incorporated unique methods to separate nozzle and airframe loads and to bridge the thrust-measuring balance with a high-pressure air-supply system.

Special test procedures involved 1) measuring the amount of bridging of the thrust balance not removed by the bellows system and making the necessary corrections to the data, 2) measuring the extent to which the afterbody-forebody seal bridged both balances, and again making the necessary corrections to the data, and 3) using a short-duration run to minimize temperature effects on the afterbody and seal. Test results were very satisfactory with excellent repeatability, and valid configuration comparisons could be made.

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AH-56A Onboard Fueling Capability

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The ability to operate from unimproved bases with minimum support equipment was a principal design objective for the Army AH-56A Cheyenne armed compound helicopter being built by Lockheed-California Company. An important element of this concept is the use of the aircraft's boost pump to fuel the ship from drums or other containers through the pressure fueling system. Pump electrical power is furnished by the aircraft's auxiliary power unit. The only ground equipment required is a suitable hose with disconnect fitting to match the ship and storage container. Tests to develop this capability were conducted on a full-scale fuel-system simulator as part of a complete fuel-system test program. With the resulting system, priming time through 38 ft of $1\frac{1}{2}$-in. hose averaged 45 sec; steady-state fueling rate was approximately 50 gal/min. Fueling from large rather than small containers is more efficient because of fewer priming operations.

Discussion

ONE of the most advanced combat aircraft to be developed in recent times is the Lockheed AH-56A Cheyenne being built for the U.S. Army. Its mission is to provide protection for troop-carrying helicopters and to furnish direct-fire support in combat zones. With a design speed of over 250 mph, it is considerably faster than armed helicopters now in Vietnam and carried much more fire power. Figure 1 is a photograph of the AH-56A in flight.

The aircraft is 55 ft long, has a main rotor-blade diameter of 50 ft, and a stub wing with a 27-ft span. It is powered by a General Electric T-64-16 gas turbine engine connected to a main transmission that distributes engine power to the main rotor, the antitorque rotor on the left side of the aircraft, and the thruster propeller at the tail. The engine has a military rating for 30 min of 3400 hp to 76°F, and a cruise rating of 3230 hp. This arrangement provides a standard day hover ceiling, out of ground effect, of 10,600 ft. Maximum rate of climb is over 3400 ft/min. Maximum range with 10% fuel reserve, at design gross weight, is 760 naut miles (874 statute miles), while maximum endurance for the same reserve and gross weight condition is 5.4 hr. By employing short takeoff and landing runs at optimum altitude, with 10% fuel reserve, ferry missions can be flown to a maximum range of 2510 naut miles (2886 statute miles).

Two men constitute the crew, a pilot in the aft seat and a copilot/gunner in the forward seat. Dual controls enable either man to fly the aircraft.

With its outstanding feature of inherent stability, the Lockheed rigid rotor system gives this compound helicopter the high degree of stability and performance that it requires as a modern aerial weapons platform.

Since the Cheyenne is intended to escort other helicopters and to operate in combat zones, one of the principal design criteria was that it be able to operate from small, virtually unimproved sites with a minimum of ground-support equipment. In conformity with this concept, the ship's fuel boost pump for the engine feed system can be used also to suck fuel from drums or other storage containers such as flexible bags, and introduce it into the aircraft's fuel tanks. The only piece of ground-support equipment required is a suitable hose with a disconnect fitting to match the ship's fitting.

To assist in visualizing how this onboard fueling capability is accomplished, Fig. 2 is a schematic diagram of the internal fuel system. Fuel storage consists of three flexible fuel cells with gravity interconnects, having a combined capacity of approximately 440 U.S. gal. The main cell is located in the fuselage aft of the wing box beam, whereas two smaller cells are located in the protruding sponsons forward of the wing, one of which is visible in Fig. 1. In level flight, the bottoms of the sponson cells are above the bottom of the main cell, whereas the tops of the sponson cells are below the top of the main cell. At the aft end of each gravity interconnect is a free-swinging check valve to inhibit flow from the main cell to the sponson cell, and also a standpipe to permit the sponson cells to be fueled by gravity flow from the main cell. A partial bulkhead toward the forward end of the main cell forms a surge box sump for the boost-pump inlet tube. Check valves permit gravity flow from the aft portion of the main cell into the surge box and an ejector operating from boost-pump pressure scavenges fuel from the aft portion of the main cell into the surge box to assure that the boost-pump suction inlet remains immersed in fuel until the internal fuel supply is depleted.

Fuel can be introduced into the internal fuel system by manual fueling through a standard filler opening, through a standard $2\frac{1}{2}$-in. pressure fueling adapter, or from ground storage, using the suction generated by the ship's boost pump.

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Fig. 1 AH-56A in flight.

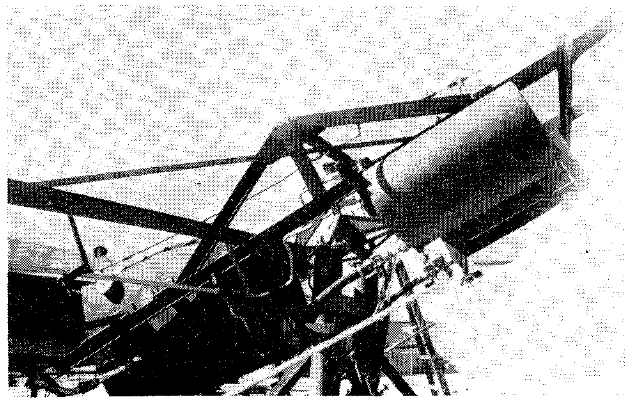

Fig. 3 Fuel-system simulator.

Manual fueling has been performed at rates up to 150 gal/min and pressure fueling has been accomplished at rates up to 200 gal/min. Fueling rates obtainable by using the ship's boost pump will be discussed later.

At the heart of the fuel system is the externally mounted in-line boost pump. A suction line from the main cell tees into the line at the pump inlet, which permits fuel to be drawn by the boost pump from ground storage. An electrically operated shutoff valve closes off the suction line to the main cell when ground fueling is desired, and opens automatically when the engine power lever is advanced to the engine start position. Entry of air into the boost pump through the ground-fueling line is prevented both by the quick disconnect and its locking dust cap seal. Whenever the boost pump is operating, its discharge pressurizes the engine feed line and the main tank scavenge ejector. When ground fueling is to be performed, a manually operated shutoff valve admits fuel to the pressure-fueling manifold, which services both internal and external tanks. When the aircraft fuel tanks become full, shutoff is automatic from the pressure fueling and transfer level control system. Since all the essential details of the boost-pump fueling operation are common to both internal and external tanks, further discussion of the external tank system will not be necessary.

Three-phase 400-cycle electrical power for the boost pump is supplied by the ship's auxiliary power unit, which also furnishes hydraulic power required for engine starting, again in conformity with the concept of minimum ground-support equipment.

The procedure for fueling from ground containers with the ship's boost pump is as follows: 1) Remove the dust cap from the ship's disconnect fitting and connect the ground-fueling hose. 2) Insert the hose suction tube into the fuel drum, flexible bag, or other ground-storage container. 3) Open the valve that admits boost-pump flow to the fueling manifold. 4) Check that the main-cell suction-line shutoff valve is closed; this can be accomplished if necessary by a manual override lever that also indicates the position of the shutoff valve closure element. 5) Energize the boost pump (assuming that the auxiliary power unit is already operating). 6) As the drum or other storage container is depleted of its fuel supply, shift the hose suction tube to successive containers as required. 7) When fueling has been completed, de-energize the boost pump, close the valve between the pump discharge and the fueling manifold, disconnect the hose assembly, and cap the ship's disconnect fitting.

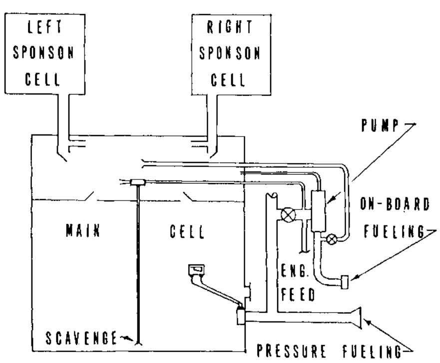

Fig. 2 Fuel-system diagram.

Tests to develop the onboard fueling capability were conducted on a full-scale fuel-system simulator as part of a complete fuel-system development test program. Figure 3 is a photograph of the simulator. Tanks are constructed of steel plate and stiffened as necessary to withstand reduced absolute pressure inside the tanks to simulate aircraft altitude. All major components are installed in their design locations. Plumbing for fuel lines, vent lines, and air pressurization lines duplicates the ship's installation.

A small plenum attached to the vent line exit is used as an altitude reference for all test work. An engine-driven fuel pump powered by a hydraulic motor is installed in its appropriate location to provide the necessary interface between the aircraft fuel system and the engine fuel system. The entire simulator is mounted on a gimbaling pivot to permit movement by plus or minus 30° in pitch attitude, and plus or minus 15° in roll attitude.

Figure 4 is a photograph of the boost-pump installation on the fuel-system simulator. The ground-fueling line enters the pump from the left-hand side of the picture, while the discharge is at the top of the pump. In the pump discharge fitting, the engine feed line is teed into the left-hand side, whereas the main cell scavenge ejector line is teed into the right-hand side. The manual shutoff valve between the boost pump and the pressure-fueling line is connected to the flange of

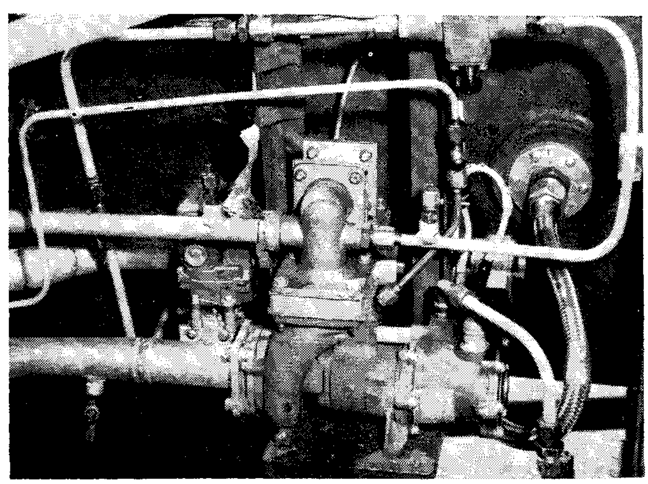

Fig. 4 Boost-pump installation on simulator.

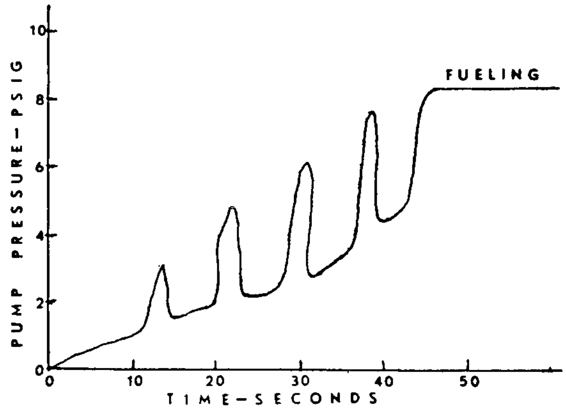

Fig. 5 Typical priming.

the pump discharge fitting, whereas an elbow on the downstream side of this shutoff valve tees into the pressure-fueling line connecting the internal system to the external tanks.

In addition to its centrifugal primary impeller, the boost pump incorporates a liquid-ring secondary impeller that primes the pump when required, circulates fuel through the pump motor for cooling, and removes air and fuel vapor to inhibit vapor lock. The boost pump is mounted in a line adjacent to the right-hand side of the main fuel cell, primarily to reduce the probability of rupturing the fuel cell in a hard landing or a crash. This arrangement also improves serviceability of the plumbing into and out of the boost pump. Power requirements for the boost pump are low, with a maximum current drain of 3.1 amp; this is only slightly greater than would have been required for an engine boost pump alone, since fueling can be accomplished at a considerably lower pressure than is desired for supplying the engine fuel pump.

When the first boost pump was being tested prior to installation in the simulator, it was found that the priming ability of the pump was unduly sensitive to the height it was required to lift between the fuel level in the storage container and the pump inlet. This was verified by testing on the simulator. To improve this characteristic, the vendor reduced the clearance between the tips of the liquid-ring secondary impeller and its housing, since this impeller must generate a sufficient rise in air pressure that the resultant flow will suck fuel through the empty ground-fueling hose within the specified time. After this improvement was incorporated, priming time averaged slightly less than the allotted 45 sec through the 38-ft length of $1\frac{1}{2}$-in. hose designated for this procedure, with a design lift between the fuel surface in the storage container and the pump inlet of 60 in. Once the pump had become primed, fueling rate was approximately 50 gal/min until the storage container was depleted or the fuel system had become full. This rate is comfortably above the specified minimum of 40 gal/min.

During the fueling tests, it was observed that the pump became primed in spurts rather than a continuous, smooth operation. Figure 5 illustrates this by a typical time history of pump discharge pressure during the priming period. In some cases the pump became primed in slightly over 35 sec. When one fuel container was depleted, it was found that the fueling hose emptied before the crewman could shift the suction tube to the next container, so that the repriming period occurred every time the suction tube was shifted from one container to the next.

While the initial boost pump was undergoing modification to improve its priming capability, an experimental vane-type, positive-displacement pump was installed in the system. It produced priming times and fueling rates similar to the improved centrifugal boost pump. However, the longer service life of the centrifugal pump rendered it a more attractive choice.

Figure 6 is a photograph of the coiled hose assembly. At the left of the photograph is the suction tube, which is designed so that its open end rests on the bottom of a standard 55-gal metal drum. A fuel-resistant rubber dust cap installed over the end of the suction tube prevents contamination from entering the suction tube when it is not in use. When the hose is being used, the dust cap is stowed on a cylindrical projection at the bend of the suction tube. A plate is welded to the bottom of the suction tube and four holes are arranged around the periphery of the tube to admit fuel and to minimize the possibility of normal condensate being drawn into the fueling hose. A grounding clip is attached to the suction tube by a cable, and a grounding jack is attached to the disconnect end of the hose assembly. Figure 7 is a closeup of the disconnect fitting on the hose assembly.

Figure 8 shows the hose assembly connected to the ship's fitting on the fuel-system simulator; no tools are required to perform the connection.

Since boost-pump refueling is accomplished through the ship's pressure fueling system, the pump can be used to refuel both the internal cells that comprise the normal combat fuel load, and external tanks that can be installed for long-range ferry missions. However, since the aircraft will require a short ground run to become airborne with its maximum load of external fuel, it is anticipated that standard-pressure-fueling equipment will normally be available to fuel the aircraft when external tanks are installed for long-range ferry missions.

Upon contemplating the possibility of refueling an entire complement of external and internal fuel tanks with the boost pump from a number of 55-gal drums, it became ummistakably obvious that being able to fuel continuously from a single

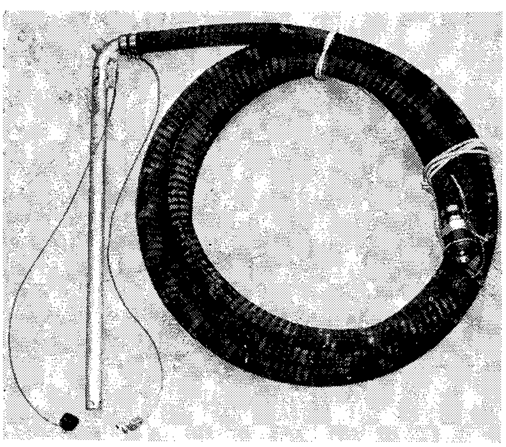

Fig. 6 Hose assembly.

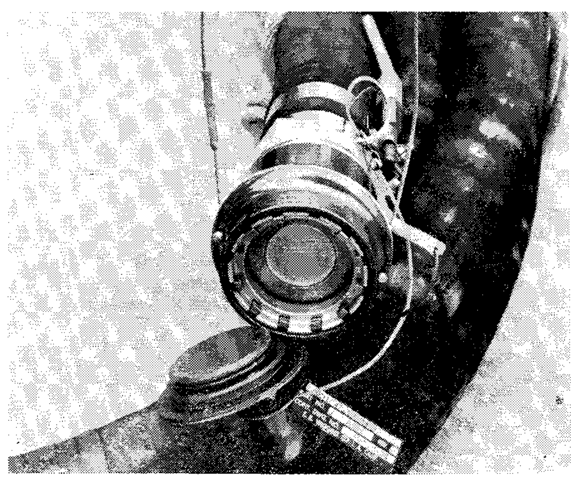

Fig. 7 Hose disconnect fitting.

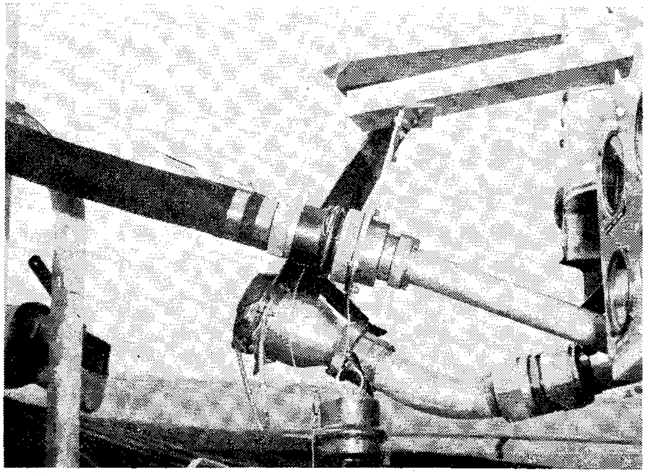

Fig. 8 Hose connected to simulator.

large container such as a flexible fuel storage bag was a far more desirable situation. Figure 9 illustrates this fact in terms of the quantity of fuel that can be loaded onboard the aircraft in a given period of time. When the storage container is sufficiently large, only one priming operation is necessary, so that the total fueling time is the sum of the priming period and the product of the fuel quantity to be loaded, divided by the fueling rate. In the case of the 55-gal drums, the total fueling time is almost doubled because of the necessity of re-

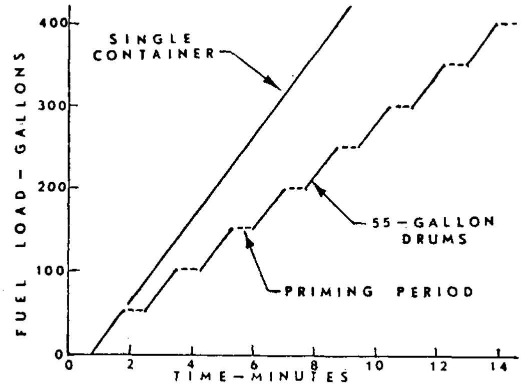

Fig. 9 Effect of fuel storage container size on fueling time.

priming each time the suction tube is shifted to a succeeding fuel storage drum.

As a result of this program, the following statements can be made. Fueling of the AH-56A can be accomplished from ground-storage containers with the ship's boost pump at approximately 50 gal/min. The only item of ground equipment required is a suitable hose and disconnect fitting assembly. It is more efficient to fuel from a large storage container than from smaller containers such as drums, since the pump must reprime each time the hose suction inlet is moved to a different container. This system is a positive step toward achieving operation with a minimum of ground-support equipment.