincident pitch, flap, and lag motion. The hub is designed for manual blade folding. Centrifugal droop and flap restrainers are also provided in the design. Multiple load paths and pressurized fluid-filled components provide fail-safety in the titanium rotor head assembly. In addition to the improved safety and survivability provided by this construction, a major step forward in improving maintainability and reliability will be achieved. The number of hub component parts will be reduced by approximately 70%. No lubrication will be required. The elastomeric bearing is designed to be replaceable on condition.

The condition of the swashplate is designed to be monitored by a pressure sensing system and the swashplate bearing by its temperature and sonic signatures. Hollow fluid-filled bolts, multilug attachments, and multiple drive scissors are designed to provide for safety and survivability.

Drive System

The HLH drive system (Fig. 7) with an over-all rating of 17,700 hp and an overall ratio of 73.8 : 1 consists of three transmissions (aft rotor, forward rotor, and combining), interconnecting shafting, and accessory drives. All three engines will drive through over-running clutches directly into the combining transmission which will reduce the engine rpm from 11,500 to 8000. The power will be transmitted through the interconnecting shafting to 10,600-hp rotor transmissions, which will further reduce the rpm to 156 at the rotor.

The major goal for the entire transmission is a 2000-hr MTBR with on-condition removal. This goal will be achieved by utilizing redundant load paths and failure warning utilizing transmission debris and sonic vibration detection monitors.

Major emphasis is placed on survivability. The design of the integral cooler and blower in each transmission eliminates all external oil lines. Internal lines and jets will be redundant. Flow monitors are included in the design. The gears and bearings will be designed to operate without lubrication for limited periods.

High contact-ratio gears will result in a 25% increase in load capacity over similar conventional gears. The Vasco-X carburized steel to be used for the gears will reduce weight and improve scuffing resistance. Bolted flanges are eliminated by the design. High-speed tapered roller bearings with self-lubricating cages in the spiral bevel systems and compliant roller bearings in the planetary system will improve reliability. Major improvements are required in the over-running clutch assembly, and these will be attained during the development test program. It is predicted that maintenance manhours will be reduced 40% over the CH-47C, and the malfunction rate will be 50% of that of the CH-47C. All accessories will be dualized at each of the rotor transmission boxes. The multiple redundant design, the integral lubrication system, the self-sealing sumps and lower transmission cases, and the capability for emergency nonlube operation are the major survivability features of this design.

Flight Control System

The Flight Control System will be Fly-BY-Wire (FBW) without mechanical backup. The FBW direct electrical linkage will be a quadruple two-fail operative system which transmits the pilot's commands to dual redundant swashplate actuators (Fig. 8). Traditional mechanical helicopter flight control systems are generally nonredundant, prone to maintenance errors and susceptible to low-level threats. The elimination of the mechanical linkages combined with the employment of separated wire runs and components with extensive built-in-test capability, will result in improved flying qualities, flight safety, and survivability, as well as reduced maintenance and weight.

The HLH Automatic Flight Control System (AFCS), designed to be single fail operational fail safe, will utilize triplex digital computers and associated sensors to provide improved flight-path/maneuver control and stabilization with selectable outer modes for precision hover, automatic approach, external load stabilization, and load controlling crewman control.

The AFCS will interface with the direct electrical linkage through limited authority differential inputs and with the pilot's primary flight controls through parallel drive (auto pilot) actuators.

Electrical mixing units will transmit the summed direct electrical command and AFCS differential input signals to

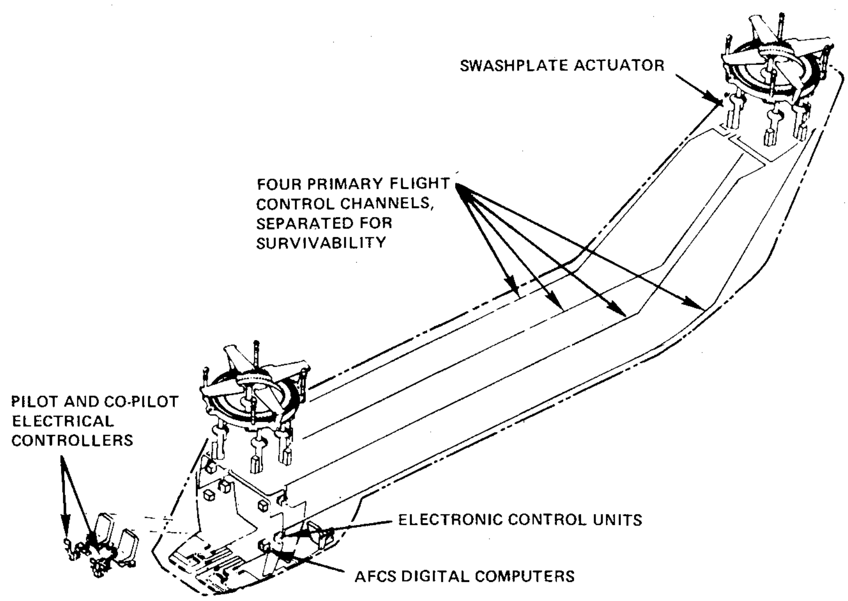

Fig. 8 Flight control system.

driver actuators which position a sextet of electro hydraulic swashplate actuators located at each rotor head. As previously mentioned, the electrical signals from the cockpit will be transmitted through quadruple redundant units. The mixing section is also designed to be quadruple redundant. The distributed nature of the quadraplex direct electrical control system and the triplex AFCS result in a vulnerable control area for the HLHS which will be only $\frac{1}{3}$–$\frac{1}{4}$ that of the CH-47.

The aircraft hover objective of automatic position hold and manual controllability with external loads to within ± 4 in. is unique to the HLH and represents a considerable improvement in the state of the art. To achieve the desired positional hold and controlability will necessitate the closure of complex automatic loops utilizing special precision hover, load stabilization, inertial velocity, and radar altitude sensors in addition to those sensors associated with the full time stability and control augmentation functions.

Cargo Handling System

The cargo handling system (Fig. 9) will utilize two pneumatic powered hoists to provide single and multipoint cargo extraction from confined areas and permit cargo attitude adjustment when necessary for inflight stability.

Boeing wind-tunnel tests and flight tests[4,5] and the Fort

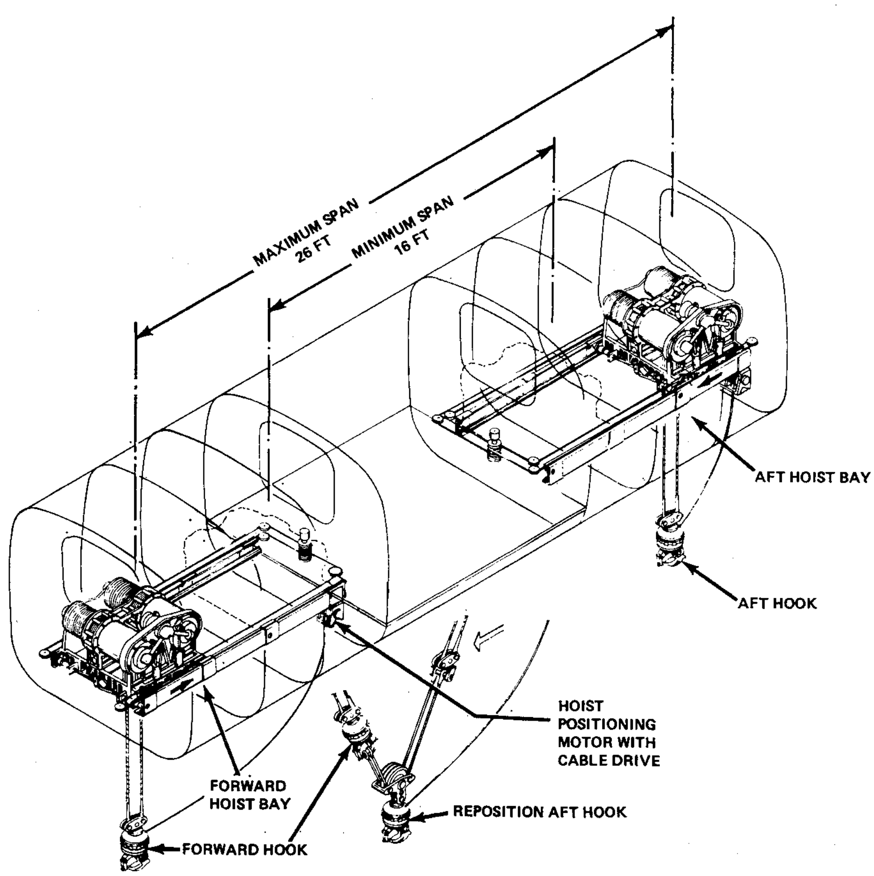

Fig. 9 Cargo handling system.

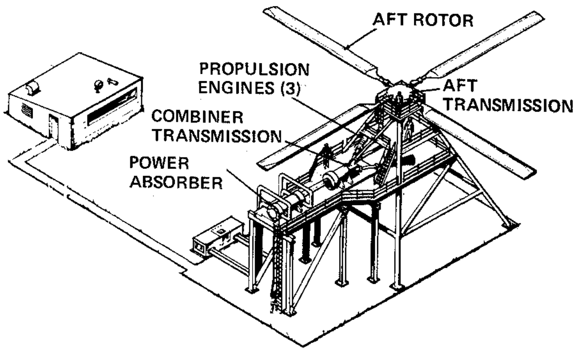

Fig. 10 Dynamic system test rig.

Fig. 11 Model 347 advanced-technology helicopter.

Story, Va. evaluation demonstrated that the tandem suspension system achieves high-speed inflight suspended cargo stability and precise azimuth control for the accurate cargo placement. The pitch control power inherent in the tandem results in relatively little sensitivity to longitudinal c.g. displacement of cargo. The pneumatic drive is designed to be lightweight and require no high heat energy/heat dissipation devices for dynamic braking.

Both single and multipoint hoisting modes will incorporate 100 ft reach, 60 ft per min hoisting speed and 28 tons capacity. The multipoint mode is designed for a 60/40 weight distribution. The span of the hoists will be adjustable from 26 ft maximum, which could be used for stabilizing 40 ft containers, to 16 ft minimum for lowering into ships' holds and for the single point mode. In conjunction with the development of the hoist system, a static electricity dissipation system will be developed to eliminate hazard to ground personnel.

An important element of the cargo handling system investigation will be a comprehensive evaluation of the load-controlling crewman station and a pilot- or copilot-monitored visual augmentation system.

Test Programs

A dynamic system test rig is an integral part of the rotor and drive system developments. This will provide for early verification of major component design and will verify integration and operation of these components as a system (Fig. 10). Similar in concept to this integrated test rig, the Boeing Model 347 Advanced Technology Demonstration Aircraft will be used in support of the flight controls and cargo handling ATC's (Fig. 11).[6] Specifically, the Model 347 will be used for flight demonstration of selected critical elements of the fly-by-wire system, the precision hovering position system, the load-controling crewman station, and the visual augmentation system.

The current HLHS program schedule indicates completion of design of the Advanced Technology Components by mid-1972 and completion of qualification and tests in mid-1974. If successful, it is anticipated that engineering development of the end-item air vehicle system will commence at that time leading to first flight as early as 1977.

Commercial Applications

Since delivery of the HLHS to the military is now projected at the end of this decade, one might not expect the system to be available for commercial purposes for many years beyond that. The HLHS, however, is currently being examined as a system which could be responsive to changing national priorities. With proper attention during design to FAA certification requirements and with recognition that commercial derivatives could be delivered concurrently with military versions rather than at the end of the military production run, the HLHS could be commercially available prior to the end of this decade. In like manner, the Boeing 747F has been configured to carry commercial containers, presenting an obvious interface with the HLHS. Proper design of ground terminal facilities and availability of heliports will provide a transport capability from long distances directly to the user's facility. Other commercial applications of the HLHS which also promise to be feasible and profitable are in such areas as power line construction, forestry and bridge building.

Conclusion

With the Department of Defense decision to proceed with the development of the Advanced Technology Component Program for the HLHS, a new era of cargo transportation capability is in its infancy. The successful development and demonstration of the HLH's operational capability will provide a solid basis for a commercial derivative. This commercial spinoff of the HLHS could have a tremendous impact in the moving of containerized freight within the framework of a restructured national transportation system.

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